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PAPERS

ON SUBJECTS CONNECTED WITH

THE DUTIES

OF THE

CORPS OF ROYAL ENGINEERS,

CONTRIBUTED BY

OFFICERS OF THE ROYAL ENGINEERS.

NEW SERIES.

VOL. XVIII.

PRINTED BY JACKSON & SON, WOOLWICH.

1870.

PREFACE.

So much space has been necessarily occupied by the important matters treated of at the beginning and end of the present volume, that without unduly increasing its already large bulk and further postponing its publication, it has been found impossible to print several papers of interest which have been sent in.

The Editor feels sure that the publication of the Casemate and Shield Experiments will be hailed with general satisfaction, and that he may express the thanks of the Corps to Lieutenant-Colonel Inglis for the pains he has bestowed upon these valuable papers.

Papers for discussion at occasional meetings will be gladly received.

C. S. HUTCHINSON,

Lieutenant-Colonel R.E.,

Editor.

Railway Department,

Board of Trade,

Jan., 1870.

NOTE TO PAPER X

(On the Statical Pressure produced by impact of a falling weight.)

Owing to an oversight in the preparation of Plate II, the ordinates, representing pressures producing extension and permanent set in armour-bolt iron, are only shewn to be about two-thirds of their proper amounts.

The mean extension of armour-bolt iron should be 0·01 of the total length, under a pressure of 1,728 tons on the square foot, and 0·10 of the total length, under a pressure of 2,600 tons on the square foot.

The mean permanent extension should be 0·002 of the total length, under a pressure of 1,550 tons on the square foot, and 0·06 of the total length, under a pressure of 2,500 tons on the square foot.

The corrected mean curves are shewn in thick black dotted lines on Plate II.

The numerical results of the example, (page 136), with these data, will be as follows :—

Maximum pressure between bolt and supports	106·75	tons.
Maximum extension of bolt	0·178	feet.
Maximum compression of supports	0·11	feet.
Work absorbed by bolt	15·06	foot-tons.
Work absorbed by supports	5·88	foot-tons.
Maximum pressure between bolt and supports, corresponding to observed permanent extension of 0·12 feet	107	tons.

T. E.

16*th December*, 1869.

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PROFESSIONAL PAPERS.

PAPER I.

MONCRIEFF'S SYSTEM OF WORKING ARTILLERY.

By CAPTAIN MONCRIEFF.

As the primary part of this system, viz., the Moncrieff carriage and battery, in one form, is now pretty well known, it may be as well to direct attention to a few of those developments of it, which have occupied my attention, particularly as some of the details connected with the carriage can only be explained by doing so.

The system is not, as many suppose, confined to the carriage and battery which now bears my name, but, among other things, it applies to a method of disposing of these carriages and batteries in such a manner as to get the greatest results from them; in other words, to obtain the greatest efficiency from the smallest number of guns, men, and money.

It also embraces the tactics of defence for given positions, no unimportant element of success, as the history of the naval operations in the late American war will testify, and which has been, perhaps, too much neglected in this country.

The dispositions for working batteries on this system would always be devised in concert with what has received more attention, viz., the arrangements for laying obstructions and firing torpedoes.

This is not the place to discuss the details of this branch of the subject, it is enough to state that the possibility of working detached batteries in concert with one another has been demonstrated in one of my experiments before the Ordnance Select Committee, at Shoeburyness, and that simultaneous fire can, therefore, be delivered from batteries on one, or both sides of a channel on an indicated ship.

I am also prepared to show, when the time arrives, that the position of any vessel can be correctly laid down in each battery, at the same moment, by telegraph, by a simple operation that at once gives the required range and the lateral position of a vessel, enabling the guns, by means of that correct range, to be laid under cover as well as ever they have been laid directly and singly.

This part of the system might be applied with some advantage to existing arrangements, but in a far more complete and satisfactory manner to that arrangement to which it belongs.

From these remarks it will be observedthat the carriage and battery are only the means by which very important ends are sought to be obtained, among which ranks first a consistent and complete system of defence, in which artillery is enabled to act under conditions of efficiency, cover, and economy, not hitherto attainable.

The present circumstances of this country, the embarrassment connected with the question of fortification, and also the enormous financial considerations connected with it, all combine to show that the adaptation of the new system to existing fortifications is the one that must first be taken up.

In order to give some idea of the probable financial results to be looked for by discarding the present system, (that is, the one for which the new works are designed), and of applying the new system, as far as possible, to these works, it is unnecessary to instance every case.

It would take too much space to discuss the appliance in connection with all those magnificent works which our engineers have elaborated for the defence of the great arsenals and dockyards, the vital foci of the force of England against invasion.

The most advantageous form of applying the new principle, in each case, will be a problem in itself, and will require much consideration and skill to obtain the best results, but for the present purpose, that is, to arrive at an idea of the probable saving, it is enough to take an illustration from one case—let that be the defences of the Thames.

The first line of defence of the Thames, after passing the Medway, consists of three forts forming a triangle, the base of which is on the south bank. These forts are Cliffe, Coalhouse, and Shorne; each is calculated to mount about twenty 12-ton guns.

To complete the three forts on the present system, with iron tops, &c., for which they have been designed, it would take probably about five years and £300,000.

If the Moncrieff System is applied now to these works, it would save the expense of all the iron and a great deal of masonry, and enable the work to be completed in one year.

This saving would not, however, be the measure of the gain by such a change of plan ; for the guns would command a larger range than they could possess if worked through ports, and would be more powerful nearly in proportion to the increase of range. Besides which, on a sudden emergency, the same guns would be available for another disposition, if the necessities of war required it ; and if such a disposition was expedient, a certain number of them might be mounted on the new carriage in rear of the sea wall, or elsewhere, and worked there with even greater effect, in support of the main position.

If the correctness of this statement is conceded, it must be allowed that the alternative alluded to has a higher military value than is expressed by the mere saving of money. That saving, however, is small when compared to advantages which are within reach, when the works could be constructed entirely on the new system.

To illustrate the saving on each Moncrieff carriage employed, take the case of a battery placed so as to command a channel circling round its whole front; by the present system this battery must have at least three faces, because the guns on these faces, from the small angle which they traverse at present, only bear on the space in front of them, and do not cover the ground in front of the others.

If these guns were mounted in one line on the Moncrieff System, they would all command the entire circle, except the two dead points in prolongation of the flanks.

It may, therefore, be safely asserted that in this case each gun is quite three times as powerful as if mounted in casemates or embrasures.

If this be allowed, it is equivalent to saying that each gun might in such a case do the work of three guns, and it is not too much to say so; for although it might not be true if the new guns only commanded three times the lateral range of the others, it is so when the power of concentrating all the guns at once on nearly every point, and of firing to the rear is taken into account.

It follows, therefore, that in this case one Moncrieff gun is as valuable as three guns on the present system. It is not wished, however, only to compare one gun with three, but a certain number of guns in a series of batteries, with the increased number required to do the same work.

The estimate for obtaining the same results in each case would, therefore, stand thus, and when the items are higher or lower than those quoted, the saving per gun may be arrived at by the same process.

PRESENT SYSTEM.

3 iron casemates, capable of meeting the fire of ships, with magazines, &c., complete at £5,500 each*	£16,500
3 12-ton 9-in. guns at £940	2,820
3 platforms and carriages, at £421	1,263
	£20,583

MONCRIEFF SYSTEM.

1 Battery with magazines, &c., without iron	£2,500
1 12-ton 9-in. gun	940
1 carriage and platform	1,000
	£4,440
Saving on each Moncrieff carriage	£16,143

* The Medway Forts, and such like, cost, with 15 inches of iron, not less than £5,000 per gun, and with 20 inches of iron, not less than £6,000 per gun.

Taking a less favourable case, say an open battery with shields costing £1,200 each, and where the guns have not to command so wide a range as in the last case, for example, Tilbury, Gravesend, Southsea Castle, &c.

PRESENT SYSTEM.

Battery accommodation for 2 guns, at £1,200 per gun	£2,400
2 iron shields, at £1,200	2,400
2 12-ton guns, at £940	1,880
2 platforms and carriages, at £421	842
	£7,522

MONCRIEFF SYSTEM.

Battery accommodation for 1 gun	£1,200
1 12-ton gun	940
1 carriage and platform, say	1,000
	£3,140
Saving on each Moncrieff carriage	£4,382

*A 2-gun turret, mounted on a part of an existing work, with foundations, magazines, iron, &c., costs	£20,000
A parapet, magazine accommodation, foundations, &c., for 2 Moncrieff carriages, at most	3,000
	£17,000
Saving on each Moncrieff carriage	£8,500

It should not be forgotten, in any estimate of this kind, that the reduced number of men required, is itself a great element of economy, and that skilled artillerymen are not too numerous.

With regard to exceptional cases, where an earthen glacis is not possible, the new carriage can always be made to act over a solid iron parapet. If this form of construction is introduced, the battery would be demi-casemated, as the iron would be curved over the interior slope, and afford complete cover from curved fire, as the form of the carriage admits of that iron being brought to within a few inches of the trunnion in the firing position.

When flank enfilade is impossible, there is no reason why the guns should not be placed very close to one another; more especially over a casemated battery, as one form of the carriage admits of suspended counterweight, in which case the platform is not wider than the gun itself. Drawings of this

* It is taken for granted that muzzle-pivotting carriages are used in the turret, which would cost about the same as Moncrieff carriages.

form have not yet been submitted to the Government, but no doubt it will work as well as the others, and will be valuable in some of the exceptional cases referred to.

Before dismissing this branch of the subject, it is as well to allude to the splinter-proof covers that can be applied, similar to those proposed for naval artillery, on the Moncrieff Principle, and which, no doubt, might be advisable for batteries planted near a navigable channel, to protect the detachments from musketry from the rigging of vessels. These covers, if strengthened, would make a Moncrieff battery a casemate at a smaller expense than any other devised, although it is confessed that it would be necessary in very few positions.

The plan and profile of a Moncrieff battery will be found to give very considerable facilities for placing and arranging the magazine accommodation, and for getting bomb-proof cover.

It has been gravely urged against the proposed system by the advocates of the present one, that the Moncrieff battery is not protected in the same manner from assault as the iron forts, which have ditches, caponiers, &c.

The same objection might be taken to an iron shield, which is a still more helpless thing, *per se*, than a gun pit.

The fact is, that the new system is not only compatible with the old appliances for meeting assault but has also a few important advantages of its own in this respect.

For instance, and confining the subject to coast defence, I should like to ask what are the provisions in most of our coast batteries against attack on the land side?

If these batteries are capable of being taken in reverse, which, of course, they would be, if possible, by an assaulting party, would they be in a better position for self defence than if their guns were mounted on the Moncrieff System? would it be any disadvantage to have guns that could open fire to the rear as well as front?

But even in defence of the front against assault, is it not something that each gun is capable of sweeping the whole crest of the parapet, which is impossible with embrasures and casemates? Would the mode of assault by throwing bridge ladders over the ditch (which has lately been recommended), become a more easy operation under this condition?

It is scarcely logical to urge that because the new system is highly adapted for temporary works where infantry lines and plenty of breech-loading ammunition is made to supply the place of permanent fortifications, therefore it is not so secure as an iron work.

A proposal for massing artillery *materiel* at certain points, leaving it to be applied at need in temporary batteries, is slightly touched on in the following remarks. This, in my opinion, is second in importance to none of the other considerations. From want of time, however, few of the designs for the appliances and carriages required, are completed. It would take a long time to do any justice to the work required for this purpose, but by no other known method could batteries strong enough to act against ships be extemporized.

Another very important branch of the subject is omitted altogether, viz., the system as applied to siege guns and ordinary guns of position in which mobility is the main feature. In a future paper I hope to be able to take up, in a more complete manner, this subject, along with others not yet touched on. I also abstain, at present, from discussing the application of the system to gun barges, floating forts, and ships. I have been in correspondence with the Admiralty in regard to the last, since the 23rd May, 1868.

There is also one more application, which I wish to refer to on account of its importance, that is the application of this system to the class of artillery which is at present only represented by the 23-ton gun; but which, those who ought to know best, appear to think will yet have heavier representatives.

It is impossible to exaggerate the importance of such artillery in coast defence. A 23-ton gun is a power in itself, a power that threatens the existence of the mightiest ship with a single shot. It is a weapon, the like of which man never wielded till our own time; and it is, therefore, very desirable that so important an individual should be left to do as much as possible when fighting for us. It is left to be decided by others, whether it is likely this system is the best suited for such artillery.

Before concluding these prefatory remarks, it may be well to indicate a propensity which is always liable to be developed in time of peace, and to receive its punishment in time of war.

This propensity is simply a tendency to overrate the power of fixed defensive arrangements, and underrate the efficacy, for defence, of the power to attack.

The most formidable thing an enemy has to encounter is not the iron casemate or shields of a modern fortress—it is the deadly character of its fire—it is the rapidity and dexterity of its artillerymen—it is the character of their guns, and the completeness of those appliances which enable these guns to be laid in all directions, and to be worked in concert by well devised tactics.

There is more real defence in this power of attack than can be got by cramping the fire with little ports, stifling the artillerymen in close casemates, and trusting to ponderous and expensive walls of iron.

It may be most emphatically stated that the system now advocated does none of these things. It is true it gives protection, but not at expense of efficiency; and I know that British artillerymen will throw off these iron defences, as gladly as they would tight tunics, for real action.

The vertical fire argument has been directed, with some assumed success, against the gun-pits, as a diversion in favour of casemates for coast defence.

It is allowed to be rather difficult to hit a moving ship from the most steady mortar battery on shore; but to hit a gun-pit, which is not one-thirtieth as large an object as a ship, and that too from a moving mortar-bed on board ship, would be an event that perhaps it might be as well not to calculate on during an engagement, but which might be looked for, with a sufficient number of mortar boats, about once a-week. It is, therefore, not too much to call it an assumed success.

If mortar practice is made at an object such as a town, or even a fort, it can be depended on; but a Moncrieff battery, which occupies less space than any other and is protected in rear as well as on the flanks, would not be a convenient or profitable object to practice at for a long time, unless the mortar boats could make themselves as invisible as the gun-pits, and had nothing else to do with their ammunition. It ought also to be borne in mind, that a properly constructed Moncrieff battery or gun-pit is an invisible object, it cannot be seen from the plane on which it is placed, the momentary glimpse of the gun (if noticed at all) and the curl of smoke are all that is observed; while every other battery is a good standing target in comparison.

On a late occasion at Shoeburyness, 100 rounds were fired at 800 yards range, and, with all the appliances of the place, without a hit, at a row of experimental casemates, which cover a much larger area than does a gun-pit.

The worst of vertical fire is, that the greatest error arises from a defect that is incurable; that is, the impossibility of getting exactly the same results in force from the same weights of gunpowder, while the smallest difference in the charges, from atmospheric or other causes, affects the range considerably, and the error goes on increasing with the increased range.

While the power of direct fire has been increased in the most marvellous manner by late improvements in ordnance, vertical fire remains not much better than it was in the infancy of artillery.

One other important condition requires remark, that is, the rapidity with which the guns can be fired. It will be easily understood that in the recent experiments at Shoeburyness the full speed was not attained. I undertake, when the time arrives for doing so, to increase the rapidity of fire considerably.

It is the opinion of practical Artillery Officers, who have been handling the present carriage lately, that they can work it as fast, if not faster, than the old carriage. When the necessary alterations and appliances are added, both facility and rapidity will be gained. Very excellent practice at the target has already been made at the rate of 5 rounds in 4 minutes 40 seconds.

Before defining the mechanical part of this invention, it may be as well to state the results hoped to be obtained by it, and the principal difficulties that had to be encountered.

The conditions desired were simply to obtain a system of firing over a solid parapet, while preserving free lateral range, and neither exposing the gun and detachment, nor involving the labour of raising and lowering the piece; in other words, of gaining the advantages of a barbette battery, without its defects.

The difficulties on the other hand were mechanical ones, but mechanical difficulties of a very serious kind, and which, no doubt, have often discouraged those who have been on the same track as myself; for it is impossible to suppose that this idea has not been entertained by many others. The advantages to be obtained are too important not to have often invited invention.

It was the consciousness of this that stimulated me to persevere with my experiments at considerable expense, and under great discouragement and delay.

Before the end of the Crimean campaign I began to design lifts for guns, and in the course of this work, the principle now adopted occurred to me; as soon as it did so, I felt I had an agent suited for the purpose.

A mechanism for raising and lowering the gun might with comparative ease be contrived were the strains statical, but they are very different, and those who know most about the difficulties of meeting the recoil of modern heavy ordnance on the platforms and slides now used, and the destructive effects large charges produce on pivots and racers, will probably be most ready to appreciate the difficulty I refer to, where, as in my case, the strain of the recoil has not to be met near the plane of its own action, as in these platforms and slides, but far below it.

The danger of the sudden strain imposed on the platform is removed by interposing a moving fulcrum between it and the gun, at the same time meeting the energy of the recoil by a counterweight or some force of equivalent power. This arrangement reduces the initial velocity of the counterweight to a minimum (without destroying equilibrium). The force of the recoil is conveyed to the gun on the discharge taking place; the energy thus generated, in fact, the destructive power, is measured by the weight of the gun multiplied into the square of its velocity. If, therefore, the velocity conveyed to the counterweight, is at first almost disposed of, the *vis inertiæ* of that counterweight has no longer a destructive action on the intermediate parts. It is by this means alone that such enormous strains and weights can be dealt with in a structure possessing little more strength than would be required for statical support. Moreover, greater durability to material may be anticipated under continued action, than is obtained with carriages on which recoil is stopped by friction alone.

In the proposed arrangement the recoil is stopped without injurious strain by an arrangement of forces analogous to those which stop the rolling of a ship, where the gradual rising of the centre of gravity of the whole structure puts a limit to the movement in one direction. The curve of the elevators can be made to control the meta-centre, and express the same movement, with nearly the same results.

Pl. I, Fig. 1, shows the general arrangement of a Moncrieff carriage for a 7-ton gun. It consists of three principal parts, viz.:—

The Carriage Proper, *A*; The Elevators, *B*; and The Platform, *C*.

$\frac{A}{2}$ and $\frac{B}{2}$ show the carriage and elevators near the loading position.

It traverses on a central pivot and a single circular racer 14 ft. in diameter, and the platform is about 16 ft. 6 in. in length. A counterweight *D*, sufficient to balance the weight of the gun, is placed between the two elevators.

In the firing position, the centre of gravity of the counterweight, and the fulcrum, on which the elevators rest, are nearly coincident, and are both in nearly the same vertical plane as the trunnions of the gun.

On the discharge of the piece the elevators roll backwards on the platform, causing the gun to descend in a cycloidal curve, while at the same time the counterweight rises (at first with an increasing velocity). The centre of gravity of both the gun and the counterweight together is also the centre of the circular part of the periphery of the elevators; this being the portion on which the elevators first roll after firing, it follows that the common centre of gravity of the gun and counterweight travels backwards in a horizontal plane. And as this circular part is about a quadrant, the detachment is enabled to work the gun for drill purposes, or to place it under cover, from the firing position, with ease, the whole structure being in a state approaching to stable equilibrium. As soon, however, as the elevators pass off the circular arc on to the greater curve the leverage in favour of the counterweight goes on in an increasing progression, until it becomes sufficient to meet the utmost force of the recoil. Thus the recoil is absorbed without necessarily using friction, and it will be observed how this arrangement takes off that shock and vibration which prove so destructive to pivots and masonry in the ordinary carriage, and which have led to so much expense lately in making foundations strong enough for the platforms of heavy guns.

When the gun has recoiled as far as it will go, it is held in that position by a self-acting pawle, and then loaded under cover. The elevation can also be given to it in this position, if desired, as there is a trunnion-pointer with segmental scale on the cheek of the carriage.

If the pawle is lifted the energy of the recoil (stored, as it were, in the counterweight) raises the gun into the firing position, its movement upwards being regulated by one gunner holding the handle of the friction band. Thus a dangerous and destructive agent is tamed, and turned into a useful servant.

When the gun is in the firing position it can be laid either with the usual sight, and in the usual manner, or it may be laid with my reflecting sight from below. In the former case, No. 1 steps off the shelf in rear of the gun on to another shelf at the side of the rail, he there can remain while the gun is fired, and the time taken to step from the one position to the other is less than that required on a dwarf traversing platform. If the reflecting sight is on, the laying can be checked from below.

In the latter case, viz.: where the reflecting sight alone is used no one is exposed, and as the elevating screw in that case can be worked in front of the carriage and the traversing at the side of the platform, a new condition is obtained, viz., the power of following a moving object, and firing at it while the gun is actually in motion. In this case No. 1 does not require to guess the distance before the object passing his front, as in laying the gun on a dwarf traversing platform.

In this paper I do not go much into details, nor shall I describe any of the other carriages, feeling that a description of one class of carriage is enough to illustrate the principle which is common to all. By abstaining from this, however, I must leave very interesting ground, as the whole question connected with siege guns must be omitted. In these the wheels are used for elevators, and in some cases the counterweight is dispensed with, when its weight would be inconvenient for transport. I must also leave untouched as belonging to this branch of the subject, the new conditions that these lighter guns would give in resisting the landing of troops covered by the heavy fire of ships—their use in covering the front of a permanent encampment—in siege operations, &c.

I have been engaged in the Royal Arsenal since the 13th of August in superintending the manufacture of a carriage, &c., suited for a 7-ton rifled gun. The Government decided to test my invention by selecting that application of the principle, which I proposed to apply to this class of gun, and required that I should produce a complete carriage, with every appliance matured for working the new arrangement. This has taxed my attention to the utmost. I conducted at my own expense an inductive series of experiments, which were commenced in 1857-1858 with models, and which I carried as far as a 32-pr. 48 cwt. gun.

There is a great margin, however, between a 32-pr. and a 7-ton M.L. rifled gun. I believe I may confidently state, that in the history of mechanics a perfectly new principle has not before been applied to control such enormous strains and weights, with so small a series of experiments.

Before finishing the description of what belongs to the carriage and going on to more important considerations, I shall briefly describe the reflecting sight already referred to, which is an important adjunct of the arrangement, although not necessarily always employed, being quite a separate invention. It consists of a reflector placed in front of the trunnions, and a fore-sight in front of the reflector. A line through zero on the fore-sight, and parallel to the axis of the gun, passes through two cross wires on the reflector at their intersection.

The fore-sight is graduated from zero downwards in yards to the extreme range of the gun, and is set at an angle to correct the permanent deflection of the rifled projectile.

The field of vision is extended at pleasure by moving the eye. In laying guns I have observed that all men have not the same facility, although their vision is good in other respects. I attribute this to the slow action in many individuals of the muscles of the iris; their sight is impaired for the moment, and its correctness affected by the effort to focus on distant and near objects at once. I anticipate that better aiming will be obtained with my sight in many cases, as the back sight, or intersection of the wires is about the same distance from the eye, as it is from the fore sight, while the object aimed at is reflected in the same plane as both. This conjecture, however, remains to be confirmed by experience.

The carriage itself possesses a few advantages, but the real value of the system is to be found in the new conditions it introduces.

The advantages which belong to the carriage itself are merely such as that of removing injurious horizontal strain from the platform, and economizing labour in working the gun, by leaving the gunners to deal with only the difference between the weights of the gun and counterpoise, instead of with the whole weight of the gun.

I shall now endeavour to indicate some of the applications of the system. Its relative value is to be estimated by comparing it with others; and in order to do so, I shall divide the subject under a few heads, that each point may be scrutinized separately, and the balance in favour of or against the proposed system ascertained in each case.

I shall omit in this comparison some special applications, such as the use of my proposed gun pits, a method of mounting artillery made possible for the first time by the invention, its use in ships, in which case steam or compressed air is used instead of a counterweight, also its application to heavy howitzers, &c., &c., as the limits of this paper will not admit of them.

The heads under which I invite discussion are the following :—

(1) Protection from vertical fire.
(2) Protection from direct fire.
(3) Lateral range.
(4) Economy in construction of works.
(5) Economy of life.
(6) Mark offered to an enemy, and power of being masked.

I believe the *first*, viz., protection from vertical fire, is considered to be the weak point of my system, but it is only at a disadvantage in this respect when compared with turrets and casemates, which, of course, are very expensive; and there is this to be said for it, that the space occupied by the platform is smaller than that occupied by those of the present construction; the distance, for instance, between the traverses on each side of the gun and between the interior slope and rear of the platform need not exceed 21 ft. for a 12-ton gun; further, this space can be reduced by contracting the top of the parapet and traverses. Vertical fire, moreover, is least to be considered, on account of its inaccuracy, and also (as those who have experienced it know) because a few traverses generally enable the men to avoid it.

Second. Protection from direct fire.

I take the liberty of quoting Captain Schaw, R.E., Professor of Artillery and Fortification :—*

"The great difficulty in all fortification, at the present, is how to protect the guns and gunners, and yet to give the fullest scope to their fire. In field fortification, barbettes and embrasures each have their advocates, and some even recommend blinded batteries. The last-named clearly are inadmissible for the same reasons that have been urged against timber blockhouses. Barbettes have been found, in the experience of the late American campaigns, and in our own experience in the Russian war, to be useless when the enemy's riflemen can converge an effective fire upon the gunners; they are too much exposed when crowded round the gun to serve it under such circumstances. Embrasures restrict the lateral range of the gun, weaken the parapet, are open doors to let the enemy's shot into the work, and targets for him to fire at, and are soon destroyed and choked up by the combined effect of the enemy's fire and the explosion of the guns fired in them; moreover, they give but little real protection to the men serving the gun from the enemy's artillery; but when supplemented by mantlets they do protect the gunners from rifled small-arms, and are, therefore, a necessary evil at present."

* Transactions of the Royal United Service Institution, Vol. X, p. 446.

Also from a paper of mine,* June 3rd, 1867:—

"The protection which my system affords is of a character that has not as yet been given to artillery. In working guns, two conditions which usually conflict with one another have to be obtained; the one is to make the gun formidable to an enemy, and the other is, to have at the same time both it and the men working it as little liable to injury as possible.

"The first condition is obtained by having appliances that expedite aiming and loading, and also those which enable each gun to traverse as large an angle as may be required. The second condition has, until lately, received very few improvements beyond the old and well-known method of the embrasure, &c. However, improved casemates, the contraction of ports by the use of armour-plating, cupolas, and Lieutenant Bucknill's ingenious system of firing through a false parapet or screen, &c., &c, have each and all their advantages for certain positions, but with one exception, viz., the cupola, they all curtail the power of the gun by contracting its free range; and, therefore, with that exception, what they gain in safety they lose in efficiency, where range is required. My system has the happy peculiarity of combining these two conflicting elements in a high degree.

"The embrasure necessitates the breaking and weakening of the parapet. It also restricts its thickness for a given number of guns, not to speak of the mark which these embrasures present to the enemy. Armour-plating on land works, at great expenditure of money, reduces these evils considerably, but by no means entirely removes them; so that on reviewing the position of my invention in this respect, I feel my only competitor to be the cupola. What can be said in favour of the cupola nearly applies to my system. We are equal in our power of traversing; and in the matter of protection, you will have to decide, after I have stated the exposure in each case.

"The cupola is always a mark, and is always exposed, and to very heavy ordnance its invulnerability is still problematical. Its port, though small, is liable to be hit for a certain time. Its gun detachments are annoyed, if not hurt by the concussion of heavy projectiles. It is of enormous weight, and to avoid a shot in the port, it requires to turn its cheek on the enemy after each round, involving a good deal of labour. On the other hand, my gun, and the men serving it, are absolutely protected from direct fire, except that the gun and one man are exposed while aim is being taken.

"When the gun is up to be aimed, it is more exposed than the cupola gun, but the moment it is fired it is safe.

"If a screen be used, the enemy cannot see whether the gun is up or down; I thus draw his fire, the correctness of which must be materially affected by having no definite object to aim at.

"The best way, perhaps, of putting the question is this: Would gunners prefer to be shut up in an iron box, only penetrable by the enemy's shot through the port, but liable to injury in other parts; or would they prefer to fight their guns in the open air, and all under cover, except the man who aims,

* Transactions of the Royal United Service Institution, Vol. XI, page 251.

he being exposed only for a very short time and partially protected by the massive breech of the gun? Are the chances of injury greater in my case, where the gun is only liable to be hit during the few seconds required to lay it, and is in absolute safety the moment it is discharged—or, as in the other case, where the cupola remains a constant mark for heavy projectiles, and runs a continual chance (though a small one) of receiving a shot through the port itself?

"It is obvious that the possibility of dispensing with a parapet, without losing command of the front of the battery, would give an advantage of an important kind. This advantage I seek to obtain in its greatest degree by employing gunpits, in which all the vital parts of the carriage remain below the level of the surface, and the gun itself is only exposed when it is going to be fired.

"For coast batteries liable to be opposed to the heaviest artillery in ships, a very strong work is now absolutely required to protect the guns from the terribly destructive effects of modern projectiles, which have a penetration far beyond what was dreamt of when most of the existing fortresses were built; and as accuracy of fire has increased, as well as its power, the guns cannot be mounted *en barbette*.

"In order, therefore, to be efficient, coast batteries must be of great strength, and proportionately expensive, especially when iron is used in their construction.

"I wish this to be borne in mind, while I point out that by taking advantage of the natural undulations of the ground, scarping down the rear of hillocks to make them into batteries, and applying the skill of our military engineers to use whatever nature has supplied in each place, many positions might be defended on my system from the attacks of the heaviest artillery, at a small per-centage of the cost which is now required to construct batteries with iron embrasures, cupolas, &c.; and that, notwithstanding the economy of these works, they would be probably as invulnerable as their more expensive rivals."

Third. Lateral range.

The lateral range of the guns is the same as of those in a cupola; this quality would be valuable in guns on the face of a work, and of course still more so on salients; in fact, it would make a few guns as valuable as a much larger number mounted in the usual manner.

Colonel Gallwey, R.E., comparing a two-gun turret with guns behind embrasure shields,* writes :—

"We may ask then, admitting the above comparison, if two guns in a cupola can cover as much ground as six mounted behind shields, what would be the number of guns in ordinary earthen embrasures that would produce an equal effect, looking at the superiority of protection as well as range controlled? The answer might be: If it be admitted that one gun behind a shield is worth three behind ordinary embrasures (as it certainly would be), then the two in the cupola would be worth eighteen in earthen embrasures, and this estimate is not extravagant if it be closely examined."

* Professional Papers of the Royal Engineers, Vol. XIV, p. 45.

Fourth. Economy in the construction of works.

The failure of ordinary embrasures on the one hand, and of barbette batteries on the other, arising in the former from weakness of the parapet, and in the latter from exposure of the gun and detachment, is due to the increased penetration and precision of modern ordnance.

The change in the conditions of fortifications inevitably produced by this increase of power and accuracy in guns, is of a very serious character. There is no way of meeting that change except by the use of iron. I need not dwell on the objections to the general use of this material for land defences. It must be borne in mind that those who advocate its use do so because it is the only alternative that has presented itself. I would only remark that a two 12-ton gun cupola completed costs, exclusive of the guns themselves, about £15,000,* and the price of a sufficient armour shield is not yet decided on.

The expense of making sufficient defences on the system now proposed would almost be defrayed by the interest of the money required to be sunk in making thoroughly efficient iron-plated works. The saving is therefore prodigious, and such as would be of the utmost consequence, and would even seriously affect the resources of the wealthiest nation; and as in war, cheapness has often the same meaning as possibility, it is difficult to over-estimate this feature.

In the event of my system partly supplying the place of iron plated land works, I hope the country will not forget what it has been relieved from. With mature deliberation, and after every other resource has been exhausted, the Government have been forced to adopt iron as the only material giving satisfactory results. It would have been false economy, indeed, to have done otherwise. To have left vital positions on our coasts insecure, whatever might be the expenditure required to make them safe, would have been a grave error, and the system now proposed, would not in every case supersede its advantageous use; it might undoubtedly however, be employed in conjunction with the more expensive batteries, and in certain positions would be preferable, while the expense would be reduced materially whenever it could be applied.

Independent, however, altogether of the consideration of the first enormous expense of building iron-plated strongholds, there are important military considerations to be taken into account in connection with them.

Such permanent and complete works, as I refer to, when once made have to be taken care of and garrisoned; they must always remain a source of anxiety, and a continual drain upon our resources in men and *materiel*: a certain number of such strongholds are necessary, but they cost vast sums to complete them, and much to maintain them, and after all if iron casemates and embrasures alone are employed, they may be found at some future period insufficient to cope with improved artillery.

For these reasons it will no doubt be considered inexpedient to multiply the

* It has been pointed out to the Author, by Captain Coles, that this estimate is apt to mislead. The iron cupola itself costs little; the foundations, magazines, &c., make the price high. Colonel Jervois, Deputy Director of Works, in a paper read some months ago at the Royal United Service Institution, estimated the price of a 2-gun iron turret at £20,000 to £25,000.

number of such works. What is then to become of secondary positions of importance? Must they be left with defences that will crumble before the new artillery of ships? Are English soldiers to have the forlorn duty of fighting armour-clads from behind crazy embrasures? Or, are those positions to be left to the mercy of any adventurous privateer? I sincerely hope that the system now advocated may to some extent prove a satisfactory solution to these questions. Captain H. Tyler, R.E.,* alluding to the requirements in future fortifications, says,—

"The great problem to be solved is, how to obtain all these advantages with economy—not such economy as would deprive the works constructed of efficiency, which would not be economy at all—but such as will make fortification, so to speak, possible, and will afford to it a maximum of efficiency, at a minimum of expense.

"In endeavouring to find the solution of this problem, I shall purposely avoid laying down anything that can be called a system. As is well known, systems have already been too much the bane of the science. Now more than ever, systems of fortifications must give way to principles of construction; and (if the word system be used at all) to systems of defence. No two fortresses ought to be alike; but each work, and each collection of works, should be adapted to the purposes, strategetical and tactical, which it is intended to answer; to the pecuniary means and material at the disposal of the engineer; to the exigencies of its site; and to the circumstances of its topographical position."

If the system this paper discusses be thoroughly developed, it might be considered sufficient in many cases of coast defence to devote attention to perfecting the *materiel* of a powerful artillery, with every appliance that could make it efficient. This artillery would be stored safely at points where attack may be expected.

If this course were taken, an enemy would no longer be able to avoid our defences by knowing exactly where they are, because we should have the power to extemporize them if required. But considering the suddenness with which wars are now decided, it would be expedient to study the conditions in each case very carefully, and prepare the ground for the reception of its armament, by levelling down, or filling up, and forming the batteries as far as considerations of economy and expediency required; securing near plantations of copse for gabions and fascines, &c., &c., leaving only such work to be done as could be completed with short notice.

I go so far as to say, that Government might have in its possession private reports from a variety of officers for each position. The data given to these officers on which to found their reports being the amount of artillery and stores set aside for a certain position, they might be required to give detailed estimates and plans for putting that position in such a state that, say two batteries of siege artillery, a company of engineers, and 3,000 labourers, could complete the work and mount the guns in a week satisfactorily, estimating time and expense.

* Professional Papers, Royal Engineers, Vol. IX, p. 95.

I venture to make these suggestions because they are particularly applicable to the kind of earthworks now advocated, which would have, in many respects, the strength of permanent works, with the inexpensive character of temporary ones.

Fifth. Economy of life.

I rejoice to think that there is reasonable cause to expect a smaller waste of life in gun detachments. The power of any arm in relation to another will be determined to a certain extent by this condition. The late improvements in small arms I do not think have been in favour either of cavalry or artillery. The exposure of gun detachments in defensive batteries under the fire of new rifled artillery has not been much tested, since the latest improvements—immense precision and penetration coupled with the perfection of percussion and time fuzes and the construction of shells—would lead one to expect heavier casualties. Where iron is used, of course the proportion is altered, but even in that case the nuts and bolt heads have shown a disagreeable propensity to fly about; and the exact injury from concussion in cupolas, where a heavy shot hits fair, is still a matter of dispute.

None of these conditions affect the gunners in the present case, occupying as they do the defiladed space in rear of a high interior slope, and with all the advantages of mantlets, but in a higher degree.

The *sixth* or last head, viz. "Masking," is one which, perhaps, is not likely to be appreciated at first sight. No doubt it is an advantage which has not hitherto been enjoyed after guns had once opened fire; and, therefore, experience does not directly bear on it. I trust, however, that practical officers will agree that the proposed system posesses no small advantage in this respect over present ones, where guns are either in embrasures, in casemates, or *en barbette*. It would be rather difficult I conceive to open a correctly directed fire on a line of batteries which presented nothing to the eye, and which had not a mark of any kind to guide the aim.

If the ground were judiciously chosen for such batteries, it would be very difficult indeed to determine the exact position of the guns, and very unsatisfactory work to direct a fire on them.

I cannot illustrate this better than by begging my readers to recollect the case of the Mamelon at Sebastopol, which fell by assault after its batteries had been silenced. I watched very carefully the sort of fire which, gun by gun, shut up this work, until there was only one left to answer the bombardment, and feel justified in saying that, had it not been for the embrasures, all the artillery we had in position on the allied front would not have produced the same result in the same time; and from the way the French fell back after their first attempt, I am convinced the assault would have failed without regular approaches had there been a few guns to sweep the glacis.

As another illustration. Suppose the entrance to a harbour, the mouth of a river near a large town, or other narrow waters, had to be defended against ships. If a few powerful guns were judiciously placed in "Moncrieff" batteries, connected and supported by trenches for infantry, could anything more embarrassing be imagined for ships, than to receive a deadly fire from the most peaceful looking hillocks, and when they looked for their enemy, to see no mark of his position except a cloud of white smoke passing gently to leeward, until their attention was distracted by the same phenomenon in some other unexpected quarter?

In connection with this subject, I beg also to direct attention to a proposal which becomes possible, viz., that of using transparent screens.

These screens would be painted the colour of whatever happened to be the back ground of the battery. They would be made of the lightest materials, and would be used to deceive the eye of an enemy when he discovered the exact position of a gun (which however would very seldom be the case). A screen of this kind, through which the gun could be laid, but which would effectually obscure the view to an enemy, has the following recommendations: it can in a moment be replaced; it forces the enemy in order to have the chance of hitting the gun in the firing position, to waste his fire all the time it is down; and as that fire is utterly thrown away while the gun is down in the loading position, it follows that an enemy, besides having to overcome the very great difficulty of hitting the proper point at all, has to take the chance of the gun not being at that point when he fires.

The officer, by watching the character of the enemy's fire, and selecting the best time to lay his own gun, might make the enemy's task nearly hopeless.

I have here to offer a suggestion which relates to this view of the question.

In certain positions where a line is not exposed to enfilade, it might be of advantage to have the platforms running on trucks on a line of railway in rear of an extended parapet.

A proposal of this kind was made some years ago for the purpose of defending parts of the coast. I need not remind my readers that such a proposal is (with ordinary carriages) impracticable, as the strain across the line with modern rifled artillery, would tear up the rails. The case is now altered, however, as far as that is concerned, as the interposition of a moving fulcrum between the gun and platform would enable ordinary rails to carry a gun in action, and the whole weight of a 23-ton gun platform and counterweight would be under that of a heavy locomotive (60 tons). The guns could therefore be pushed by their detachments to any point of the parapet at which they might be required, without being exposed to view.

To recapitulate shortly what has been said, I submit that my proposed system is calculated to produce, to a certain extent, the following results:—

It absorbs the recoil in such a manner that it is turned to useful account instead of acting as a destructive force.

It takes away horizontal strain from the platform.

It gives security from direct fire.

It increases lateral range.

With equal efficiency it effects large economy in construction of works for coast defence, &c.

It economises life, and it makes batteries more invisible, and, therefore, more easily masked before action, and more difficult to attack in action.

For thirteen years great attention has been given to the improvement of ordnance; in no country has the subject engrossed more attention than in England, the best mechanical skill which the nation possesses having been brought to bear on it.

I have watched its progressive advances for ten years with a special interest, and each improvement has acted as an additional stimulus to the work this paper discusses. Impressed more and more, with the urgent need of some method of meeting the increasing penetration of projectiles, I struggled first with the mechanical difficulties in my way, and latterly with the not less formidable difficulty an inventor has to experience, viz., passive resistance to new ideas.

I hope, however, that I have now, to some extent emerged from both.

Probably the eagerness with which improvements in artillery have been pursued has had some effect in withdrawing attention from the new conditions that these improvements themselves imported into the land service.

The problem presented itself most urgently, and in its most formidable aspect, to the navy, and large sums have been expended, and are now being spent, in solving it for this service.

The land service has been content to follow in the wake of the navy, and the country is at this moment on the brink of a gigantic expenditure for iron fortifications.

The imperative necessity for improved works, pointed out by Engineer officers, who have clearly seen the dilemma approaching (some of whom are quoted) is at last acknowledged on all hands, and there appears nothing for it now, in order to protect our guns and gunners, but to borrow the unwieldy armour which is necessary for ships, and clothe our batteries on shore with the same expensive material.

I cannot help thinking that some method, such as mine, would in a great many instances fulfil all that is required, and even occasionally enjoy advantages of its own, independent of economy. These remarks apply with equal if not greater force to our distant colonial possessions. I trust, at any rate, to be permitted to develope a system which promises to be successful, and which, if it does succeed, will save millions to the country, and, what is of still more importance, will place our defences in a more satisfactory and efficient condition than even the most expensive of those methods that have been proposed.

A. MONCRIEFF.

Annexed is a letter from General Simmons, C.B., Director of the Royal Engineer Establishment, Chatham, dated 18th March, 1867, criticising in a very lucid manner the results of my experiments at the date it was written, and the objections which, at that time, were supposed to stand in my way.

My dear Sir,

I have been looking lately with much interest at the description and plans of your proposed system for raising guns, so that they may fire over a parapet, and in their recoil, fall down below it, so as to be completely concealed from view. The object, the solution of which you have proposed to yourself, is one of very great importance to the service, and one which, before I knew you had turned your attention to it, had occupied mine so much, that I had tried to direct the attention of my brother officers to it, and I have also suggested it as a problem requiring solution to some Mechanical Engineers, thinking it might probably be accomplished in a convenient manner by hydraulic power.

The importance which I attach to an invention of this nature is very great. By it the gun is effectually concealed when not in action, and is kept under cover for the greater part of the time it is in action. The gun, when placed behind a parapet or epaulment, or in a pit, presents no object upon which an enemy can direct his fire; the importance of this, when exposed to rifled guns (both small and great) cannot be exaggerated, and, moreover, it disposes of the difficulties attending the embrasures in earthworks, whether for attack or defence. These difficulties are very great:

(1) The embrasures present a fixed and constant target upon which guns may be laid.

(2) Embrasures weaken a parapet, and, as usually constructed, present the most favourable conditions for bursting shells fired with percussion fuzes, the thin part of the merlon affording just resistance enough to fire the fuze.

(3) The gun is always more or less exposed to injury from direct fire.

(4) No revetment has yet been found for the cheeks of embrasures, which is not readily destroyed, either by the fire of their own guns or those of the enemy, thus shutting the guns up and necessitating repairs, which are among the most dangerous duties of the soldier.

Various means have been proposed for palliating these evils, such as fixed iron shields, revolving cupolas or towers, and many other schemes which lessen the efficiency of batteries, by restricting their lateral range, and all of which, that I have ever seen, are exceedingly costly, and after all are only a very partial cure for the evils complained of.

It appears to me that the system of loading guns below the parapet, which may be of earth of any thickness, and, therefore, very difficult to destroy, and only bringing them up to an exposed position at the moment of firing, gets rid of all these difficulties.

Of course, any system which may be proposed for this purpose must have objections of its own; but I confess that your scheme is more free from objection than any I have seen; and having given it my best attention, I see no reason why it should not succeed with guns of any weight, however great, that are ever likely to be introduced into the service. If successful, it will save an enormous outlay to the country in its fortifications—which in these economical days, is almost more thought of by those who control expenditure than efficiency—

at the same time that it will add enormously to their practical value when submitted to their true test by an enemy's fire.

Your scheme appears to me to present no mechanical difficulties but what might easily be overcome, and it gets rid of one great mechanical difficulty which has not yet, I believe, been solved with guns as now mounted on the most approved pattern of carriage and traversing platform. I allude to the horizontal strain brought by the recoil upon the various parts of the carriage, platform, racers, and traversing bolts. This action is a very serious difficulty with guns on traversing platforms, whereas, according to your system, there will be little or no tendency to force the turn-table or traversing platform back.

You may expect objections to be taken to the weight and bulkiness of your counterpoise; but I don't think they need disturb you, as, when once the gun is mounted, this counterpoise actually diminishes the labour of working the gun, forming as it were a reservoir of power to run it up; and with regard to its bulk, you may reduce that considerably by the employment of lead, cast in ingots, so as to pack very closely, and still be manageable on the rare occasions when it may be necessary to dismount the guns.

I see no difficulty whatever in constructing a proper turn-table, for, after all, the weights to be dealt with are not greater than are to be seen daily on turn-tables on railways, and absolutely nothing compared to what may be seen in operation on board ship with cupolas and revolving towers.

One great objection which may be raised to any system of this nature is, that it is not compatible with the protection of the guns from vertical fire. The question between guns protected in this way and others in casemates is therefore one of the relative danger of horizontal fire at embrasures and vertical fire. For my own part, I should not hesitate to choose in favour of the system as worked out by you, the gun being protected on its flanks and rear by traverses, which would reduce the danger to a minimum.

There are many situations, however, where casemates are inapplicable, and, when opposed to shipping, there is very little danger to be apprehended from vertical fire. In such situations I have no hesitation in saying, that some plan such as this of yours, if it succeed, will be an immense improvement on anything we now have, and will be invaluable. I hope, therefore, you will persist with your system, and get it thoroughly tried.

I am, &c.

(Signed) J. L. A. SIMMONS.

APPENDIX.

On the Curved Rack in Moncrieff's Protected Barbette Gun Carriage.

The following paper, by the Rev. James White, M.A., on the form of the rack attached to the elevators of the carriage, has been communicated to the Royal Artillery Institution, and is published in their "Proceedings."

The curve is traced by a fixed point in a wall upon a circular disc rolling against it along a right line. As applied in the carriage the rack of its form fastened to the elevators as they roll back turns a pinion on the rail by which the friction and pawle wheels are moved. But it is manifest that the curve is not limited by the circumference of the wheel or circular disc generating it; if the plane of the rolling circle (on which the curve is traced) be indefinitely extended, the curve might be prolonged without limit. It is in this general form that it is proposed here to consider it.

It should be remarked, to prevent misconception, that part of the curved rack in Captain Moncrieff's carriage is generated by that portion of the elevators which is not circular, but as that is very small, and also the form of this generating portion undetermined, it will not be taken into account.

The curve can be obtained by reversing the supposition, *i.e.*, by considering the circle fixed while the line carrying the given point on its plane rolls round it. This will give one-half of the curve commencing from the point of it nearest the centre of circle, the other half being equal and opposite. Thus it may be defined as the locus of a fixed point on the perpendicular to the normal of the involute of the circle; or, in other words, the locus of the extremity of a tangent of given length (p) to the involute.*

Taking the particular case in which the length of the tangent is equal to the radius of the circle $(p = a)$ the curve is the spiral of Archimedes, whose equation is $\rho = a\omega$, for that is the *pedal* of the involute, or locus of foot of the perpendicular from the centre of the circle on the tangent to its involute, and the part intercepted on the tangent between that perpendicular and the normal is evidently equal to the radius. From this the general equation for any length (p) of the tangent can be easily deduced.

Let PQ be the normal, and QS the tangent to the involute of the circle PAD. Then, let $QS = CP = a$, and S is a point on the spiral $\rho = a\omega$, and CR is the radius vector. Pl. I, Fig. 2.

* The subject of involutes has been very extensively pursued, partly in connection with the curve here treated of, by Professor Sylvester. *Vide* Philosophical Magazine, Vol. XXXVI, p. 295, October, 1868.

Let $QR = p$ and $RS (= a - p) = d$, it is required to find the equation of the locus of R. CS will be its radius vector.

$$CR^2 = CS^2 + RS^2 = a^2\omega^2 + d^2,$$

consequently,

$$\rho^2 = a^2\omega^2 + d^2; \therefore \frac{\sqrt{\rho^2 - d^2}}{a} = \omega,$$

but ω is the angle made by CS with CD (at right angles with CA), therefore, in terms of the angle θ made by CR (ρ) with CD,

$$\omega = \theta - \angle RCS = \theta - \sin^{-1}\frac{d}{\rho};$$

$$\text{therefore } \frac{\sqrt{\rho^2 - d^2}}{a} = \theta - \sin^{-1}\frac{d}{\rho},$$

$$\text{or } \theta = \sin^{-1}\frac{d}{\rho} + \frac{\sqrt{\rho^2 - d^2}}{a}.$$

Professor Sylvester has proposed to call the rack of this form the "Moncrieffian," as it has been first used by Captain Moncrieff. The curves in general he has proposed to call "convolutes;" their existence has been occasionally slightly noticed, but their properties and application seem to have been entirely overlooked till Captain Moncrieff employed a rack of this form in his gun carriage.

Three cases of the curve are worthy of notice:—

(1) Let $p = 0$, that is let $d = a$, and then the curve becomes the involute of the circle. This may be found by making the substitution in the equation given above, remembering that for the Moncrieffian curve θ is measured from CD, but in the equation of the involute as usually given

$$\theta = \frac{\sqrt{\rho^2 - a^2}}{a} - \cos^{-1}\frac{a}{\rho}$$

θ is measured from AC.

(2) Let $p = a$, or $d = 0$, then as before seen the curve is the spiral of Archimedes.

(3) Let $p = 2a$, or $d = -a$, and then the curve takes a remarkable form, which may be called the *counter-involute*. Taking its rise from B (the point diametrically opposite to A, see Pl. I, Fig. 2), its equation will differ from that of the involute commencing at the same point only in the sign of $\cos^{-1}\frac{a}{\rho}$, but its form will not be at all similar. The involute may be defined as the locus of a point taken on the tangent to a circle making the length of the tangent equal to the length of the arc from the point of contact to a fixed one on the circle. The counter-involute admits of the same definition; but the tangent is taken in the direction *from* and not *towards* the fixed point on the circle. It may be described as traced by the extremity of the line round the circle when rolled off backwards tangentially, instead of unwound directly, as in the case of the

involute. This will be easily seen from the figure. Let $VS = QS$, and V is a point on the curve; draw VP' a tangent, and PCP' will be a diameter of the circle: produce QC to meet VP' in Q', and CQ' will equal CQ, and the angle BCQ' will equal ACQ; therefore Q' is a point on the involute commencing at B; and it is manifest that VP' is equal to QP which is equal to $Q'P'$.

The involute and counter-involute may be thus described as tan $= \pm s$; s being the arc of the circle from a fixed point to the point of contact of tangent. The Moncrieffian curve generally may be described as tan $= \pm ks$; when $k = \frac{a}{d}$, and s is the arc of a circle whose radius is d. This is evident from Pl. I, Fig. 3.

$$BR = PQ = PA = k \, . \, BA'.$$

It may, therefore, be defined as the locus of the extremities of tangents to a given circle whose length is a given multiple of the length of the arc from their points of contact to a fixed point on the circle. The radius of that circle will be d of the equation given before. When p is greater than a, *i.e.*, when d is negative, the tangents must be measured from and not towards the fixed point on the circle, and the curve will resemble the counter-involute. By a common property of rolling curves, it follows that the normal of the curve is PR in Fig. 2, the line joining the point of contact of the normal of the involute with the generating point. It will also be observed that the complete involute of a circle (*i.e.*, when unrolled on both sides from the same point on the circumference) has a cusp, the counter-involute has none.

It will be remembered that the Moncrieffian curve is the locus of the extremity of a fixed length taken on the tangent to the involute of a circle: now the involute continually approximates to its tangent, for its radius of curvature is continually increasing up to infinity, hence it follows that all Moncrieffians derived from the same circle are asymptotic to the involute, and, consequently, to each other.

A brief notice of the mechanical application of the convolute or Moncrieffian curved rack may be added.

By a rack of this form a moving fulcrum can be controlled or applied; as, however, the fulcrum rolls, the rack will pass through a fixed point, and therefore will act upon a wheel or pinion. Of the moving fulcrum, for which Captain Moncrieff first employed this curved rack, most valuable and important use has been made in his protected barbette gun carriage. The sudden and violent strain of the recoil of a heavy gun has not only been subdued but also utilized; and the principle may admit of many further applications to machinery subject to sudden strains and violent jerks. In some cases, moving fulcra might be advantageously substituted for pivots, so that the effect of the strain instead of being confined to one point would be distributed over some space. In the engines of war, where the destructive effects of great forces acting instantaneously have often to be provided against, this method may be found useful in many other cases besides that in which it has been first and so successfully employed.

This curve being of the family of spirals has an infinity of convolutions.

Consequently, the rack to govern a moving fulcrum may be of any length or at any distance from it.

To illustrate the application of a rack of this form: were it fixed to any circle, a pinion at the height *p* from the ground-line would roll the circle along it; or if the circle was the moving power as it rolled it would cause the pinion to revolve.

The manner in which this curve has been obtained has caused the rack to be sometimes called cycloidal. But this is a confusion of thought, as the cycloid is generated by a point fixed on the rolling circle, this curve by a point in the wall against which the circle rolls.

A small instrument by which this curve in its various cases may be freely drawn has been devised. It consists of a simple artifice by which a ruler carrying a moveable pencil is kept always perpendicular to a thread unwound from a circle.

DISCUSSION.*

MAJOR GENERAL FROME, I.G.E., &c., &c., IN THE CHAIR.

THE CHAIRMAN: Field Marshal Sir John Burgoyne having expressed a wish not to take the chair, that duty devolves upon me. The subject we have met to discuss is so well known, that if I were to go into any description of Captain Moncrieff's invention, it would only be taking up time, and I should be describing what, no doubt, many officers know more about than I do. I think then we had better proceed to read such portions of Captain Moncrieff's paper, as appear to bear most upon the subject, and then leave it open to any officer to make such comments as he may think proper to offer.

LIEUT. COLONEL HUTCHINSON read portions of Captain Moncrieff's paper:—

The CHAIRMAN: Perhaps General Lefroy, the President of the Ordnance Select Committee, if he feels disposed to offer any observations, will be the best person to commence the discussion. I believe the report of the Ordnance Select Committee is finished, and I hear that that report is in a great degree favourable to Captain Moncrieff's system, as regards its mechanical construction.

MAJOR GEN. LEFROY, R.A.: I am happy to say that the report of the Ordnance Select Committee does bear the character which you have given it, that it is entirely favourable to the success of Captain Moncrieff's gun carriage, viewed as a mechanical arrangement. Entertaining, as I do, the most sincere admiration for the skill, ingenuity, and perseverance with which Captain Moncrieff has developed this very

* Held at the War Office, on the 17th of November, 1868, Officers of the Royal Navy and Royal Artillery, and Captain Moncrieff being present by invitation.

novel and original idea, I trust that neither by him, nor by any other gentleman in the room, shall I be understood as depreciating that invention, if I feel it my duty to, in some degree, qualify or submit for your discussion, points which are not so favourable to it as those which have been advanced in the paper which has just been read. I leave to the officers who are conversant with the estimates and constructions of works whether Captain Moncrieff's estimates of expense are well founded or not. But, as an artilleryman, I cannot admit that one gun upon a Moncrieff carriage will represent three guns upon any carriage whatever. There are occasions, and never more urgent than in the smoke and confusion and chance medley of a great engagement, such as that alone in which we can conceive these guns employed, in which a multitude of guns are indispensable to effect your object. Captain Moncrieff, judging from the success attained by the most skilful gunners and the most powerful and able body of men that can be produced, anticipates the use of this gun at the rate of one round per minute. I fear that is too rapid a fire to be calculated upon for a continuance, or under the ordinary circumstance of men less trained than those skilful gunners at Shoeburyness. The first trials were at the rate of one round per two minutes and a half ; and if we may assume that as the ordinary rate of firing, I am persuaded it is as much as will be realized in practice. A ship moving at the moderate rate of eight knots per hour, alters her position by 600 yards in two minutes and a half. To meet the condition of a ship travelling at that rate, a number of guns, and not one gun is necessary. We cannot take one-third of the number of guns as equivalent to the full number.

The security of this gun against vertical fire has also, I think, been overrated by Captain Moncrieff. It is true we have no great amount of data as to the chances of hitting an object with a mortar at a great range ; but it is often asserted that the greater the distance, the more accurate in point of range is the fire, inasmuch as with a full charge of powder, there is greater uniformity attained than with small charges. To quote a single instance, I find that in some practice that was made from a mortar boat attached to the *Excellent*, about two years ago, nine shells out of thirty-five, that is about 25 per cent., would have fallen upon the top of one of the Spithead forts, taking that as a circle of 200 feet in diameter. Assuming that nine shells, at a distance little exceeding one mile, out of thirty-five that are fired, fall upon the top of that fort, how many may be expected, either by first impact, or by rebound, or by rolling, to get into some of these pits ; or if they do not actually do so themselves, how many splinters will fall in ? The security against vertical fire is not so great as Captain Moncrieff supposes. Taking the narrowest limits of the pit to be 22 feet against the 200 feet of one of the Spithead forts, we should get about one shell in 400 to fall into any single pit aimed at. In the case supposed, we have a circle of several pits round the point aimed at. If an enemy were to attack Spithead forts, or any great cardinal point in the defence of this country, he has charts of the approaches, and he will have as many mortar boats as he thinks will accomplish his object. If ten will not do, he may have a hundred ; therefore, the probability is, that the security of his guns in these recesses against vertical fire, is much less than Captain Moncrieff represents. But it is not merely the shells that fall into the pit that we have to consider. A gunner must have more than iron nerves, if he can see unmoved a rain of mortar shells coming in the sky. Knowing the effect of them, it must make him hesitate, and interfere with the rapidity and accuracy of the fire from the pits. But besides the probability of direct effect from vertical fire, it is impossible to disregard the effect of lateral injury. Mortar shells falling anywhere in the neighbourhood, to the right or to the left, and scattering large splinters many pounds in weight with great violence on either side, will attain the great lateral surface of these guns, which is as much as 120 square feet—a considerable target. And though it may not happen that this shell or that shell will hit it, yet if you keep on throwing shells all day, and for two or three days running, as was done at Sweaborg, a sufficient number will attain the point to disable these guns. An enemy having that in view, and having his mortar batteries in a position of entire security, will simply perform that operation as a preliminary one ; and having done that, he will proceed to do what he contemplates next.

With regard to the actual working of these guns when exposed, as they would have been exposed, if, for example, they had been introduced during the wars before 1815, I think one cannot altogether contemplate the continual efficiency of a great structure, weighing, as in the case of the 7-in gun, three or four times the weight of the 12-in., 10-in., or 9-in. service guns—a great moving structure weighing 50 or 60 tons—one cannot altogether contemplate that remaining unaffected by the injury of time and chance, and of a thousand accidents. It appears to me very probable that under the long continued steady weight upon them, some of these moving parts may bend, the journals, for example ; the effect of changes of temperature may throw out the nice adjustments ; at all events, that the correct mechanism, the perfect working which we have admired so much in the first carriage and platform of Captain Moncrieff, may not be found after the gun has been on a work of defence for twenty or thirty years. These three points, that you cannot often replace three guns by one ; that these guns are not so secure against the effects of vertical fire, particularly in the position in which it is contemplated to place them, (I assume such positions as well-defined forts at sea), that they are less free from risk of injury, notwithstanding their disappearance from the front of the parapet ; and that they are still much exposed from lateral injury to casualties of every kind, are the points which, as an artilleryman, I wish to impress upon the officers present There are, no doubt, other points that will be spoken to, and perhaps Captain Alderson, who has had practice with this 7-ton gun, will tell us what his experience is ; but these are points that struck me as most important in considering the use of this system for permanent works of defence. That it may be applied to extemporised works, if its weight permit it, and that individual guns scattered about may have all the advantages that Captain Moncrieff maintains, I freely admit.

THE CHAIRMAN : General Lefroy has mentioned Captain Alderson as being in the room. I think the first point we have to consider is the efficiency of the gun as a gun. That is an Artillery question ; and it might be well that Captain Alderson should follow General Lefroy, and let us know his opinion of it as such. Then, the next question will be its adaptation to purposes of defence. Perhaps, Colonel Gordon, also, will tell us his experience with the gun.

COLONEL GORDON, R.A. : After the remarks with which General Lefroy has been favouring us, I do not think it would be desirable for me to take up your time. Captain Alderson, who has actually carried out these experiments, will be able to give you the benefit of his experience in working the gun. I have myself only fired a very few rounds from it ; and I would bear testimony to the ease with which the gun has been worked, not by a skilled detachment of gunners, but by a party of officers undergoing the long course of instruction. Before sitting down, I would ask you to allow me to return thanks on the part of Colonel Elwyn and the officers of the School of Gunnery for your kindness in asking us to come up here. I will not detain you longer, because Captain Alderson has carried out the experiments, and can give you practical information upon the subject.

CAPTAIN ALDERSON, R.A. : Sir, with regard to the ease of working this gun-carriage, which is one of the points mooted, I can only say that, as far as trained gunners are concerned, nothing can be simpler. It can be worked not quite so fast, perhaps, as the service carriage, but there is very little difference between them—about one minute in five rounds. Captain Moncrieff's has been fired at the rate of five rounds in 4 minutes 45 seconds ; with the ordinary carriage, the five rounds can be fired in about 4 minutes.

With regard to the danger from vertical fire, I must say for myself, I should have no fear on that point, judging from the late practice at the experimental casemates. We were very lucky the first day. In 15 rounds we got three hits, and it took 120 rounds to get another hit.

AN OFFICER : What was the range ?

CAPTAIN ALDERSON : 800 yards. With every appliance that we could get, and weighing the charges most carefully, I think it took 200 and odd rounds to get the other hits we wanted. The part we wished to strike covered a very small area, about the same, within a few feet, of what the Moncrieff pit would be.

Another thing in connection with the practical working of the gun is the loading. There is a slight difficulty at present, because we have to use rope rammers and rope sponges, such as they employ in the navy. These will answer very well with 7-ton guns and light projectiles, but I do not think they will do at all when you come to 12 ton guns. We tried the other day to load a 7-ton gun with the ordinary rammer, and I found we could by giving 4° of elevation over the parapet. Then the question is, whether you could load above the parapet, or with holes through the parapet, for I think that it would be impossible to load a heavier gun than a 7-ton gun with a rope rammer, with the men placed as with the 7-ton gun. As far as the action of the carriage goes, and the wear and tear, we have fired up to the present time 130 or 140 rounds from the gun and we have only had one accident ; and that arose simply from inattention, or from not quite knowing what to do. And here, in my opinion, the difficulty will arise with these carriages when you come to deal with heavier weights than you have at present. Suppose that something happened to No. 1 (who is the man that we attach to the break, the man who, in fact, looks after the whole apparatus of the gun), or that he was not looking after his work, or was wounded, and the break was let go, up would fly the gun with great momentum, and the only thing to check it from dismounting itself at the present moment are a few small screws in the cap squares in the axles. On the occasion I allude to, No. 1 did not attend to the break in time, or he let the gun run up and applied the break suddenly when it was at its greatest speed ; the result was that the whole strain was suddenly thrown on the screws I mentioned, one broke and one bent in the cap-square, the axle shifted, and the gun was put *hors-de-combat.* That would not have happened perhaps with a 7 ton gun if there had been stronger screws I mention the fact because when you come to heavier guns it will be a still more serious difficulty. There is no provision in the present arrangement for checking the gun, should, as I said, any thing happen to No. 1, who is looking after the break. I have no doubt that is a point that Captain Moncrieff has paid attention to. At present it renders the gun liable to be put *hors-de-combat* in case of anything happening to No. 1.

AN OFFICER : I should wish to ask Captain Alderson what was the angle of elevation with the vertical fire at Shoeburyness ?

CAPTAIN ALDERSON : Sixty degrees.

THE OFFICER : That is higher than the usual angle ?

CAPTAIN ALDERSON : Yes.

THE OFFICER : It would affect the accuracy of the practice ?

CAPTAIN ALDERSON : To a certain extent, of course.

THE OFFICER : Not with regard to range ?

CAPTAIN ALDERSON : When the range is known, I do not think it would affect it so very much.

THE CHAIRMAN : Colonel Wray would very likely wish to say something.

COLONEL WRAY : I have very little to say, except that I have the greatest confidence in the whole thing, from beginning to end.

THE CHAIRMAN : Is there any other officer of Artillery, or any visitor, who would like to speak upon the mechanical efficiency of the gun carriage, before we come to any question of its adaptation to works. If not I will call upon Colonel Jervois.

CAPTAIN MONCRIEFF : With your permission, Sir, I would now reply to some of the remarks that have been made. In the first place I should like to allude to the view which General Lefroy takes of the artillery part of the question. The first part of his remarks referred to a statement made in the preface to the paper, about the possibility of the Moncrieff gun-carriage making one gun perform the duty of three. Of course I am quite aware that in a great many cases that would not be the measure of the difference ; at the same time I do not think I overstated the matter. To illustrate what I mean. Take the case of a battery placed so as to command a channel, extending along its whole front. By the present arrangement, this battery must have three faces. If the guns of the present system are capable of doing the same work, what is the use of the two extra faces ? In my system you have one face, and each gun commands the same range that all the others command. I do not pretend to say that that necessarily makes my gun three times as powerful as the others to the front. Take another case, where the difference is twice as great. I think it will be allowed that in the great majority of cases, you would get at least twice as much range, or two-and-a-half times as much range. Guns in cupolas or guns in Moncrieff batteries might be placed where they could sweep round the whole circle ; therefore, it is a modest statement to say that a gun mounted on the Moncrieff carriage might command three times as much range as one in a casemate or embrasure. With regard to protection against vertical fire, I do not require to make any remark, because that point has been very well answered by other officers. With regard to the lasting quality of my carriage, that is a matter which I can speak to better than any one. General Lefroy seems to have an idea that because my carriage has perhaps a complicated appearance, and so on, that it will not last very well ; but I venture to think that if that question were properly investigated, it would be found that the chance of lasting is more likely to belong to my carriage than to any other ; for this reason ; the arrangement used for stopping the recoil, namely, by making the position of the counter-weight in the firing position always coincident with the point of support, takes off entirely the first great strain upon the carriage and platform. The strain is brought on very gradually indeed, representing more the action of an animal lift or the action of a hand than the blow of a machine. I am very confident that experience will confirm my view. I predict it will be found that carriages made upon my principle will not, as General Lefroy supposes, be likely to wear out soon, but that they will be found to last uncommonly well. The most serious objection that has been made was that by Captain Alderson, and that objection I agree to at once. It is the loading difficulty. Captain Alderson only alluded to the use of the rope rammer, however. I am not aware whether he was present when the telescopic rammer was used. It was found to answer very well in the first experiments. Being a very light and handy rammer, it might be increased in weight and in power very much, without making it inconvenient ; and even though there were no such changes as he himself suggested, and others which I should like to hear suggested by and bye, I believe the telescopic rammer might be found to answer at least for a 12-ton gun. When the time comes for mounting heavier artillery, I do not think it will be impossible to meet that difficulty in another way. With regard to the danger of the gun running up, which caused an accident the other day with a detachment that were not acquainted with the gun, that also is a flaw which I acknowledge, and which I hope to be able to overcome. I do not think it is a hopeless difficulty, but it is an objection, and I am always glad to have these objections brought forward. I like every criticism that can be made, because I believe the principle is sound, and will be found yet to meet the most serious objections that can be made against it.

MAJOR GENERAL DICKSON : With your permission, I wish to say a few words upon the subject. I have had a knowledge of Captain Moncrieff for many years; his invention was brought to my notice first as a model, in Edinburgh, in 1865. I then thought very highly of it, and I considered it an invention that might be of very great utility if worked out properly. That has been done. I wish to refer to a few points that have been already spoken of by General Lefroy. One is the subject of vertical fire. I think Captain Moncrieff treats the dangers from vertical fire a little too lightly. I have myself seen a great deal of the effects of vertical fire. I think when you come to have a continuous fire of many heavy mortars, they must search out and find the spots where your guns are placed, and many of them must be injured or disabled in the course of such a fire. There are risks to be run, but I do not think the risk is one that can counterbalance the advantages to be derived from the use of Captain Moncrieff's carriage. In the same way I think this gun is not perfectly safe from direct fire. Although the gun rises and is seen for a minute only, and may be shrouded by the smoke, I have that knowledge of gunners, that I believe by an ingenious system of marking with pickets—the men have quick eyes, and can mark almost the spot where the gun rises—many guns will be disabled ; I do not say all, but many will be. But, again, I say that this risk does not counterbalance the advantages of the system. The great value of this invention is its application to earthworks. The great weakness of embrasures has been the cause why we are now trying to shield our forts and do everything we can to protect them from fire ; but we know not yet what is the power of penetration into earth possessed by heavier ordnance. We know that the great defect of all earthworks has been embrasures. By closing the embrasure, the gun is protected from direct fire, and from any liability to be destroyed, except at the moment of rising ; but I do not think we can dispense with the number of guns that Captain Moncrieff thinks we can do without, by the introduction of his system. We might take away one in every three in a work, and allow more space between the guns, which ensures the safety of the guns and men ; but in an important work, I am of opinion that you cannot reduce the number of guns so materially as Captain Moncrieff suggests.

COLONEL JERVOIS, C.B., R.E.: Like Colonel Wray, I have great confidence in Captain Moncrieff's system of mounting guns. Captain Moncrieff describes in the pamphlet, portions of which have been read, the object which he desires to attain by this invention: "The conditions desired were simply to obtain a system of firing over a solid parapet, while preserving free lateral range, and neither exposing the gun and detachment, nor involving the labour of raising and lowering the piece; in other words, of gaining the advantages of a barbette battery without its defects." That appears to describe in one sentence what is attained by Captain Moncrieff's system of mounting guns. It is said, however, that we shall be able to improvise works by means of this system, and it is implied that hitherto we have been unable to do so. I cannot concur in that statement. Anything that can be done with respect to the construction of temporary works for guns mounted on the Moncrieff principle, (excepting, of course, the fulfilment of the condition for which this carriage is expressly designed) could be done before the introduction of this invention, as easily as now. We have always had the power, where the conditions permitted its exercise, of constructing temporary earthworks, temporary magazines, and of making every arrangement for mounting guns temporarily; but with this disadvantage, that the guns were either open to the objection to which embrasures in an earthwork subject them, or were continually exposed if placed *en barbette*. Captain Moncrieff has found a remedy for these defects.

With respect to the application of this system to permanent works of sea defence, the several conditions under which we have to consider the question are: first, in comparison with works constructed with embrasures but without iron shields; secondly, with reference to barbette batteries; next, in comparison with works provided with iron shields at the embrasures; again, we have to consider whether this system in any way affects the employment of casemates.

As regards the first point, there cannot, I think, be a question that the system of placing the guns behind a solid parapet and merely exposing them when fired, affords a great advantage as compared with the ordinary embrasure battery. It does not require any observation to enforce such a view.

With respect to the application of the system in cases where barbette batteries have hitherto been used, the question is one of expense. Probably, at an elevation of from one to two hundred feet above the water, it would not be desirable to incur the additional expense of Moncrieff carriages, although, even at such heights, some additional security would be obtained by adopting them. In all cases of barbette batteries at no great elevation above the water, it appears desirable to apply the Moncrieff system of mounting guns; that is to say, to guns for which the system is hereafter found to be applicable. As yet, it has only been tried with the 7-ton gun.

When compared with batteries constructed of either earth or stone with iron shields at the embrasures, it will probably be found that a considerable saving of expense may be effected by adopting the Moncrieff system. In such batteries the guns have usually been placed at about the same intervals apart as would be adopted in the case of a battery for the Moncrieff carriage. It is only necessary, therefore, to fill in and form in a segmental shape, the space where it has been proposed to place the iron shields, provide circular racers, and generally, in other small details, form the work for the reception of the new carriage. And this can be done at a comparatively small expense, provided we are content with the protection afforded by a parapet either of masonry only, or of earth and concrete, with an interior revetment of brick-work or stone. In this case, it will probably be found that the saving of expense will be considerable. Such saving, however, will disappear, if, as many think necessary, the superior slope of the parapet be plated with iron. The amount of saving effected, supposing iron be not employed, will depend on the additional cost of the Moncrieff carriage over the ordinary carriage. I believe the Moncrieff carriage, together with its platform, for a 12-ton gun, will cost about £1,000. The ordinary carriage, when applied to a 12-ton gun, together with its platform, costs about £400. An iron shield costs, say, from £1,000 to £1,200. Therefore, if these figures are correct, and £50 be allowed as the extra cost of the parapet for the Moncrieff gun-carriage, there would be a saving of from £350 to £550 per gun, by the adoption of the Moncrieff carriage for 12-ton guns. This saving would be less in the case of larger guns, for the cost of Moncrieff carriages for such guns would, probably exceed what I have stated. Nevertheless, we should still have the advantage, whenever we want it, of the increased lateral range afforded by the Moncrieff system, when compared with the splay of 70° training, which is obtained from an iron shield with a port 2 ft. 6 in. wide.

We now come to the consideration of the question whether the introduction of Captain Moncrieff's carriage will lead to the abandonment of casemates for sea batteries. I think that an investigation of that point will show that it will not. In the first place, we can only get one gun on the Moncrieff system in place of two, when casemates are employed, and although, no doubt, considerable concentration can be obtained by the adoption of the Moncrieff system, you do not obtain the same amount of concentration on one point that you would from double the number of guns in casemates; and if you take the case of attack by a squadron of several ships instead of by one vessel, the concentration on any one vessel will be very largely reduced. Again, the protection against direct fire is not so good as it is in casemates when the small embrasures of the present day are taken into account. The gun mounted on the Moncrieff system is exposed to shot and shell fired at high angles. The parapet covering the gun is liable to be knocked away at its interior crest, and so the gun will be exposed, unless special means are applied to meet the case. Then as regards vertical fire, I think this is a point which should not be entirely lost sight of. In the case of a bombardment from a number of mortar vessels, firing shells that burst in the air, or in the works round you, and behind you, you would certainly not disregard vertical fire, and I think it would be found advisable to have protection against it. We thus have a greater concentration of fire from the casemate battery; better protection against direct fire; and protection, which is not obtained in the other case, against vertical fire. So that we come to this: although we can apply the Moncrieff system, and obtain a saving of expense by doing so in the case of open batteries, it is not desirable, as a general rule, to apply it in lieu of casemated batteries; although we might in certain cases substitute the Moncrieff system for a casemated battery—such substitution being for determination, according to the circumstances of each particular case—we should not altogether disregard the considerations which I have ventured to submit. In some instances, it should be observed, the area for the foundations of a work is limited, and the capacity of the work is very small. In such cases you cannot get the amount of fire you require by the adoption of the Moncrieff or the ordinary barbette system. The guns in the barbette system are necessarily so far apart, that the amount of fire obtained by applying this system in the instances referred to would not be worth the expense of the foundations and basement. It would be better to expend the money in some other way for the same purpose. This observation would apply to such cases as the Spithead forts, the work on the Middle Ground, Bombay, and other places. As regards substituting guns mounted on the Moncrieff system for turrets, there is no doubt that guns mounted on the Moncrieff system would cost much less money than guns mounted in turrets. A turret for two guns would not cost less than about £20,000, whilst perhaps two guns on the Moncrieff system might be mounted complete for about £4,000. On the other hand, the two guns in the turret are thoroughly protected at all times ; and although perhaps not absolutely protected against vertical fire, there is a great advantage in the turret, if the question of expense is not taken into account. I do not think that so far as the application of the Moncrieff system to works of sea defence is concerned, there is any other case for consideration.

As regards the application of the Moncrieff system to land works, such as the Portsdown works, the works at Antwerp, the Gosport forts, the Plymouth, and other land defences, it seems to me that it would be most valuable ; not to the entire exclusion of batteries covered over ahead, and protected in front by iron shields, but as forming the main portion of the armament of such works. I may say in conclusion, that I think we are greatly indebted to Captain Moncrieff for this invention.

MAJOR GENERAL SIR WILLIAM DENISON : We owe, in the first place, very great thanks to Captain Moncrieff for the talent and energy that he has displayed in bringing this machine to perfection. We are discussing it now from two points of view. We must look at it first as a weapon provided by the Artillery ; and next as to the mode in which we Engineers, are to apply it. As to the first we have to look at its capacity for delivering its fire, and to the efficiency of its mechanical parts. With reference to those two points, I must say that everything has been admitted ; that is to say, its action is shown to be perfect—there is no jar—at least, with the single exception mentioned by Captain Alderson. With reference to the difficulty of checking the action of the counterweight when bringing the gun up again, I have no doubt Captain Moncrieff will find an easy means of modifying that arrangement. The gun and the carriage—the carriage, rather, which carries the gun—seems to me to be as perfect a mechanical adaptation as we can possibly require. I am sorry that I was not able to go down and witness the experiments at Shoeburyness, but I have heard from officers present what has been stated by officers to-night, that nothing can be more perfect than the action of the carriage. As to rapidity of fire, I think that is a matter of very little moment. Whether you fire five rounds in four minutes, or whether you fire steadily one round every two minutes, is a matter of little importance, except in particular circumstances. But taking the gun generally as a weapon, nothing can appear more perfect than this for particular purposes.

Now, as regards our mode of applying it: we are told that when in a battery, it is exposed to vertical fire. That is perfectly true; but so is every gun. I do not think we really can expect to turn out soldiers, to put them behind batteries, and expect them to fire away and hit their enemies, and not run the chance of being hit themselves. Of course, there is risk ; and there must be great risk. But, again, I must say, I think the risk has been exaggerated. I freely admit that if you have got 100 guns or mortars firing shells at one isolated gun pit, the chances are that after half an hour, or an hour, or two or three hours, you might pitch a shell into the pit and destroy the gun. But that would not be the case where you have got a number of gun pits; you would probably have 50 or 60 of them, and every gun would be bearing upon the guns of the enemy in return. Therefore, to tell you the truth, I do not think the action of vertical fire upon a gun of this kind will be a bit worse than the effect of vertical fire upon ordinary guns placed in an ordinary battery not covered by casemates. As far as regards the action of vertical fire upon a gun, it is reduced to this: the Moncrieff carriage is a little more expensive carriage. I do not know exactly the amount, but it is, perhaps, a more expensive carriage than the ordinary carriage, and, therefore, liable to involve more cost for repairs if injured. The next objection made was with reference to the effects of lateral fire, that is, splinters and shells. But, I suppose, as in every other case, the gun will either be in the pit or it will be covered by some sort of expedient such as is usually employed, and the risk it will run will not be more than in the exact proportion of the additional surface exposed; that is to say, if it expose double or treble the surface of another gun, of course, the risk from splinters and shell flying about, will be double or treble; but I do not think that is a risk which requires much notice. Of course, there is risk. You cannot go to war and have people firing at you without sometimes being knocked on the head. Then, as to the wear and tear, if I understand aright, it is all formed of iron.

CAPTAIN MONCRIEFF: The carriage.

SIR WILLIAM DENISON: The carriage. I believe you propose that it shall be formed of iron.

CAPTAIN MONCRIEFF: Yes.

SIR WILLIAM DENISON: I do not think there is any more chance of that corroding than there is of any other iron construction corroding. I do not think the bearings are likely to sag or give, if properly constructed in proportion to the weight they have to carry. Therefore, looking at it as a weapon, I think we are fairly entitled and perfectly justified in thanking Captain Moncrieff for giving us Engineers the opportunity of placing behind our works an article of that kind which can be made so very effective. I was coming home from India, and I thought it was desirable to stop at Malta and Gibraltar on my way. Nothing struck me so much as the totally indefensible condition of both those places. Malta is a place built of soft rotten stone, more like chalk than anything else, with an enormous number of small guns mounted upon it. The largest guns that I saw there were 90-pdr. breech-loaders; these were mounted *en barbette*. Very much the same was the case at Gibraltar, although the guns were placed further back, and were not exposed so much as these were. An iron-clad might have sailed into the harbour, and firing right and left, might have smashed the whole of Malta in a very short time. I thought it necessary to bring the subject under the consideration of the Inspector General at the time, and pointed out that if an enemy came against us clothed in iron, it was absolutely necessary that we should put ourselves in iron too, in order to resist him. I proposed that we should cover our barbette guns by putting them in turrets or something analagous, and that we should get ourselves fairly covered from fire before we could hope to contend with people who came covered and protected in the same sort of way. I went down to see some of the practice at the shields which are going out there for that special purpose. I think it is one cause of our thanks to Captain Moncrieff, that he has produced a weapon of this kind which renders such an enormous outlay for iron shields unnecessary. The carriage costs what may I say?

CAPTAIN MONCRIEFF: You might safely say £1,000.

SIR WILLIAM DENISON : The carriage costs £1,000 ; that is for a 10-ton gun.

CAPTAIN MONCRIEFF ; A 12-ton gun.

SIR WILLIAM DENISON : I think we may safely say, that for a 12-ton gun the ordinary carriage, the traversing carriage, and the platform would come to £400. But in one case the gun is exposed, in the other case it is concealed. You have here the power of placing a gun behind even an earthen parapet, or a stone parapet, of sufficient thickness to resist whatever shot may be fired against it. The gun is exposed for a very short period. You have got the power of laying the gun while it is concealed ; and then all you have to do is to bring it up to its proper position and fire it, and the very act of firing it brings it down again under cover. Therefore, I consider, for all purposes of coast defence, the defence of salients, and everything of that kind, nothing can be better adapted than this particular gun. I quite agree with Colonel Jervois that it is not adapted for every site. If you are going to build a fort on a quicksand, or upon a shoal with limited area, and your object is to get as much fire out of that fort as you possibly can, you cannot then use a gun of this kind, though you might use it on the top ; you cannot, probably, dispense altogether with the casemate in such a position. But with coast batteries, it strikes me that your plan is, not so much to concentrate a number of guns on any particular point, as to extend your line of guns, so that while one gun is firing on a vessel and taking it on its broadside, another may fire and take it on its quarter, thus spreading your fire as much as you can, instead of concentrating it on a narrow area. That would be, perhaps the better mode. But that is not the question now. The question is whether Captain Moncrieff's mode of mounting heavy guns does not offer to us Engineers a very convenient and useful mode of getting a heavy fire with a fewer number of men, of covering your men, and enabling them to work the guns with less risk to themselves, and with positive good effect for the defence. I can hardly imagine a place in which it would not be available, except in casemates ; as I have already said, you cannot put a thing of that kind into a casemate. As to the proportionate efficiency of the gun, you cannot say that it is worth two guns or three guns everywhere ; but you can positively say that, in certain places, where it has the power of traversing thoroughly, like a gun in a Martello tower, it is worth half-a-dozen guns fired through ports or embrasures. I do not know that it is necessary to say more. In my opinion we owe very great thanks to Captain Moncrieff for his capital invention.

ADMIRAL SIR FREDERICK GREY : It is difficult for a naval officer to give an opinion upon a subject which so peculiarly belongs to the artilleryman and the engineer. But I think Captain Moncrieff stated that you might do with less guns by the adoption of his plan. He illustrated that by saying that in a channel a battery of the ordinary kind would require three faces : one to fire across, the other two to fire up and down ; while in his plan you might have a battery with one face with guns all in a line, and, therefore, get a greater amount of fire than in the other case. The question I should like to ask is this : I presume it is always contemplated that in such a case as this the battery would be attacked, not by one ship, but by a powerful squadron. No single ship would attempt to attack a battery of that kind. Then, supposing a squadron to attack it, they would, of course, attack each part of the battery. The fire from the ships below would attack the battery at one point ; if they succeeded in passing it, their fire would be directed at another. I should like to know, unless these guns are protected by traverses, what the effect of that oblique fire from the ships below would be upon the guns which were engaged with the ships directly opposite? Is it not probable that a great many of these guns would be very soon disabled? That is a question to which I should like an answer. It is a point that has struck me as having an important bearing upon the question of the reduction of the number of guns.

SIR WILLIAM DENISON: I think that observation would apply just as much to one set of guns as it would to another. These guns would, at all events, except in the actual instant of firing, be under cover. The lateral fire from below or from above, or the direct fire, would be equally inefficient against them, except during the instant they are on the parapet. But if you take the case of an ordinary battery, you have a single straight line containing a dozen guns, or rather a broken line containing 36 guns, twelve on each face, firing part up, part down, and part abreast. A portion of these 36 guns, the dozen guns to the right, would open as the vessels were coming up. As soon as the vessels had passed them, their fire would cease. Then the fire would be taken up by the 12 guns in front while the vessels were coming abreast of them. Of course, as soon as the vessels had passed them, their fire would cease. So again with the remaining 12 guns, they would take up the fire as the vessels passed them. But with these guns, being capable of traversing all round, you might keep up their fire the whole time. I do not mean to enter at all into the question whether one gun mounted on a Moncrieff carriage is worth three other guns, or not; still, I think the difference of range—the extraordinary amount of range which these guns possess—must give them greater power.

ADMIRAL SIR FREDERICK GREY: That is not my question.

THE CHAIRMAN: I think that what Sir Frederick Grey meant was whether a battery armed with Moncrieff's guns would not require traverses the same as any other barbette battery. I should say certainly it would. Although the gun itself might only have its muzzle over the parapet, yet, if the battery is exposed to oblique fire, it must require traverses.

LIEUT. COLONEL RICH, R.E.: I think the Moncrieff gun has its own traverse. The very pit forms its traverse. Each gun is in its pit, and the pit itself forms its traverse. The Moncrieff battery is traversed *per se*, without a traverse at all, because every pit is its traverse; and the moment the gun is fired it is behind that traverse.

LIEUT. COLONEL INGLIS, R.E.: The point that is now being discussed, seems to me to involve the question of the greatest objection to Captain Moncrieff's system; that is, as I understand it, the exposure of the gun while it is in its firing position. When it is down and being loaded, it is all right. When it is up it is fully exposed, and, to my mind, a great deal too long exposed for the accuracy of the fire of the present day. On one of the occasions of the gun on the Moncrieff carriage being fired for rapidity at Shoeburyness, I happened to be at about right-angles to the line of fire, and some 200 or 300 yards distant from the gun, and I observed each time it was brought up, how very much exposed it was. If I had had a gun in the position I was in, or even at a considerably greater distance, I feel sure I could have hit the gun in the Moncrieff battery almost every time that it was up; that is to say, I had time to lay with accuracy, and fire. Therefore, I consider a gun on the Moncrieff carriage, while it is in the firing position is too much exposed for the fire of the present day. With regard to the case of a gun engaging a single ship or any one object, of course, the gun then presents a very small mark to the enemy, but when the fire from the ship is oblique, and the enemy gets the full broadside view of the gun, then it i evident that the gun will require more protection than it is likely to receive under this system. I think it will be found in practice that considerable time will be taken up with the gun in the firing position. At any rate, I cannot believe that the actual work of the gun will resolve itself into that of its being loaded, brought up to the firing position, fired immediately and dropped behind the parapet. I do not believe that will be the case at all. The fighting of a gun cannot be so simple a thing as that in actual service. You must have to watch your opportunity to lay the gun, to wait your opportunity to get the object in a favourable position, to wait and hold on from time to time, and only to fire at the best advantage. At any rate, I cannot believe that it will ever resolve itself into the simple process of a gun being popped up over a parapet, fired off at once, and let down behind it again. If it should be so, then the invention will be a great success indeed. Neither can I think that in those positions where a gun would be exposed to fire from more than one direction, that the Moncrieff system could be very well applied.

COLONEL GORDON, R.A. : I fancy that the officers who are now down at Shoeburyness, who have been practising with this gun, will not be of the opinion which has been expressed by Colonel Inglis. I think Captain Alderson will agree with me that the gun can be laid with the greatest accuracy by making marks on the racers, and by having buoys and pickets in front of the gun ; this has been done at Shoeburyness, marking out certain positions. The pickets being placed in front of the gun, corresponding with certain marks on the racers, the gun can be traversed when below. Let it be said that a ship is between certain pickets ; the gun can be traversed over to the corresponding marks, the elevation (which is known by the buoys) can be given down below, and the gun, having the line given by placing the traversing platform on the marks on the racers, can be raised and fired *immediately*.

LIEUT. COLONEL CHESNEY, R.E. : There is one point in the original paper which no speaker has touched upon in the slightest degree. It is said that this gun is applicable for use in the field as a "gun of position," at least so I understood from one of the passages that was read. May I ask one of the distinguished Artillery officers present to tell us in a few words whether it is possible, in his view, that this gun carriage can ever be thus applied in the field? To my idea, I confess it is totally impracticable that the Moncrieff mounted gun, as it now is, can be either used in the field as what is termed a gun of position, or moved like any ordinary gun that might be employed for the support of an army in action in open ground.

GENERAL LEFROY : I would merely reply to the question as to whether it is possible or probable that an apparatus of this description should accompany a field train, and be extemporised in a position chosen on special occasions. I entirely concur with the officer who has just spoken, that such a thing is not to be contemplated. The apparatus is of a very ponderous nature. In the case of this gun it weighs three times the weight of the gun itself—a 7-ton gun ; the whole thing weighs 28 tons ; and from the time required to put it together, and a great many other conditions of accurate equipment, it appears to me a thing not suitable for accompanying an army in the field, whatever the other purposes it may be applied to. A word as to the time during which this gun is exposed when in the firing position. Here, also, I agree with Colonel Inglis that it must be exposed a much longer proportion of time than is taken for granted in the paper. Unless we are content to give up the accuracy of the rifled gun, the laying must be done by vision, and take the usual length of time. Captain Moncrieff's clever reflecting sight will not, in my opinion, satisfy the requirements of actual engagement ; I can only regard it as an ingenious toy. I should like to have Captain Alderson's opinion, whether, if he were personally engaged, he would ever dream of using the reflecting sight rather than direct vision.

CAPTAIN ALDERSON : With regard to what General Lefroy has said about using the reflecting sight, I certainly should not use it on every occasion. Except to correct the line, I do not see the slightest advantage in it. Captain Moncrieff has prepared a plan for a trunnion-pointer, which answers all the purposes of elevation and at Shoeburyness with the running target the reflecting sight was not used at all. The line was taken by marks on the racers, and the elevation given by the trunnion-pointer with the gun down. When the gun was run up, I think not more than 20 seconds, on the average, elapsed before it was fired. We were not lucky enough actually to hit the target. The target was only a 6-foot one, and moving as it was seven miles an hour, it was not an easy thing to hit ; still we went near enough to satisfy most people that if it had been a moderate sized ship, or even a gun boat, it would have been struck nearly every round.

AN OFFICER : Was the target going ten knots an hour ?

CAPTAIN ALDERSON : Seven knots an hour. With regard to the mortar fire, I should have said that the vertical fire we tried was at sixty degrees of elevation, but then, remember, the range was only 800 yards. I do not believe that any mortar boat would dare to come in at 900 yards ; if it did, it would very soon be sunk ; and at 1,600 and 2,000 yards, I think we ought to hit an ordinary mortar boat with the guns we have at the present day. The other day we fired the 7-inch guns with five rounds at a six foot target 1,600 yards off, and it was hit three times in five minutes. A mortar boat is a larger object than a six foot target; if she altered her range, she would be thrown out of her accuracy of fire, and if she anchored so as to obtain accuracy of fire, I think we should sink her.

LIEUTENANT INNES, R.E. : With regard to what Captain Alderson has said about vertical fire, I think it is the fact that mortar boats have never been brought into action at all since the introduction of rifled guns, in consequence of the increased accuracy of fire. Also, with reference to giving the guns elevation under cover, and without being exposed, I might state that the Confederate artillery during the American war, used an arrangement for that purpose, which I dare say, is something of the same class as the trunnion-pointer. It was a scale painted roughly on the breech of the gun, and a slip of wood fixed upon the carriage and pressing against the scale on the breech. You could tell at once by examining the scale, what number of degrees of elevation the gun had above or below the point blank, and could consequently give it elevation without looking over the sights at all. This was found to work perfectly in practice at night time. One man gave the elevation from this scale by a small lantern, whilst another was giving the line by looking over the sights.

MAJOR HARRISON, R.E. : There is one point I should like to bring before the meeting and leave it to more competent officers than myself to decide whether or not it is worth discussion. It is generally admitted that the carriage is a good one ; it is also admitted that a gun mounted on this carriage will be very advantageously employed in certain positions in our coast defences. But there is still one thing that I have not heard discussed, and that is as to the description of pit in which the gun and its carriage is to be placed. One of the great advantages claimed for Moncrieff's system is its cheapness ; and this, I presume, presupposes that the pit is made of earth, and that either the gun is sunk in a pit, or that a tower of earth, varying from 40 to 50 feet in thickness, is built all round it. Well, a good many of us know the effect upon earth of any kind of projectile; how a 13-in. shell falling, will, if it does not injure the gun itself, throw up a mound of earth around it, which certainly would very much come in its way, rising out of the pit to fire at a distant ship. I should like to hear from Captain Moncrieff whether he considers it advisable to iron plate the top of his pit, and if so, what would be the expense? That is just one suggestion that came across me during the discussion this evening.

CAPTAIN MONCRIEFF: In answer to that question, I should simply say that I should never present any exterior slope of earth at such an angle as to allow penetration from shot. The angle of incidence would always be sufficient to cause *ricochet*.

COLONEL JERVOIS: I believe it must have escaped Major Harrison, that when I spoke before this evening, I alluded to the point to which he refers. It is difficult, without a black board, to give the meeting any idea of the point in question; but perhaps this sketch may serve. Here is a rampart of the ordinary description. It is obviously very weak at the crest, whether it be constructed of masonry or of earth. One way of getting over the objection would be to cut away the angle, and plate with iron a certain portion of the superior slope. Another way is to insert a mass of cast-iron. These points are details for consideration in the construction of works adapted to the Moncrieff system.

THE CHAIRMAN: Perhaps Captain Moncrieff would like to reply to some of the remarks before we break up?

CAPTAIN MONCRIEFF: I should like very much to reply to all the points that have been brought forward, but I am suffering very much from the effects of a converging fire. I have had objections fired at me from so many directions, that it is very difficult to meet them. If you take each point of my plan by itself and analyse it, no doubt, you will be able to find objections to my system. My system is not perfect—it has its objections; but I never wished to bring it forward as a perfect one. All I would say is, that if you take it as a whole, I challenge comparison with any other. I think, perhaps, the best thing I can do, in attempting as shortly as possible to answer these objections, is to go backwards, beginning with the last. The last difficulty that was started with regard to the battery was the weakness of the revetment or wall of the interior slope of a gun-pit. Colonel Jervois also pointed out the possibility of a shot striking near the top of the slope. In answer to that I would remark that the revetment can be made stronger for the same money than with any other form; because it is a well known thing that in building a domed wall, you get the quality of the arch both ways; you have the strongest structure that nature produces, whether it is built with brick or stone, or whatever material is used. I have seen 13-inch shells penetrate the ground and burst near me, and I know the kind of crater they form. It is, perhaps, three or four feet in depth, and three or four feet in diameter, at the very most. I maintain that if a shell fall within six yards of a gun pit, properly formed, with a 3-foot wall, the chances are that the crater would not go near the pit. With regard to the American trunnion-pointer which one gentleman spoke of, he attempted to make out that mine was not original. I have had a description of the instrument, which he spoke of as a first invention, from a very good authority, namely, General Ripley, of the Confederate States, under whose command, I believe, the instrument was used. I understand it consisted of a piece of common stick, whittled by an American knife. It was adjusted by trial, and was put in its place, and answered admirably—as well as my trunnion-pointer would; but I beg to add that a trunnion-pointer was not applied as I have applied mine in this case. The flank exposure of my gun is certainly a weak point; but there is not so much in it as Colonel Inglis seems to think. After the remarks of Captain Alderson, as to the time required for firing, it will be allowed that it is not worth putting traverses above the level of the crest, to save the gun, if you only expose it for a few seconds. In working batteries upon my system, those arrangements which enable you to prepare the gun for aiming before it comes up, should never be neglected. I do not know whether gentlemen present have seen the gun worked very much, but a great part of the laying is done before the gun comes up. Therefore, it is the fault of the men if they keep the gun up as a target for any length of time. I should like to ask Colonel Inglis a question if you will permit me. I suppose he will be able to answer it. I want to ask him what is the price of an iron casemate complete, with magazines and foundations, such as that at Plymouth Breakwater, or at the Medway Forts.

LIEUT. COLONEL INGLIS: I cannot undertake to answer that, but perhaps Colonel Jervois will.

CAPTAIN MONCRIEFF: Colonel Jervois; can you answer my question—the price of an iron casemate complete?

COLONEL JERVOIS: For how many guns?

CAPTAIN MONCRIEFF: For one gun.

COLONEL JERVOIS: One gun in a casemate?

CAPTAIN MONCRIEFF: An iron casemate for one gun, with magazines complete.

COLONEL JERVOIS: In making a comparison, you should take into consideration the cost of the magazines and all the appliances which are necessary in either case.

CAPTAIN MONCRIEFF: I want the cost of building the magazines and everything complete.

COLONEL JERVOIS: One casemate of an iron-fronted battery (masonry included) must be put down at about £5,000 per gun.

CAPTAIN MONCRIEFF: A very unfavourable comparison was drawn between the exposure of the detachment in a Moncrieff battery and the detachment in a casemate. I should like to ask any gentleman who has been at the temporary Moncrieff battery, which was put up for £6 or £7 at Shoeburyness, whether he would not rather stand in that battery against the fire of a ship, in preference to standing in the best experimental casemate that has been put up there?

CAPTAIN CORNES, R.E.: No, certainly not. You must take into account the probable ranges at which the guns will attack the casemates.

CAPTAIN MONCRIEFF: Would you prefer a casemate?

CAPTAIN CORNES: Certainly.

COLONEL FREELING, R.E.: Perhaps I might inform Captain Moncrieff that the penetration of a 600 lb. shot, fired from a 13-in. gun at 200 yards, is about 50 feet into a butt of earth, and that the penetration of a 150-pdr. 9-in. shot, fired at the same distance, with the service charge of powder, is about 30 feet. Therefore, he would have to provide protection for 60 feet in front of his gun, if he is likely to be attacked by 600-pdr. guns, and a protection of 40 feet in front of his gun, if he is likely to be attacked by 150-pdrs.; and if the enemy are firing shells with heavy bursting charges, he would also have to provide extra protection to secure himself against the extra crater that would be made by the bursting of the shells in the earth.

CAPTAIN MONCRIEFF: With regard to another point that is brought against my system, namely, the limited space in some positions, I should like to mention to this meeting a fact which is apparently unknown, that the carriage which is now being experimented upon at Shoeburyness, is not the only carriage upon my principle. I have many others. I have carriages which take up much smaller space than any carriage that is now used, so far as breadth upon a parapet is concerned. I have also, as you will see in my paper, siege carriages for guns of position, which are as easily moved as any other siege carriages are, only with the addition of an extra weight. Of course they bear no resemblance to the one we have before us. I have had so much difficulty in getting anything brought forward, that I am very glad to confine myself to one part of the system until it is acknowledged. When this form, which is being experimented upon, is acknowledged to be sound and good, then it will be time enough to bring forward the other parts of my invention. With regard to the first part of the subject, namely, getting a number of guns in a limited space, the way I obtain that result is this. I am supposing that the space is one where great lateral range is not required. In that case I dispense with the carriage proper. I put the trunnions of the gun on the elevators, and I have a suspended counter-weight, which passes down through the platform into a cell beneath. Suppose these guns were required on the top of an iron casemated work, I should pass iron rods down to the bottom; and there a large iron basket, filled with rubble, would be sufficient to act as a counter-weight to my gun. I have been afraid to bring forward too much, as I find that every opening I present is very soon filled by those people who wish to assail my system. Therefore, I think it is better to confine my attention to this carriage, and afterwards, when the proper time arrives, I hope to be able to give the Engineers a good deal to think about in the way of carriages, different from the carriages they have now got.

AN OFFICER: I should like to ask Captain Moncrieff whether a carriage on his principle for a 12-ton gun is now in process of construction?

CAPTAIN MONCRIEFF: In answer to that question, I beg to state that about six months ago, after the first successful experiment at Woolwich established the soundness of the principle of my carriage, I urged the Government very strongly to permit me to have that assistance which would enable me to prepare working drawings for mounting heavier ordnance, but my urgent request has never been attended to; and I am sorry to say that no such carriage is in process of construction. I think I have said quite enough.

COLONEL JERVOIS: I wish to make one or two observations with reference to the question Captain Moncrieff asked me, with regard to the cost of a casemate for one gun, mounted on an ordinary casemate carriage and platform. I stated it to be £5,000 per gun. I should observe, however, with reference to that statement, that we have worked out a drawing of the casemate which would be required if the Moncrieff carriage were mounted in casemates. Captain Moncrieff does not propose to apply it in that manner, nor do I; but in order that a comparison may be made between the cost of a casemate giving 70° lateral range on the ordinary plan, and a casemate adapted to Captain Moncrieff's carriage, giving 120° lateral range, I may mention that the estimated cost of the latter at the same price is £11,320 per gun.

CAPTAIN MONCRIEFF? How much does the other cost per gun?

COLONEL JERVOIS: The other costs about £5,000 per gun.

CAPTAIN MONCRIEFF: I cannot accept that statement upon a drawing I have never seen and have never been consulted about.

COLONEL JERVOIS: I only mention it by way of comparison. I do not think your carriage is applicable to cases where overhead cover is desirable.

LIEUT.-COLONEL FISHER: I wish only to observe, with regard to the exposure of the gun mounted on Captain Moncrieff's carriage, that he has taken up a very bold position, a bolder position than we should have called upon him to take, in proposing that his gun, when employed in coast defences, should fire all round the circle. There are few cases in which you would require a coast gun to fire over a lateral range of even 180 degrees. I imagine that by means of bonnettes the gun might be very much protected from enfilade fire without loss of efficiency. The part of the gun exposed would be very much smaller than the entire broadside, which we have been taking into consideration as being exposed. You might require a gun at each end of a sea battery capable of being turned through 180 degrees, but you would hardly ever desire to give that amount of lateral range to any gun in a face of a battery.

THE CHAIRMAN: I am afraid that the hour is approaching to adjourn the discussion. We all beg to return our very sincere thanks to Captain Moncrieff for attending here. There is no doubt that his gun-carriage has proved a perfect success.

ADJOURNED DISCUSSION.*

MAJOR GENERAL FROME, I.G.E., &c., IN THE CHAIR.

THE CHAIRMAN: At our last meeting we discussed the question of the Moncrieff carriage, more particularly with reference to its mechanical construction, as on that occasion we took up the subject, in the first instance, as an artillery question. We were then favoured (as I am glad to see we are to-night) with the presence of a number of Artillery officers—General Lefroy and others—who gave us their opinions from that point of view. I believe the result of the discussion was the admission that the Moncrieff carriage, as a gun-carriage, was a perfect success; and that the Report of the Ordnance Committee bore out that view. There were certain trifling mechanical improvements suggested, and some little difficulties pointed out; the principal of which were with regard to the break apparatus and the difficulty of loading. Assuming that the carriage, as a weapon of war, is an efficient one, I think we should start to-night with the question of the way in which it can be advantageously applied, and not revert to its mechanical construction. It would be, perhaps, desirable if we were to classify the uses to which we propose to apply the carriage: first, to coast defences, either to cover some port which has to be protected,

* Held at the War Office, December 16th, 1868.

or to defend a channel against the approach of a hostile fleet; secondly, to land defences; and, thirdly, to its adaptation to existing defences or to works in progress. I think we need not make any comparison between Captain Moncrieff's system and casemates, because it does not appear applicable to such works. It is a self-protecting carriage, and no one would, I think, dream of putting it in a casemate. That is, therefore, rather beside the question. The only open work to which you can in any way compare a Moncrieff barbette battery, is an earthen battery with iron shields to the embrasures. There the question becomes one of comparative cost, and also of the difference of lateral range between a gun mounted on a Moncrieff carriage and a gun fired through an embrasure. I think we may take the question up in that way, first to assume the success of the gun-carriage as a proved thing, and then to consider the way of applying it to coast defence, to land defence, and finally to existing works. If we classify our remarks in the way I have pointed out, it may, perhaps, save confusion. I dare say there are many officers present who are prepared to speak upon the subject of utilising Captain Moncrieff's invention, and I have now to ask them to commence the discussion.

MAJOR GENERAL SIMMONS, R.E.: I regret that I was not present at the last meeting when Captain Moncrieff's invention was discussed, but having had the opportunity of glancing over the shorthand-writer's notes, it appears to me that the Artillery part of the question was not fully ventilated at that meeting. I understand that there are several Artillery officers here who were not then present; perhaps, some of them might be inclined to throw additional light on the question. Several moot points were raised, and there was a difference of opinion upon those points, and I think, therefore, it would be desirable to get as much information as we can upon them, because, it is upon the balance of opinions, where they differ, that the final opinion as to the carriage is to be formed.

THE CHAIRMAN: I have not the least desire to curtail this part of the discussion. I only imagined, as we afterwards diverged from the mere mechanical construction, to a great number of other general points, such as those raised by Sir Frederick Grey, that the mechanical part had been disposed of (subject to modifications) as a success. But if there are any Artillery officers present who wish to speak further with regard to the mechanism of the Moncrieff gun carriage, we had better clear that point up before we advance to the more general question.

MAJOR GENERAL LEFROY, R.A.: I would rather that some other gentleman rose first. I have nothing personally to add to what I said last time, but as there seems to be a desire that an Artillery officer should rise, I avail myself of that for the purpose of saying that I have reason to think that a portion of my remarks were misunderstood by some officers who were present on the last occasion, and that I was understood to speak less favourably of Captain Moncrieff's carriage as a mechanical contrivance than I really feel. I applied the word "ingenious toy," not to the carriage and elevator of Captain Moncrieff, but to a subsidiary part of it, about which opinions may differ. As far as the artillery element of the question is concerned, I think we all agreed that up to the 7-ton gun—which is as far as it has been tried at present—it is, mechanically, a very great success. There is scarcely anything left to be desired as to the facility of working it, the rapidity and accuracy, and the simplicity of it, so that there will be nothing which uninstructed men, such as we must expect to employ to work it, will not be capable of coping with. I do not think there is much left to be said in the artillery point of view. It stands now to be considered in a constructive point of view; that is, what are the circumstances in which it may be best applied; in what way may it be best applied; and what economy will attend it. Artillery officers will agree with me that we have come to hear from Engineer officers their opinions upon these subjects. They cannot bury us too deep in a gun-pit, or protect us too much; and if Captain Moncrieff can give us a parapet 12 ft. high, instead of a parapet 7 ft. high, no objection need be anticipated on our side.

CAPTAIN MONCRIEFF: Before finishing the artillery part of the question, I should like to make one remark, namely, that I never intended this carriage to be considered as the only exponent of the principle which it embodies. It is the first complete carriage manufactured, and it illustrates the principle; and that principle, I can assure the meeting, is a flexible one, and can be applied in a great many other ways and for other purposes, such as siege artillery, and for a heavier class of artillery than the one which has been brought before you. I should like that to be borne in mind while the other part of the subject is being discussed.

THE CHAIRMAN: No doubt you may be able to apply the system in the way you state, but at present it is in embryo; I mean the form of appliances.

LIEUTENANT ARDAGH, R.E., read the following remarks: The carriage, as applied to the 7-ton gun, has been a complete success. It might reasonably have been supposed that a new system would present some defects on its first trial, that some serious hitch would occur, but there was nothing of the kind. The trifling accidents which happened to the carriage (in some instances the result of carelessness) only tended to show the extremely minute attention bestowed on every detail, and the refined ingenuity with which mechanical appliances for diminishing the amount of human labour, and facilitating the different operations of traversing, raising, and pointing the gun, have been brought into play. These refinements increase the vulnerability of the gun, but they are external to the principle of the invention, and may perhaps, in some cases, be advantageously dispensed with. There is a reasonable prejudice against complicated and elaborate contrivances, and where the object can be effected by a block and tackle, or by a handspike, those primitive mechanical powers should be used; or, at least, provision should be made with a view to falling back on them if the toothed gear or brakes get out of order.

The theoretical action of Captain Moncrieff's carriage is best illustrated by imagining the section of a heavy cylinder placed vertically upon a horizontal plane, with a force equivalent to that of the recoil, applied tangentially to the highest point of its circumference; then will the point of support be the instantaneous axis of rotation, corresponding to a centre of percussion at the point where the force of the recoil is applied, and that force will produce no strain at the point of support, but will communicate to the body a combined and equal motion of rotation round its own proper axis, and of translation in a horizontal plane. If it be supposed that in the carriage itself half the weight of the moveable portion is concentrated at the centre of the trunnions, and the other half at the point of support, or, to be accurate, if the latter point is in the instantaneous axis corresponding to the former point as a centre of percussion, similar results will be produced; on the first supposition by equating the momenta of the shot and the moving portion of the carriage

$$115 \times 1450 \div 2240 = 22\text{ V}, \therefore \text{V} = 3{\cdot}4 \text{ feet per second,}$$

corresponding to a height of about 2 inches, through which the centre of gravity will require to be raised at the end of the recoil. This Captain Moncrieff effects by gradually increasing the radius of the curve on which the structure rolls.

The fact that there is no strain on the point of support, in the shape of recoil, is dependent on the relations of the centre of percussion and the axis of instantaneous rotation ; this nullification of the destructive action of the recoil on the pivots, racers, and platforms, is not the least important part of the invention.

The mode by which the axis of the gun is made to preserve a parallelism to its original position is very ingenious, and so is the curved rack motion which is employed to manœuvre the carriage for drill, etc.

Turning to Captain Moncrieff's pamphlet, it is there stated that a Moncrieff battery or gun pit, if properly constructed, is an invisible object, and cannot be seen from the plane on which it is placed. Now, putting out of account the natural inequalities of ground, which afford far more cover than engineers can obviate by giving great command to works, the disadvantages of a low battery are so great, that the besieger of a work constructed on such principles might almost open his trenches at the crest of the glacis on the very first night of the attack, since a mere scratch in the ground would conceal him, and a parapet two or three feet high would, in a flat country, conceal the whole of his approaches.

There is another proposal, "to collect artillery stores only, and throw up works when required." Captain Moncrieff believes that the works could be thrown up and the guns mounted in a week. To engineers it appears needless to refute these views. If the works, which even with the most simple kind of magazines, would take months to prepare, were ready, the mere arming of them would occupy considerably more than the time he allows.

Captain Moncrieff has also an idea of dotting down guns at intervals for the defence of harbours or coasts. The defensive enceintes, the magazines and stores, and the barracks, necessary in each case, do not appear to have entered into his calculations. The old Martello towers with ditches cost £11,000 ; and if constructed on the scale necessary now-a-days, the accommodation for each Moncrieff gun, behind an earthen or masonry parapet only, would not be less than the same amount. These isolated guns might be effective, but they would not be economical. They are subject especially to be reduced by the fire of the smallest class of mortars, which can be carried by hand from place to place. The isolation of small garrisons is also very objectionable. It is, therefore, considered that the idea of constructing detached gun-pits, without the accessories mentioned, cannot be entertained.

With these preliminary objections, which in no way affect the merit of the invention, I proceed to consider the application of Captain Moncrieff's system to our defences, taking first the land and then the sea.

As the 7-ton gun, which has proved so successful on Captain Moncrieff's carriage is probably the heaviest which we shall find it necessary to mount on our land defences, we shall be able to speculate with a far greater degree of certainty on the effect of this invention on the attack and defence of fortresses, than on its application to coast defence. We know absolutely, that Captain Moncrieff's 7-ton gun-carriage is a success, and the inventor contemplates the construction of a carriage which will be adapted to siege guns, and which I have no doubt will be equally successful, and probably very portable as well. The question before us is, the probable effect of substituting the new carriages for those now in use.

We must begin by assuming that the fortress will consist of an interior enceinte, probably an old fortified town, with a line of detached forts two or three miles in front of it, connected in some cases by lines of earthworks. The enemy would, if it were at all practicable, prefer to assault these works by a *coup de main*, even at the certainty of a great loss of life, to undertaking their capture by a regular siege, which would, under the most favourable circumstances, be a very protracted operation ; for his gaining possession of one work, would not necessarily involve the fall of the position. Against such field artillery as an enemy, with the intention of trying an attack *de vive force*, would bring up to oppose the armament of that particular work he had determined to assault, the protection afforded to the guns firing through embrasures in our new works may be considered fair and sufficient.

If the escarps and flank defences are of such a nature as to render the chances of the success of a *coup de main* infinitesimally small, in the case of such works, for example, as those on Portsdown Hill, there is no other alternative to a siege, than the abandonment of the enterprise. In these works we should calculate on being attacked by the heaviest artillery which an enemy can carry into his trenches.

Where railway or water carriage offers a convenient means of transport, we may find a few 7-ton guns in the batteries of the besieger, but as a rule he would not be able to bring up pieces of a greater weight than our 110-pdr. breech-loader, or the 64-pdr. muzzle-loading rifled gun, weighing 3 tons 4 cwt. The shells fired from these guns respectively contain 6 lbs. 8 ozs., and 4lbs. 13 ozs. of powder, and their destructive effect on earthen parapets is very considerable. If a sufficient number of these guns were placed in battery against a detached fort, whose pieces fired through embrasures, it is probable that the effect of shells lodged in the parapet adjoining the embrasures would be so destructive, that the embrasures could not be kept open without increasing enormously the width of the throat, and virtually depriving the gun detachment of cover. The besieger would, of course, encounter the same or greater difficulties, for he would probably be opposed by a heavier armament, though he would have a numerical superiority, and possibly also the advantage of Captain Moncrieff's portable carriage. However, the work of destruction would proceed on both sides, and the rifle pits of the attack would have great power against the artillery of the work, for their occupants would have but feeble opponents in the few men who could occupy the space in the parapet between the guns, small in itself, and subject to all the effects of the direct and enfilade fire of the besieger. The riflemen in the trenches and pits would be comparatively exempt from artillery fire, for the besieged could not afford to expend their ammunition on single individuals.

In this state of affairs let us suppose that the work is armed with guns mounted on Captain Moncrieff's system. The perfect protection of these guns from enfilade is difficult on account of their height, and important because of the expense and labour in replacing them if damaged. It is necessary, therefore, to place a high traverse between each gun and its neighbour, and the distance from centre to centre of each gun cannot be less than 60 feet in land works. The present embrasures are 40 feet apart, with large traverses, (sometimes containing haxo-casemates), one for every two or three guns, according to the liability to enfilade. Between these large traverses, which also cover the expense-magazines, we should now have respectively one and two guns on Captain Moncrieff's carriages, in lieu of the two others. I assume that on the whole, there will be room for two-thirds of the present armament.

Suppose this change to be effected, the following advantages would result :—

1st.—The gun detachments would have an almost perfect protection from direct fire behind parapets 25 feet thick, such as all those in the works recently constructed.

2nd.—The danger, delay, and exposure of repairing embrasures, would be altogether obviated.

3rd.—The guns would have an increase of lateral range of very considerable importance; for in the existing works it is not contemplated to make embrasures of more than 40° to 50°, since larger ones would so much weaken the parapet; this lateral range would be increased to 90° or 100°, without intrenching too much on the traverses which protect from enfilade. This doubling of the lateral range would enable a greater number of guns to be concentrated on a given point, and would enable the besieged to resist successfully batteries in embrasures, probably even of twice as many pieces, by dealing with them by successive concentrated volleys.*

4th.—The main object of the besieger, viz., silencing the artillery fire of the work, might, by the negative means of exposing the guns as little as possible, be rendered extremely difficult.

5th.—The protection of the interior of the work, of the magazines, and of the men engaged in remounting guns, would be vastly improved from the absence of embrasures.

6th.—Guns might be more easily reserved to the advanced period of the attack, for they could be brought into action at any moment, while on the ordinary system an embrasure would have to be cut, an operation almost impossible under a close fire of rifles, and yet of the very highest importance towards the close of a siege.

The conclusions which can be drawn from these considerations, are: 1st—That for 7-ton guns and under, the Moncrieff carriage is vastly superior to the present traversing platform firing through earthen embrasures in land defences, probably doubling the efficiency of a gun; in some cases even more than that. 2nd.—*We must have* these carriages for the armament of our land defences. A few iron shields will be useful in some cases, (and it must be recollected that these shields will only need to be capable of resisting the lighter class of guns, and may be considerably cheaper than those used for coast defence); but, as a rule, the Moncrieff carriages will be more economical. The possibility of being attacked by batteries similarly mounted will, however, render it essential to substitute the Moncrieff carriage where-ever an earthen embrasure is now contemplated.

Nothing has been said about the detail of comparison between 7-ton guns on Moncrieff carriages, and those on ordinary platforms firing through shields.

In a land-work, where the enemy's guns rest on a firm foundation, a shot would, sooner or later, pass through the embrasure and dismount the gun on the common platform. The same may be said of the gun à la Moncrieff, for, while it is exposed, there is much more of it; and the parapet in front of it may be ruined by shell fire, unless iron is used as a protection. A mantlet or shutter would, of course, be used with the shield, but even with that, the gun detachment would be more exposed in loading. We must recollect, however, that it is not with guns behind shields that the Moncrieff system is now to be compared, but with those firing through embrasures in earth.

Putting £550 for a 7-in. gun, £350 for an ordinary platform, and £750 for a Mon-

* I have not mentioned the advantage of having nothing to fire at, for I put no trust in it, and believe that it will be far preferable to have high traverses to protect the gun perfectly from enfilade, although they point out accurately its position to direct fire.

crieff carriage, we have £900 against £1,300. If as proposed for three of the former we substitute two of the latter, the cost will be about equal, being £2,700 for three guns on the present system, against £2,600 for two on Moncrieff carriages ; and though the total number of guns will be diminished, and the rate of firing also, the efficiency will probably (it may be said certainly) more than make up for the loss.

Rapidity of fire, though of the highest importance in sea batteries, is, within reasonable limits, not of much weight in attack and defence ; for the quantity of ammunition to be fired away, will, in both those cases, be limited, and more particularly in the former, where every ounce of material carried into the trenches represents vast difficulties of transport to be overcome by the besieger. Even this consideration may, as regards siege trains, and heavy but moveable artillery, counterbalance the advantages of Moncrieff's system, if he applies it to such purposes. As to the desirability of applying it to our permanent land defences, there can be no manner of doubt.

Unfortunately, although the 7-ton gun-carriage has been a success this past 6 months, no carriage has yet been tried, or even made, for the 12-ton gun, and the practical working of the system, as applied to that gun, is yet a field for speculation. Of its possibility, I have not the slightest doubt ; what I am most anxious to ascertain, and what will most probably determine its introduction, or the contrary, is the rate of firing.

On Sea Defences, whether a hostile ship, or fleet, steams in at 10 knots an hour, or whether she is at anchor before a battery, rapid firing is of the highest importance. A few minutes will take a ship in and out of range ; 10 knots an hour is 333 yards a minute. On sea defences then, a gun which can fire twice as fast as another, is, *ceteris paribus*, twice as valuable. This principle led to the adoption of the needle-gun, the Snider, and the Chassepot, and it will probably determine the fate of Captain Moncrieff's system as applied to heavier guns than the 7-ton.

Captain Alderson states that the 7-ton gun, on a dwarf traversing platform, can be loaded, aimed, and fired in 55 seconds, and on a casemate platform in at least 10 seconds less, and that the Moncrieff requires from 65 to 75 seconds. The average proportionate rate is as 10 to 14.

The 12-ton gun, on a casemate platform, requires from 50 to 60 seconds to load, aim, and fire at a moving object.

The moving weight in the 7-ton, mounted on Moncrieff's principle, is 22 tons.

The probable weight of the moving part of a 12-ton gun and carriage on the same system would be 35 tons, or more than half as much again.

The range through which the 7-ton gun is now raised, is hardly sufficient to give it complete cover in the loading position. The range in height of the 12-ton gun must be considerably greater, viz. from 6 to 7 feet. On these data then we must speculate as to the probable rate of firing.

Captain Alderson does not think that it will take much longer than on the service carriage. His opinion, backed by that of other experienced artillerymen, carries great force, but considering that the weight to be raised is 35 against 22 tons, the weight to be traversed, 40 against 28, the height to be ranged through, 7 ft. against 4 ft. 6 in., and the time required with the 7-ton gun 70 seconds, it seems to me most probable that the 12-ton gun thus mounted will take at least twice as long to work as the gun on an ordinary casemate platform, which, as I have said, requires from 50 to 60 seconds. *Ceteris paribus*, the gun which can fire twice as fast, is, on our coast defences, twice as valuable.

At page 3 of his paper, Captain Moncrieff takes the case of a battery placed so as to command a channel extending along its whole front, which, by the present system, must, he says, have three faces; while on his system, the guns would all be mounted on one line, and would all command the same ground, besides being capable of being brought into action by the rear. He then considers it safe to assert, that each gun on his principle, thus mounted, would be three times more powerful than if mounted in casemates or embrasures.

Let us analyse this theoretical case.

It is impossible for a straight line of guns to have, all, a lateral range of 180°. From 20° to 30° with the line of parapet is the nearest safe limit against the danger to collateral guns of the premature explosion of shell; the lateral range will therefore be from 120° to 140°. This may be slightly improved by curving the line. The protection against enfilade is very indifferent unless the traverses are considerably raised, and the lateral range of the guns further curtailed to 90°. The lateral range of the guns behind shields is usually 70°, in some rare cases 90°. To give the most favourable position to the Moncrieff system, I will take its lateral range at 140°, and that of the guns behind shields as 70°; and although I believe that two minutes will be required for the 12-ton gun on a Moncrieff carriage, I will suppose that a minute and a half will be sufficient; i.e., that the rate of firing as compared with a gun on a casemate platform is as 2 to 3. The offensive efficiency of a battery of several guns on a straight line of coast, will depend about equally;—1st, upon the number of guns which can be concentrated upon a given point, which on a straight front will be approximately proportionate to the lateral range of each gun, *i.e.*, the Moncrieff gun, 140°; the Shield gun, 70°; or as 2 to 1. 2nd, upon the power of resisting a general attack over the whole front, which will be proportionate to the number of guns, assumed to be equal. Combining these two conditions, the relative efficiency of the Moncrieff gun to the Shield gun, (irrespective of the rate of firing), is as 3 to 2. Introducing this latter element, which is assumed to be as 2 to 3, the absolute offensive efficiency of batteries on the two systems, is found to be equal ($3 \times 2 = 2 \times 3$). If the lateral range of the Moncrieff gun is diminished, or the time per round increased, the shield gun will become superior.

Having determined the relative offensive value of the two systems, let us turn to the defensive capabilities. Vertical fire, all open batteries are subject to, and it is therefore left out of consideration. Horizontal fire is the great danger to be guarded against. The 12 in. and 9 in. projectiles have penetrated respectively 50 and 40 feet of earth. Against these guns earth is but an illusory protection. An iron shield 20 inches thick, will resist both perfectly. The exposed part will be the port, about 3′ 6″ × 2′ 6″. Shutters may keep out splinters and rifle shots, but it is questionable whether a practical port stopper will be found. That of Lieutenant English—a sphere of wrought iron, weighing about three tons, of greater diameter than the port, and worked by the recoil of the gun—appears to be the best hitherto proposed.

It is necessary to determine whether the top of the gun pit can be constructed of earth, as supposed by Captain Moncrieff. Let the superior slope of the parapet be 1 in 10, which is much flatter than any are now made, a 12 in. shot striking at a depression of 6° (or 1 in 10), 40 feet from the crest, would pass through and come out 8 feet below the crest, with force enough left to drive it through 10 feet more of earth; and if it were a shell, with 35 lbs. of powder, ready to burst in the gun pit.

I think that disposes of the idea of using earth.

Concrete offers about 3 times the resistance of earth, and is about 10 times as expensive. Granite 10 times the resistance, but it is 100 times as expensive. Iron over 40 times the resistance, but it is between 2,000 and 3,000 times as costly. The relative cost of protection in the different materials is—earth, 1 ; concrete, 3 ; granite, 10, and iron, 50. This, however, is only true in long developments. Which, then, is to be adopted, for earth we must abandon ? Nothing but iron will do for the crest of the pit if it is to compare with the shield ; and a semi-circular rim of that metal about 2 feet thick at the top, diminishing to nothing at 6 feet below the crest, and backed by 10 feet of concrete, besides the earth, (made up to 50 feet) would probably meet the case. A gun pit for a 12-ton gun will need to be at least 25 feet in diameter. The semi-circular iron rim in front, with the concrete, &c , will be more costly than a shield 20 ft. × 8 ft. and 20 in. thick.

However, we must first compare the shield gun with the Moncrieff gun for safety.

The Moncrieff gun in an earthen pit has hardly any protection from direct fire beyond the fact, that when it is down it is not seen. With an iron curb or rim, sufficiently thick, it is perfectly protected, except from fire at high angles. The gun behind a shield is subject only to the chance of a shot coming through an embrasure. The Moncrieff gun is only liable to be hit when it is up, but at that time it offers a very large mark, particularly to enfilade. The embrasure is perhaps the easier to hit, but if a good port stopper be found it will at once give it a superiority over the gun-pit even when protected by iron. The gun detachment in the pit will certainly be safer than behind the shield ; but the risk to the detachment, from direct fire, will be small, for the enemy will not care about the gunners, provided he disables the guns, and for every dozen shots that used to be fired formerly, there will seldom be more than one in future. It is shell and musketry that drive men from their guns, and mantlets, or shutters, in a shield will guard against that. As long as the gun is uninjured, there will always be men to work it.

It must also be considered that the gunners required to work the Moncrieff carriages will need a much more refined course of training than those employed to work the ordinary system ; and that there is more complication, more liability to get out of order, and more difficulty in replacing the Moncrieff guns than those on ordinary platforms.

The cost of a 9-in. gun and platform of ordinary construction is estimated at £1,360. That of a gun à la Moncrieff, £1,940, being £580 more. Suppose that the defensive capabilities of the pit and shield are the same, they are brought out on terms of perfect equality as regards absolute effectiveness. The fact remains, then, that the Moncrieff gun is £580 more costly than the other, and that it is, therefore, not desirable to introduce it in lieu of shields on our sea defences, until we are satisfied that its rate of firing is nearly equal to that of the casemate platform. If the time per round should prove to be less than 1½ minutes, its position may be improved so as to turn the scale the other way.

When compared with guns which it is not contemplated to protect by iron shields, it is, undoubtedly, far superior, even considering a probable slower rate of firing ; and in those cases it will most likely be adopted. Captain Moncrieff's claims in regard to economy, appeared to me so extravagant, that I must make them my excuse for depreciating, even in a small degree, an invention which I consider to be of the highest importance, though not quite reaching the degree claimed for it by its advocates in the press.

MAJOR GENERAL SIMMONS, R.E.: As no other gentleman seems to be rising, I will make a few remarks with reference to a portion of Lieutenant Ardagh's paper as to the application of the Moncrieff gun-carriage, firstly, for land defence, and secondly, for sea defence. As regards land defence, in fact, with regard to both, I may say that I think it is hardly fair to discuss the merits of the carriage in connection with a number of propositions that have been made. Some of those propositions have, I think, been made rather hastily. I think, having before us an invention of great ingenuity, we should endeavour to see if we can apply it in any way in our defences, without picking to pieces so narrowly the modes that have been proposed for its application. For instance, the idea of putting a number of these guns in gun-pits, without having any obstacle in front of them and comparing them to a fortress, is simply a proposition which it is useless to consider; as it is absolutely necessary to place an obstacle between all heavy guns in position and an enemy, in order to constitute a fortress.

With regard to land defences, Lieutenant Ardagh has, I think, discussed the question very well indeed; and has brought out that guns on these carriages would be of immense advantage when mounted in such positions. But I think the advantages have hardly been sufficiently shown in his remarks; for I am of opinion it will be found in service hereafter that guns fired through embrasures on land fronts will be closed almost immediately after the opening of fire from the batteries of attack. To attack a work armed with artillery firing through embrasures, the process will be to establish a larger number of guns on a larger circle, and to fire at those embrasures; and before many rounds have been fired, I believe the fire of the fortress will be completely closed. The accuracy of artillery fire from a fixed platform is so great, that when the ranges have been once ascertained, shot after shot will be poured into those embrasures with such fatal effect that I do not believe that a gun would be there to fire a shot out of them after those batteries had been opened but a very few hours. That, I think, disposes of embrasures to a very great extent; and it brings us back to the point which, when I first entered the service I heard taken up by an officer of Engineers, a well-known officer of considerable talent, the late General Blanchard. He endeavoured to apply his ingenuity, which was very great, to make a gun-carriage so contrived that the gun might be fired over the parapet, falling down again when not in action. He also added to it the idea of a railway or tramway which would make that gun moveable along the parapet. If such an addition could be made to Captain Moncrieff's carriage, and I do not at all see that it is in any way impossible, or that it need be exceedingly expensive, I think you will have a great advantage gained for the defence. We all know that a gun in the last period of attack is worth anything. If you could keep a few guns, and by means of a railway could move them from place to place, bring them up, and fire them when you require to do so, either at the head of the sap or at any point of the attack, you would be able to delay the attack far more than would be done by ten times the number of guns fired through embrasures during the first period of the attack. Guns fired through embrasures during the first period of attack will not delay the attack perceptibly; they will only entail upon the assailants the necessity of making greater preparation, of collecting a greater number of guns and more materials in their artillery park, and of placing a greater number of guns in battery; but when that is once done, the number of guns on the defence will delay the attack very little; whereas, a few guns, the fire of which can be reserved to the later period of the attack, will have a very great effect, as I think, in delaying the attack. Therefore, I consider this carriage is of immense value. But it does not follow that the gun that is to be mounted on it should be a 7-ton gun or a 12-ton gun ; there are much lighter guns that will be very effective, that will carry heavy shells with quite sufficient velocity to penetrate and even perforate any of the works of the attack as they are now made, and that will drive the besieger into making saps of great depth to protect himself, even a depth equivalent to the whole height of a man—five or six feet—which in rocky or in very wet marshy ground becomes almost an impossibility. Therefore, for that reason this invention—if it can be brought to a state of perfection, and I do not see any mechanical difficulty in the way—is, I think, for such a purpose, invaluable.

Next, as to the applicability of Captain Moncrieff's system to sea defences. This is a much more difficult matter to deal with, because, unfortunately, we have had no experiments with a 12-ton gun; and, if I am rightly informed, no 12-ton gun-carriage has been as yet completely designed in all its details ready for construction. I am not certain whether that is so, but I believe it to be the case. If it be so, I think it is very much to be regretted that six or eight months should have been lost, since the 7-ton gun-carriage was tried, and that no experiment has been made with a heavier gun. Such an experiment would have settled a question, which, in considering the applicability of the Moncrieff carriage for sea defences is of vital importance, that is the speed with which the gun can be worked and fired. Upon that point General Lefroy told us that the 7-ton gun had been fired one round in a minute, or something like that, but that, nevertheless, he did not think more than one round could be realized for every two minutes and a half in practice. I think I am correct in stating that it would not be right to take an average, or to form an absolute opinion upon practice made with gunners of the experience possessed by those with whom the experimental practice has been carried on at Shoeburyness. Now, on that point, what is sauce for the goose is sauce for the gander, and I think the argument applies equally to the minute or the 55 seconds which is given as the time that a gun takes to be fired from an ordinary service carriage mounted on a traversing platform, because those times are derived under like circumstances, with the same gunners. Therefore, if you add to the one, you may reasonably add to the other ; and I suspect you would have to add, in many cases, in a far greater ratio to the time allowed for the gun on the service carriage and traversing platform, than you would have to do for a gun mounted on the Moncrieff carriage. My reasons are these : Captain Alderson told us that from 130 to 140 rounds had been fired with this gun with only one accident; that accident was caused by a man letting the break slip, when the gun ran up violently without any check. An objection, I may observe *en passant*, was taken to the Moncrieff carriage on that score ; that if the man who held the break were killed, the gun would be liable to an accident of that sort. With reference to this objection, I would observe that the carriage has two breaks, and if you want to provide against the contingency of one man being killed, you have only to put a second man to hold the other break ; and then, you have the chance of two being killed. There is another way of meeting this difficulty. In order that the gun may run up, the break is now held by a gunner told off for that duty. The operation of the break may be reversed, and it may be so made as to be always on, except when the man is performing an act to keep it off. It is a simple mechanical arrangement to reverse the action of the break, and then if the man be killed, the break would go on of itself and continue to act until another man came to take his place. That is a simple mechanical arrangement which, if experience required it, might be very easily applied. Therefore, I do not think that objection can be held against the carriage for a moment. To return: I was speaking as to the speed with which guns can be fired. The week before last I happened to be at Portsmouth, where I saw the results of an experiment that had taken place there. Two 12-ton guns had been mounted in Gilkicker fort with a view to an experiment being made to ascertain the speed with which guns can be served from the magazines of the fort. Before the experiment was made, however, it was thought advisable to fire three rounds from each of these guns. I did not see the practice, but I happened to be there the next day, and I will describe to you what took place. With the first gun that was fired, the compressing gear, for checking recoil, was put on too tight, (it was an Armstrong compressor I believe); the consequence was, that the gun, in recoiling, met with a great amount of resistance. There was a great horizontal strain. The gun lifted, first of all, upon the rear racer as a fulcrum, the rear truck acting as a pivot; and the front trucks rose. It so happened that the traversing platform had a cast-iron frame fixed in rear of it, with Cunningham's traversing gear. This frame soon touched the ground, and became the fulcrum on which the whole thing was rearing; but not being strong enough to carry the weight when the gun had got fairly off both racers, the cast-iron gave way, and the traversing platform, with the gun and carriage on it, shot off the racers six inches to the rear. Now, as regards speed of fire, how long, may I ask, would it have taken to fire the next round from that gun. Therefore, I do not think we can take the present recognized system of mounting guns as perfect. In all these inventions one is obliged to make a comparison of one with another. All of them have absolute advantages and absolute defects, but you must compare one with the other, and try to make out from the balance of experience which is best for the service. The other gun which was fired behaved much in the same way; only this time care was taken not to put on so much compression. The gun ran the length of its tether on the platform, the platform reared up, the front trucks rose 5 feet 6 inches from the floor, and the gun itself having nearly capsized, fell down again on the racers. This statement will give you an idea of the difficulties that have to be contended with, even when the present service gun-carriage is used. I believe I am not wrong in stating that these are the first two guns that have ever been mounted on traversing platforms according to the modern and most improved system of armament in our new casemated works. Therefore, in the question of rapidity of fire, these difficulties have to be considered, and I dare say, quite as many difficulties will arise with the new armament, fitted up according to the approved system, as I expect will arise with Moncrieff's system, and therefore, if you add a minute and a half, as done by General Lefroy, to the time required for each round in the one case, I am of opinion you will have to add much about the same in the other, if not more. So much as regards rapidity of fire. It is very much to be regretted, however, that there have been no actual experiments with the 12-ton gun, so that we might have some positive idea of what that rapidity of fire is. Next, as to the penetration of shot into earth, Lieutenant Ardagh gave the relative resistance of different materials. His statement, I have no doubt, is perfectly correct; but the experiments from which the figures were taken were those of projectiles fired into earth for the express purpose of ascertaining their maximum penetration; and it ought not to be inferred from them, that if a shot strikes the superior slope of a parapet at an inclination of 10 degrees, it is going to penetrate 48 feet and come out at the foot of the parapet. I think the experiments on board the *Excellent* show that you may fire one of these conical headed shot at a depression of 7 or 8 degrees at a very high velocity against water, and that the shot will rise out of it;—*a fortiori*, it will rise from well rammed earth at a greater angle, the material itself being harder; and I confidently expect that if it impinge upon earth at 10 degrees, it will deflect from it and go off at a high angle. I may be wrong, but I think there is no reasoning, in this respect, that you can apply to water that you cannot equally apply to earth. But for sea defences, unless the batteries are placed in such situations as on the banks of the Thames, or at Southsea, I do not think you would use earth to protect the guns. If you have an expensive foundation, where the area upon which you have to build your work is small, you may have recourse to concrete, to granite, or to iron. There is no reason why Captain Moncrieff's guns should not fire as well behind an iron parapet as behind an earthen parapet. Earth would be used in those positions where there is space for earth; concrete or masonry where there is not space for earth; and iron would be used where neither earth nor masonry are applicable. I think we, as engineers, should apply the system in such a way that we should use either one material or the other, according to the position in which the guns are to be placed. As regards the protection afforded to a gun mounted on a Moncrieff carriage, I conceive it will be very great as compared with that of a gun fired through an embrasure (I mean an iron embrasure) or a gun fired through a port hole. The size of an iron embrasure for a gun mounted on a carriage not adapted for muzzle pivoting, is 3 ft. 11 in. by 2 ft. 6 in., or thereabouts, giving an area of nine square feet and a half, the vertical height of the embrasure being 3 ft. 11 in. Now, I believe it is a much easier thing in artillery practice—and in saying this I shall be subject to correction, if wrong, by the Artillery officers present in this room—to hit an object of a given area that is low, than one that is high. I mean to say this, that it will be a much more difficult thing to hit an object, say six feet long by one foot high, than it would be to hit an object six feet high by one foot long. That is an extreme case. When a Moncrieff carriage is used, the only way you can injure the gun, when it is not actually being discharged, is by hitting a space near the crest of the parapet that is a foot, or a foot and a half or so, in height; and to do that you must get your elevation very exactly, otherwise the gun is protected. I believe that is an extreme difficulty in artillery practice. I have seen a very large amount of practice, and I think the result of that practice, so far as I can judge, shows that it would be very uncertain, in fact, a perfect chance whether you hit a foot or two above, or a foot or two below, your bull's-eye. You see practice carried on at Shoeburyness, at 200 yards, with full service charges. A disc is put up and a gun laid at it at 200 yards, when it is a chance whether the shot strikes a foot above or a foot below. What would be the chance then at 1,000 yards? If the chances decrease in proportion as the range increases, your chances of hitting are five times as small. I think this is a point that has hardly been considered sufficiently. It is true you may reduce the size of embrasures by employing muzzle-pivoting carriages, but by doing so you add very much to the expense, and you still have about two-thirds of the area, rather more than six square feet for an object to fire at, and which is 2 ft. 11 in. in height, and you always have that object to lay your gun upon. But when you consider that those who are going to attack these guns have to fire their guns from an unstable platform, at ranges that are unknown, and that they have no means of correcting their range, I think it becomes an utter chance whether or not they will ever hit near the crest of the parapet. They may possibly fire all day long and never do it, or the first shot may do it ; it is quite a chance whether they hit or not ; the chance is similar to that of vertical fire. I used to see the practice of vertical fire on Woolwich Common, when I was a cadet, regularly twice a week ; but during the whole time I was there, I never saw the flag-staff hit but twice. When Marshal Soult was in this country, he came to Woolwich, and among other things, saw some mortar practice. The first shot cut the flag-staff in two ; the second struck it at the root. There was no other flag-staff to put up, and it was a fortunate thing there was not. It is all a mere chance. You may hit the line near the crest of the parapet with the first shot, and you may fire at it for a week and never hit it, particularly when firing from an unstable platform like the deck of a ship. I think this is a point of very great importance as regards the Moncrieff gun-carriage.

And now, Sir, I should like to say a few words with regard to vertical fire. I think too great stress has been laid upon the effects of vertical fire, and that much more attention has been paid to it than it deserves. General Lefroy gave us the results of some practice on board the *Excellent*, from which he deduces that 25 per cent. of shells fired vertically, would fall upon the space of one of the Spithead forts, 200 feet in diameter.

AN OFFICER : At what range ?

MAJOR GENERAL LEFROY : 900 or 1,000 yards.

MAJOR GENERAL SIMMONS : Therefore, as it would take 100 rounds to put 25 shots into a space 200 feet in diameter, it would take 8,250 rounds to put 25 shots into a gun pit 22 feet in diameter, or 330 rounds to put one shot into it. Then General Lefroy went on to develope an imaginary attack by mortar boats. If one mortar boat would not suffice, then ten might, and if ten would not suffice, then one hundred might. But I make out from the above calculation that as mortar boats carry only about 100 rounds, each individual pit would require three mortar boats to attack it. So you might soon get up to 100 mortar boats for the attack of a battery, formed of guns in pits, and there would still be very great uncertainty as to hitting the object. Let me add that the practice to which General Lefroy referred, was carried on in smooth water, from a gun boat that was tolerably steady, that the ranges were ascertained between each round with considerable accuracy, and that, therefore, there was an opportunity of correcting the fire of the mortars between each round, which at last brought it to almost as great a degree of certainty, as the fire of mortars are capable of. Still you see how uncertain it was. This view is quite confirmed by what Captain Alderson stated, that although there were three hits in the first fifteen rounds, it took 140 rounds to get the next hit, in the late experiments at the casemates at Shoeburyness. Therefore, I do not think that mortars should at all be taken into account, in considering an attack by sea on these works. I do not believe that any nation will ever develope means sufficient to carry on an attack, such as General Lefroy described as that by which these gun pits would be assailed. The weak point of Moncrieff's system is when the gun can be taken in flank. I think this is the weakest point in connection with it, unless the guns are in places where they are not exposed to enfilade fire, and then this objection is eliminated. But in other positions where exposed to fire from a flank, certainly the objection holds, unless you can raise traverses to cover the guns. But the objection is one of a limited character, too, because the gun is only up and exposed for a very few seconds at each discharge. I suppose that the time a 12-ton gun will be exposed will not be much greater than with the 7-ton gun. I doubt very much whether it will be at all greater. That period of time will also be reduced by the employment of skilled gunners ; and if guns are worked as Captain Alderson seemed to think they might be, by laying out buoys, and having corresponding marks on the racers, it seems to me it might be reduced somewhat more. If the gun be exposed for 25 seconds in an ordinary way, it is not unlikely that with practice the time of exposure for each round will be reduced to 15 seconds. Therefore, I do not think that objection is so very strong. As to the objection taken that the gun-carriage may be hit by splinters and so disabled, I do not attach much importance to it. Unless the splinters are very large they will not do much harm to a great mass of iron like that. There will be slight grazes skin deep on the surface, but it is not one splinter in ten thousand that will do any serious harm to that gun-carriage.

MAJOR GENERAL SIR WILLIAM GORDON, K.C.B., R.E. : Having had some considerable opportunity of seeing the designs and the execution of coast batteries, I will make a few remarks upon this invention in an Engineer point of view. It comes before us simply as an open earthen battery in the first design of the inventor, and I will confine myself to comparing it with what we have of similar construction. A few years ago, when we had to make coast batteries, we designed them *en barbette.* When rifled arms were introduced, we were obliged to cease firing guns over the parapet, and to lower them down below the crest of the parapet, and fire them through embrasures. In an important position it became evident that the protection to a gun in a battery with an earthen embrasure was so small that it must be increased, and iron shields were introduced—not introduced, but they were designed, and will be introduced. With reference to earthen batteries, we have been, as it were, obliged to abandon those which have been hitherto constructed of earth alone, whether *en barbette* or with embrasures ; but here we have an earthen battery of a very considerable amount of efficiency, without strengthening in any way, and it can be strengthened like anything else. Therefore, we are vastly indebted to Captain Moncrieff for producing a battery in earth without the weakness of embrasures, and with the advantages of *en barbette.* The value of his battery over former ones is very great, and compared with an earthen battery with an iron shield, I consider that his battery, without any strengthening, comes into competition with it. We might argue about the defects and weaknesses of both, and I think you will find there is a great deal to be said on either side. Speaking roughly, I place the value of the Moncrieff battery as about equal to an earthen embrasure with an iron shield. Going still further, however, I do not think it enters into competition with a casemate, or with a turret. Captain Moncrieff has told us that he has other notions, other views, other arrangements ; and when these are brought forward, then will be the time to discuss them, and consider them in comparison with existing works. Mention was made of siege works. My opinion of siege-work batteries is, that if embrasures are made now as formerly, they will not want the enemy to blow them to pieces ; they will be destroyed by their own large guns. Embrasures of the old construction afford some concealment, but very little protection. Captain Moncrieff has shown us how we can abandon embrasures in permanent open works. I think we shall have to abandon them in siege works too, and I hope he will turn his attention to that question, and help to solve it, perhaps as successfully as he has done in the invention before us.

CAPTAIN SCHAW, R.E. : I wish to offer a few remarks on this subject. There is one application of this carriage which has not been alluded to, and although it has not been tried, I believe that it may prove of value to the country. We know that one of the great advantages of the system is that it changes the horizontal strain of recoil into a vertical strain, which it is much more easy to deal with. General Simmons has already alluded to this question of recoil in the case of our new very heavy guns ; but there is another class of guns now being introduced into the service, viz., our old smooth-bore cast-iron guns, strengthened on Major Palliser's system, and converted into powerful rifled guns. In firing these guns with full charges, a difficulty has been experienced in checking their recoil, which is excessive, owing to their being exceptionally light guns. In Captain Moncrieff's system we have, I believe, an efficient mode of controlling this recoil, and, therefore, of utilising these cheap guns in many cases for which the more expensive wrought iron guns are now considered necessary. This is a collateral advantage which probably may result from the introduction of Captain Moncrieff's carriage. The advantages of the carriage for our land defences have already been ably brought before the meeting ; I have only to add that I have every confidence in the invention. I have watched its progress from the beginning with great interest, and the success of the experiments which have been made, has convinced me, as it has most of us, I think, that this is the right carriage for our land defences, and that no time should be lost in adopting it. As regards the application of the invention to sea defences, there appears to be more difficulty. I confess that when I came into the room I was entirely of opinion that the Moncrieff system of mounting guns was the best we could use in all cases, wherever earth could be used as a parapet ; and I had thought of putting before the meeting a resolution to that effect. I still think that, with a slight modification, we should be very generally inclined to agree to such a resolution, because the carriage gives us all the advantages of both embrasures and barbettes, without their disadvantages ; and, although there can be no doubt that the attempt to work, on this system, guns of greater weight than 7 tons, may be attended with difficulties with which we are unacquainted, yet I, for one, do not anticipate that these difficulties will be insuperable.

CAPTAIN E. H. STEWARD, R.E., read the following remarks : Captain Moncrieff claims such a superiority for his method of mounting and serving guns over any other methods of placing them in works, that one is liable to overlook the great merits of his invention, in considering how far some of the advantages that he claims are borne out by facts. At our last meeting a great deal was said about the effect of vertical fire on the Moncrieff gun. This was no doubt due to the gun pit being advanced as a substitute for casemates. Now, if the Moncrieff type of battery is merely considered as liable to be applied in situations where an open battery is required, the question will be narrowed to a comparison between the Moncrieff type, and an open battery with embrasures and shields ; it being understood that ordinary embrasures are out of court altogether, when compared with the Moncrieff system.

To begin with the merits of the Moncrieff system. These may be best understood by comparing it with the well known barbette battery, to which it is nearly allied. The barbette system of mounting guns affords great lateral range and free space for working the guns. It also gives unpierced parapets, and has no parapets above the sill to stop percussion shells. All these advantages are however purchased at the expense of the partial exposure of both gun and gunners. The Moncrieff system has the same advantages; and what is more it affords admirable protection to the men serving the gun, and, to a certain extent, to the gun itself. I say, to a certain extent; for the gun as at present designed does not appear to sink sufficiently low when recoiling, to lie below the path of shot descending over the crest of the pit, at an angle of 10 or 12 degrees. It is not, however, right to judge of the gun in its present state, for Captain Moncrieff has had probably in view only a pit *à fleur d'eau*, and as such a case does not require depression, he may have counted on a higher parapet than he could otherwise do, without altering the gun carriage. There is no doubt that the principle having been once established, the carriage can be made to accommodate itself to different conditions.

The principal claim made for the type of battery under discussion, is that it is invisible; that it reduces the number of guns; and that it will lead to extensive economy in works of defence. With regard to the first claim, there is no doubt that a work containing a single gun planted on a low shore would be undistinguishable, except at the moment of the discharge of the gun; but where many guns are grouped together, and anything like a rapid fire is opened from the battery, its position, and even the line of the crest, will be clearly defined. This will be sufficient to direct the enemy's fire, particularly the horizontal shell fire and the plunging fire. It is difficult to believe that, when a vessel is engaging a fort, and is itself in motion, particular guns are laid at by the gunners on board. One is inclined to attribute the dismounting of guns to lucky shots. If this view is correct, a general fire at a Moncrieff gun battery should be counted on, and if in great quantity and plunging, the invisibility of the gun will not count for quite as much as has been anticipated. It should also be observed that the existence of a back ground would greatly assist in the lining of the guns. In siege operations where the guns would be stationary, the position of a Moncrieff gun could be told to a foot, after it has once opened fire, and its rising would be waited for. These, it must be remembered, are only arguments against invisibility. There is no question, however, about the system making the silencing of guns a difficult matter, and of attaining that object in a simple manner, though I fail to see that the Moncrieff gun has greater immunity from being silenced than the shield gun. It must be remembered that the gun on the casemate platform is much nearer the ground than a gun on a Moncrieff carriage.

The next point is the reduction of the number of guns that may arise from the employment of the Moncrieff system. There is no doubt that a single Moncrieff gun, occupying the end of a spit of a land would command a great angle, twice or three times larger than that commanded by a gun firing through an embrasure; but if one places several guns close together as in a battery, or along a shore at great intervals, the field of each Moncrieff gun will be materially diminished by the position of the guns on either side. The smaller the angle of lateral command required for a battery, the less chance there is also of making the Moncrieff guns do double work. For instance, a narrow channel enfiladed by six embrasure guns, would require an equal number of Moncrieff guns for its defence. The effect of an attack from two or more points, should also be considered in calculating the reduction of the number of guns due to the application of the Moncrieff system. The diagram shows a battery of seven embrasure guns, having the great lateral command of 180° (measured from the extreme line of fire on the left of the battery, to the similar line on the right). This battery can give a concentration of three guns to the front, and two guns to the right and left. Now, three Moncrieff guns arranged in a battery of a slightly convex form, as shewn in the diagram, can be made to afford the same concentration, and might be considered as effective in this respect, as the seven-gun embrasure battery, so long as the attack is made by one ship only. If two ships or points of attack have to be calculated for, the number of guns must be increased to *five*. Thus at the outside, the reduction of guns under most favourable circumstances, is not more than 28 per cent. As the lateral command diminishes, the reduction will also decrease, for in the case of a battery firing through 160°, it would not amount to more than 15 per cent. In making these calculations, I assume that Captain Moncrieff will ultimately succeed in making his gun fire as quickly as the gun on the casemate platform.

With regard to economy in works, the alteration of the type of gun-carriage does not modify any of the requirements of a battery. The necessity of providing an obstacle in front, of guarding the gorge, of providing ammunition and other stores, also of quarters for the men, is common to all types of batteries ; so economy can alone be expected to arise from the employment of a cheap parapet. The dotting of guns along a shore would be anything but an economical plan, for it would multiply the works, render the supply of ammunition to the guns difficult, and introduce awkward land questions. In a battery, the slight saving arising from the reduction of the guns, and the simplification of the trace, due to the Moncrieff gun, will probably be quite absorbed by the strengthening and raising the parapet, also by the increase of the gun interval requisite for the Moncrieff guns, beyond that required for ordinary guns. There, therefore, remains as regards the works, the saving due to the non-employment of iron shields, and this can only be counted on provided that iron is not employed for the protection of the crest of the gun pit. The money for shields could not, however be regarded wholly as a saving to the public, for the extra cost of the gun-carriage will prove a heavy set off against it. But large saving, or small saving, the gun remains a great invention, and a credit to the country.

LIEUT. COLONEL C. CHESNEY, R.E. : I think it would be safer for their results if gentlemen who offer calculations would consider the premises they work from. We have had read a paper founded partly upon the idea that ships are likely to run past defensive batteries at the rate of 10 knots an hour. I do not know what the theory may be ; but, practically speaking, I do not think there is a notion of any Engineers spending money to a large extent in order to have the chance of hitting a ship that is running past at the rate of 10 knots an hour. In all the cases known in modern warfare where ships may come in to attack batteries, it is understood that the ship is to be delayed in passing or in approaching the land defences. Either you may have submarine explosive agents outside the battery, (as was the case at Mobile), or shoals, (as in the upper part of the same harbour), or a line of obstructions across the channel, (as at Charleston), or a turn in the river, where an elevated battery completely checks the advance of ships up the channel, (as at Richmond), or a complete stoppage by means of booms or chains, (as at New Orleans), or a very moderately extended piece of water, (as in the harbour at Sepastopol) ; but no one would deliberately put down money in the form of batteries with the idea that he is going to get a shot at a ship moving past under full steam. Moreover, if ships going at such a rate were to fire at batteries, I imagine the gunners inside the works would care very little for the ships. Ships cannot make good practice unless they keep within a very moderate rate of speed. In the action between the *Kearsage* and the *Alabama*, it is well-known, that although both kept moving, they were obliged to move extremely slowly, or they could not have worked their guns to any effect. Therefore, if I am not mistaken, such calculations may be fairly dropped out of the question, nor do I think it vitally affects our discussion whether a gun be supposed to be worked in 2 minutes 20 seconds, or in 1 minute 20 seconds, provided it fires well and the gunners are well protected. I would say one word more about Captain Moncrieff's system, as to an important case which does not seem to have been considered. It was lately proposed by a well-known officer of Engineers to put up at one of our colonial harbours some single-gun towers, to provide resistance against a single ship of war, or armed privateer, which might come there to take up a commanding position inside the harbour, and to lie there quietly, and to lay the town under a heavy contribution. Now, it is quite certain that in most of our colonies they expect to have a land force of their own, of volunteers, in fact, sufficient to resist the landing of a few boats' crews. In such a case as where a single ship is detailed to attack a town, and the local forces can prevent a landing, a mere gun pit, with one or two Moncrieff guns commanding the inner parts of the harbour—such a battery, in fact, as might be easily made in many of our colonial harbours—protected by the body of volunteers concealed by the nearest rising ground, would offer the very best defence, and save the town from being thus endangered or insulted. I think that application of the carriage should be borne in mind. It appears a cheap and efficient means of protection for this special, but by no means uncommon, case.

LIEUT. COLONEL PASLEY, R.E.: I think General Simmons gave very good advice when he recommended that we should spend our time in endeavouring to consider how we could make Captain Moncrieff's invention applicable to existing works, or to works that have to be constructed, rather than in picking holes in his argument or in his design as it stands. With regard to what Lieutenant Ardagh said, if I understood him aright, he confined himself to a comparison between Captain Moncrieff's barbette system and the ordinary embrasure, leaving out of consideration altogether the shields. But I think that is scarcely a fair way of putting it.

LIEUTENANT ARDAGH: No, no.

LIEUT. COLONEL PASLEY: I understood him to say so.

LIEUTENANT ARDAGH: In the case of land works; in the case of sea works with shields.

LIEUT. COLONEL PASLEY: Then I misunderstood his remarks on that point. However, I think the shield, after all, is merely a device, an excellent one, no doubt, as far as it goes, but still an imperfect method of getting over the radical dangers and faults of embrasures—

THE CHAIRMAN: In open batteries?

LIEUT. COLONEL PASLEY: In open batteries—these embrasures, which have been the difficulty and despair of military engineers since the birth of modern fortification. We may divide the question into three parts, but I am not going to enlarge upon them; I will only say a very few words upon two of them. There is the land defence, that is to say, the defence of fortresses; the defence of the coast; and the attack of fortresses. With regard to the defence of fortresses, I think that part of the subject is comparatively of little importance to us just now. We have a great deal to do with coast defence, and we may possibly have to do with the attack of fortresses, but we are much less likely to be called upon to deal with their defence. We may, perhaps, for the present leave that part of the question to the continental nations who have a more immediate interest in it, and who may be trusted to pursue the enquiry with zeal and intelligence, and we may confine ourselves to the two which concern us most.

As regards coast defences, we may put casemates out of the question altogether. When protection from vertical fire is required, or when, from want of space, guns must be placed in tiers, one over another, it is necessary to construct casemates. It may, perhaps, be found possible, hereafter, to adapt Captain Moncrieff's system to casemated works, but it can scarcely be said to be applicable to them as it now stands. But, wherever open batteries are required, it seems to me that the advantages of the system are perfectly clear. You get rid of embrasures altogether, and with them of all limitation to the thickness of your parapet. In fact, instead of a parapet, you may place your guns under the cover of a *glacis*. I quite concur in the opinion expressed by General Simmons as regards the extreme difficulty of getting the range (however well the enemy's guns may be pointed) with sufficient accuracy to strike such a parapet at its weak spot near the crest. Probably not one shot in a thousand (from a ship, at any rate) would so perfectly combine accuracy of direction and of range as to injure a gun which cannot be seen except for a few moments at a time, and the position of which when out of sight is not denoted by shield, embrasure, or other mark on the parapet. If a shot should chance to strike the crest of the parapet between two guns, it will do no more mischief than if it struck the parapet of an ordinary battery between two shields.

In comparing a Moncrieff with a shield battery, it must be borne in mind that in the latter, besides the embrasure or port, which is entirely unprotected, there is a very weak spot on each side of the shield. The drawing on the wall shows very clearly the existence and the nature of this defect which is inherent in the system, and cannot be avoided consistently with giving any lateral training to guns behind shields. All that difficulty is got rid of by a system which enables you to put your guns, with all the advantage of having large lateral range, behind what I call a glacis, unbroken by embrasures, instead of a parapet. With regard to the comparative value of earth and masonry, it has been stated to-night, very correctly, that the choice of materials must depend in a great measure upon the space you have available. As to earthen parapets, it has never hitherto been disputed that, assuming a certain amount of inaccuracy in the enemy's fire—and it is sure to be a great deal more inaccurate than it is often assumed to be in discussions of this sort—an earthen parapet, if you can only get rid of the embrasures and keep your guns, or at all events your gunners, behind it, affords the best protection you can have ; far better than masonry, and probably better than iron, provided it is thick enough. I am very much inclined to believe (and I should like to see the thing thoroughly tried, which, as far as I can learn, it has not yet been), that for coast defences, parapets made of dry sand, would probably prove to be better than the best rammed earth. I am led to this opinion by General Gilmore's description of the attack on Fort Wagner, near Charleston, where the parapets were made of sand. The besiegers had the disadvantage of being confined to a very narrow front of attack ; in fact, the space they were able to occupy was actually narrower than the front they were attacking. But they had the advantage of a far more powerful artillery, including guns of very great range ; so they were able to establish rows of batteries one behind the other, firing over each other. Although a very heavy fire was kept up for a long time, no material injury was done to the works of the fort. So large a proportion of the sand thrown up by each shot or shell fell back into its place, that the parapets proved practically impenetrable, and the damage done by a day's firing was easily repaired in the night. Now, that would not be the case with well rammed earth. I am informed that at Shoeburyness, a good many shells have been fired into sand, apparently with a good deal of effect, each shell increasing the size of the hole made by the first ; but, then, I understand that was sand which the tide had just left. In order to see the difference between that and a parapet made of dry sand, you only require to go down to any watering place where there is a sandy beech, and see the children throwing up their little fortifications. Below high water mark, where the sand has been moistened and pressed down by the tide, they make castles and mounds with great facility, but with the dry sand higher up they can do nothing. The difference is so important, that I do not think the results hitherto obtained at Shoeburyness afford any indication of the value of sand in works of defence. A parapet should be constructed of dry sand, and fired at systematically.

As regards the question of guns generally, I do not think there is any reason to assume that there will be any difficulty in adapting the Moncrieff system to the 12-ton gun, or to guns of even greater weight ; considering how perfectly successful the very first experiment with the 7-ton gun proved to be, I do not feel the least doubt that it will be equally successful with the 12-ton gun.

With regard to siege operations, that point is of very little importance, because it is not likely that 12-ton guns will be carried in a siege train ; but 7-ton guns probably will be, and the advantage of being able to establish your batteries of attack without being obliged to build elevated parapets and make embrasures, offering a good mark for the fire of the garrison, is, I think enormous. When your fire is once opened, it is a question which side can pound away the hardest and keep it up the longest. You have generally the advantage of position, but the difficulty has always been to erect and arm your batteries under the fire of the fortress. That difficulty would be greatly aggravated by the increased accuracy of rifled artillery, and we shall gain an immense advantage by being enabled to keep the enemy in perfect ignorance of the position of our batteries up to the moment of opening fire. Captain Moncrieff proposes to adapt his plan to siege operations, by making the gun portable on a railway ; and this has been talked of for land defences also. The carrying out of this scheme in siege operations would often be impracticable, and always attended with more or less difficulty, because if we allow that the recoil is so completely absorbed by the peculiar action of the counter-weight, that there will be no lateral strain on the rails, the dead weight of the gun and carriage is so considerable, as to require a substantial line with heavy rails and numerous sleepers to carry it. This, however, is a question for experiment and mature consideration. The great fact with which we have now to deal is that we have actually got an invention which enables us, wherever open batteries are to be constructed, to dispense altogether with embrasures and with shields. If Captain Moncrieff had given us that alone, without holding out any further hopes as regards the future, I think we should have reason to be very much indebted to him.

MAJOR-GENERAL SIMMONS : In order that it may appear upon the short-hand notes, I should like to correct what I said in considering the amount of vulnerability of an embrasure with an iron shield. I stated that the embrasure was 3 ft. 11 in. high by 2 ft. 6 in. broad, which would give 9·8 square feet of target. But I ought to have added nearly a foot all round the embrasure, because a shot striking anywhere within that foot would cause a vast number of splinters, and probably a great many of them would pass within the embrasure. This would increase the superficial area of the target to nearly 27 square feet, instead of 9·8 square feet; similarly, it would increase the area of the embrasure for a muzzle pivoting gun, from 6·6 square feet to 21 square feet. I think it is very important that this should be borne in mind in considering this question.

COLONEL JERVOIS, R.E.: I do not desire to refer to the point mooted by General Simmons with the view of raising an objection to the adoption of Captain Moncrieff's system. I merely rise to speak with reference to the relative protection afforded by an iron shield, and by an earthen or masonry parapet, for the protection of a gun mounted on the Moncrieff gun-carriage. We will suppose that you require 120 degrees of lateral range. The section would be this, (showing the same on the black board). I do not suppose that anyone will question that shot, coming at an angle, such as that, will carry away that portion of the parapet (showing same), and strike the gun and the gunners. That, of course, can be got over by applying iron, or other material, to strengthen it. You will find, that in order to obtain the protection that is desired from that height of parapet, it would be necessary—that is if the views prevailing at the present day as regards protection are adopted · that some portion of the parapet should be of iron. For myself, I should be ready to run the chance, without the iron addition. But we are considering the degree of protection afforded by an earthen or a masonry parapet in front of the Moncrieff gun, in comparison with the protection afforded by an iron shield; that is the point before us. Now the port in an iron shield for an ordinary casemate gun-carriage, as General Simmons says, is 3 ft. 11 in. by 2 ft. 6 in. I do not admit that you are to add to it a foot all round; for the protection afforded by the sides of the embrasure, although not quite so strong as it is at the other parts of the shield, is very considerable.

CAPTAIN JASPER SELWYN, R.N.: As my senior, Admiral Key, has declined to take up the subject on the present occasion, may I, as a naval officer, be permitted to say a few words in this assembly as to the kind of defence I would not choose to to attack; because I think you will agree with me that those who have to attack the defence have a very good idea of what defences are likely to annoy them most. Now, I have had considerable experience in the service, with various kinds of defence and of attack in foreign countries, and with some nearer home. I have always found that there were two kinds of battery which were most formidable to shipping. One was that which was raised very considerably above the plane, and which therefore gave a plunging fire, against which, not even iron-clads have any protection whatever. The other was the battery a *fleur d'eau*, established on a mud bank, not rising much above the surface, which was not approachable by boats, by reason of the shallowness of the water. Hitherto, such batteries have been established on piles with earthern parapets, and we have been able to ruin the parapets and to destroy the embrasures. But if a caisson be sunk in a mud island, and a Moncrieff gun were in it, I have no possible means of silencing that gun. I cannot attack it in any sort of way; and it will generally hit as long as it is in my line, however badly it may be aimed as to elevation, because I am considerably above it, and it ricochets along. That is one of the most formidable guns we have to attack. I think it is beside the scientific view of the question, when people take the existing modes of fortification and ask their application to an entirely new system of carriage, which is calculated to meet very many of the difficulties which have hitherto been felt in fortification, and to change the conditions under which guns can be used. One of the first considerations we have to bear in mind in these islands is, that no enemy coming under steam would approach any fort at all ; and one of the best places for landing is where there has never been a fort, on one of the deeps of Norfolk, where I could run a thousand men on shore in the course of half-an-hour, with my vessel's nose on the beach, and back her off afterwards. If I had a dozen steamers, I could repeat the operation with the whole dozen. It is not now necessary to wait for tides or winds, or to approach harbours with the same precaution that we did formerly. I must, however, dissent entirely from any idea that ships can run past forts at ten knots an hour in a narrow channel. We are very reluctant, in fact, we should be "court-martialled" immediately, if we attempted it. If we go into shallow waters at all, we use the lead ; and we cannot go at ten knots an hour using the lead. We may have charts, and the channel may be buoyed, but the buoys may have been removed or altered, and the landmarks shewn in the charts may have been falsified. We dare not run fast into shallow waters, set perhaps with torpedoes ; we dare not go at ten knots, nor even at five knots. Therefore, that idea is to be left out of the question altogether. The mode in which a squadron makes an attack is for the admiral to form a plan of attack beforehand ; the ships run in and take up their positions, and pour in their fire on anything that is visible. But they would be very much puzzled, even before the smoke begins to surround them, if they were called upon to fire upon something that was invisible, or which was only indicated by a puff of smoke that rose over the land some ten minutes ago, while the men were bringing the ship to anchor. What are we to do to silence such a gun ? We cannot ruin its embrasure, for it has none ; we cannot hit it, for it is invisible. It may be said that vertical fire may plunge a shot into a gun-pit. I answer, that for such a chance, half the shot in the ship would be thrown away, only that you might hope you had produced such an effect. And when you take into consideration that Jack's gun just gives out its smoke while Bill is taking his aim, the shot would be thrown away *ad infinitum*. Still worse if mortar boats are placed behind a promontory, where the enemy must ascertain the position of the defence (if he ascertain its position at all) by compass ; a most fallacious means, if the vessel has any iron in her composition, still more if she has a varying quantity of shell or shot on board ; I should not trust to any such thing. I say, distinctly, my impression, as a naval officer, of vertical fire directed against coast defences, is, that no man in his senses in command of a mortar boat, or in command of a mortar boat fleet, would ever attack, in any such fashion, any but a large fort or a large town. He could not hope to operate successfully against detached guns, or against small batteries. The system of utilising this magnificent invention—I call it magnificent, for I say it is the application of a great principle—is not alone the affair that we see before us in its present development, but it is the application of a great principle, which is as capable of as much modification and of as great improvement, as the steam engine since the days of Watt. It is no more wise to talk of the Moncrieff carriage of to-day as being the *ne plus ultra*, than it would have been of Watt's engine.

I will speak now of the development of the defence of our coast. I say, if you give me a mud island, and allow me to sink a caisson in it, and leave a ditch outside it, which contains water, I shall not fear any penetration of the mud around. I think water, which was adverted to by General Simmons as offering a very solid defence against shot, may very well be left where nature has placed it, and that it will prove a very great defence against any such penetration as 50 or 60 feet into earth, which is supposed to have been obtained, but which I deny. The water may be left there, and similarly sand may be left there. It is well known to engineers that dry sand has a most efficient power of resistance against motion. If you want to establish a Nasmyth hammer on a solid foundation in a marshy ground, you need not use any other foundation than sand. Some of the largest structures in Holland, where I was the other day, are built upon sand piles. They offer a resistance to weight, let alone impact. With regard to impact, I would instance this experiment. A glass tube was taken, of two inches bore and of very moderate thickness. It was filled with six inches of sand, the tube being two feet long. The bottom was covered with silver paper. An iron bolt was let fall from the whole height of the tube on that sand. It failed entirely to break through the silver paper, simply because the particles of sand had a motion of themselves, and slowly absorbed the force by friction.

I cannot end without speaking strongly on the subject of a railway in connection with coast defences. I do say that if I, in a squadron of ships, had to attack the Thames, or any other river, having also to encounter the tide of that river, which would diminish my speed below that which I could otherwise attain, I should fear most such guns as had no fixed point of attack, but which might be moved along a coast railway, devoted during peace to other most useful purposes, to re-appear at points where I never could expect them, and to which I had no knowledge that they were being moved, and which would also accompany my ship along the river side, and wait for me at my defenceless moment, when I was in difficulty with a shoal, or strong tide, or anything of that kind. For this purpose, and for such as this, I do say that a gun which disappears, as on a Moncrieff carriage, after firing, has an invulnerability which cannot be over valued. Speaking as one of the possible attackers of coast defences, I say that is one of the defences that I should most reluctantly attack, and which I should most persistently avoid.

THE CHAIRMAN: I think this subject is very far from being exhausted. It is now too late to continue the discussion; and we must part to-night, merely looking upon it as an adjournment. I think there are a great number of officers present who would like to speak upon the subject. I do not know whether Captain Moncrieff wishes to say anything.

CAPTAIN MONCRIEFF said he had a great deal to say, but as the time had elapsed, and the meeting began to break up, he decided to defer his reply until the next meeting.

THE CHAIRMAN: The subject is one of very great interest to us all, as shown by our having had two meetings, and I hope we shall have a third, and even a fourth. It is very desirable that we should know what has been said upon the subject, and my proposal is that the short-hand writer's report of the discussion, both to-night and the previous night, should be printed and circulated before we meet again.

ADJOURNED DISCUSSION.*

MAJOR GENERAL FROME, I.G.E., &c., IN THE CHAIR.

THE CHAIRMAN : I have received a letter from Sir John Burgoyne who regrets he is not able to be present at this meeting through indisposition. He, however, tells me that he has sent a memorandum by Lieut. Ardagh, and I should be glad to have it read. Captain Moncrieff, also, is not able to attend through illness, but Captain Selwyn has a paper from him with reference to the last meeting, which Captain Moncrieff is desirous should be read. I think it quite right that we should hear these papers in the first instance, before we go on with the discussion. When Lieut. Ardagh comes in we can hear what Sir John Burgoyne says, and, in the meantime perhaps Captain Selwyn will be kind enough to read Captain Moncrieff's remarks.

CAPTAIN SELWYN, R.N.: Captain Moncrieff being confined to his bed by a feverish attack has requested me to read a few remarks which he has hurriedly written today in order that the observations made during the last discussion, which there was then no time then to answer, may not remain without some reply, and that he may not lose the opportunity of expressing his acknowledgement to those officers who on that occasion declared themselves so strongly in favour of his system. Captain Moncrieff remarks : In the adverse criticisms which I feel called upon to answer there are certain main allegations. First, It has been alleged by Lieutenant Ardagh that the system is not suited for coast defence. To this I would reply that the whole of the arguments he uses to prove his point are based on premises as to the rate of fire being less with my system than with ordinary carriages. He admits that if the rate of firing with my carriage for a 12-ton gun were $1\frac{1}{2}$ minutes per round, the balance might be turned in my favour. Now, the time given by Captain Alderson is 57 seconds per round with the 7-ton gun against 48 seconds with the service gun carriage. Lieutenant Ardagh's opinion that the time required will increase out of proportion with heavier guns is only an opinion, and ought not to have more than its due weight in the face of the expressed conviction of officers who have more practical experience of the working of the new carriage. Lieutenant Ardagh has entirely overlooked a condition which materially affects the speed of firing of all guns in casemates, and even to a certain extent in embrasures. It is, that the smoke invariably clings to and surrounds all such structures, and it is well known that the rapidity of fire which the particular carriage might be able to attain is rarely called into action, on account of the time during which aiming is impossible. This objection is peculiarly applicable where the target is a moving object. Dismissing, therefore, all the arguments based on an assumed rate of firing, I turn to the statement that the system I advocate does not give real protection. Here I find Lieutenant Ardagh again assuming a slope of glacis which I never contemplated, and a depression of gun which cannot be obtained

* Held at the War Office on the 10th of February, 1869.

by a sea attack. If he means by depression the curve of a long range trajectory, I answer that, to this all defences not casemated are equally exposed, that such modes of attack are not pursued generally in consequence of the undecided results they obtain, and that it has not yet been proved that any great thickness of earth can be penetrated when the shot is falling one foot in ten. Besides, if earth were insufficiently resisting there are many other materials that may be used in such cases short of the expensive iron he seems to think necessary. There are two other assumptions to which I strongly object. The first is that my system will find its best application in existing fortifications; the other, that the system is itself incapable of expansion and improvement to suit each situation which it may be called upon to occupy. Lieutenant Ardagh seems also to take for granted that the protection given by our present coast works is all that could be desired. With regard to the first assumption, I would recall your attention to the remarks of Lieutenant-Colonel Chesney on the defence of our colonial ports, and I should wish to ask this meeting whether there are not many such places which might now be insulted with impunity by a single ship, even on our own shores. As to the second assumption, it is not to be imagined that because I have only hitherto devoted my attention to a particular adaptation of my principle, and by doing so have secured myself against many of the errors and defects which usually attend a first trial of any new system, I am not in a measure prepared to show how in a special case, special appliances may be made use of; neither is it fair to compare the results of long training, and great experience in an accepted method with those that can be obtained with a new system on its preliminary trial. I have referred to the question of the comparative protection afforded by the different systems of defensive works. That protection is of two kinds—protection to the men and protection to the guns. With the limited gun detachments available for coast defence it is clear that protection to the men is of the first importance. I am not now called upon to compare my system with guns in casemates, where a special application of my principle would be necessary; but I affirm that even a casual observer would soon be satisfied of the greater protection afforded by a system which is without embrasures or other openings as compared with one which has indeed iron shields, but shields with holes in them, capable of deflecting shot into the work, which might otherwise pass it harmlessly. But besides this, the protection afforded to the men cannot be fairly discussed, till the arrangements of the interior of the gun-pit are made the subject of a study, which I have as yet not felt at leisure to give to them. General Simmons puts the vulnerable surface of a port in the iron shield at 27 square feet. A shot or shell, hitting any part of this, is likely to injure the gun, or make havoc among the detachment, and it is to be remembered that this exposure is a permanent one, and has therefore no parallel in a gun-pit. This, too, is more than the greatest temporary exposure on my system, even were I to entertain the idea of the side of the gun being fully exposed to a flanking or enfilade fire while firing itself at another enemy in front. The horizontal exposure, even in such a case, is but temporary, and may compare favourably with the constant exposure of the 27 square feet above alluded to.

A few of the instances in which my critics have greatly erred may be here given, in order to free me from the necessity of refuting seriously or seriatim all the hasty conclusions at which some of them have arrived. It is supposed, that in the defence of an existing fortification, I should resort to high traverses, built up for no other purpose than to define the position of the gun. Why I should not instead dig out the necessary space does not appear. When existing fortifications are to come to their trial, it appears that an " almost perfect protection " can be given by parapets 25 feet thick ; but even as a glacis, and not a parapet, 40 feet cannot be relied upon to keep out shot from the gun-pit. As to the expense and time required to establish these gun-pits, I may point to a fact which is patent to every one. The gun-pit at Shoeburyness was made at an expense of a few pounds by half-a-dozen labourers, employed during about a week. Now this is just what could be repeated at any threatened points of the coast, when coast defence became necessary. I need not say that no officer who knows practically the requirements and expedients of real war, would find much difficulty in establishing the necessary magazines and stores, behind a parapet 10 feet high. Neither is it to be supposed that in such emergencies there would not be a great deal more work done in a given time by a given number of men, than is ever the case under contracts and correspondence in time of peace. If the sort of battery of which Lieut. Ardagh is evidently thinking is to take months to prepare, it is certainly not the right thing for such an occasion.

I am content to leave the question of the exact value of my gun carriage in the hands of those who have found occasion for friendly criticism of my system ; the more so, as at this moment it is well known that the subject is receiving the consideration of a committee. I can only say, in conclusion, that no one can be more anxious than myself that no unnecessary delays should interfere with the rapid development of the principle. But I regret to state that up to this moment, I am still as powerless to proceed as I was after the first trial which took place nine months ago.

THE CHAIRMAN : I would now propose that this memorandum of Sir John Burgoyne's, which has just been put into my hands, may be read. With regard to Captain Moncrieff's paper, I do not think it will be necessary to make any comments upon it ; it speaks for itself. After Lieutenant Ardagh has been kind enough to read Sir John Burgoyne's paper, we will go on with the discussion. The ques-question we were entertaining last time was principally the application of the Moncrieff system to land defences, to sea defences, and to existing works. That is the subject we should return to as soon as possible without going into the question of construction, or repeating what has been said before.

LIEUTENANT ARDAGH, R.E., read the following remarks by FIELD MARSHAL SIR JOHN BURGOYNE :—

In common with the general, I think I may say universal, opinion, I consider this invention of Captain Moncrieff extremely valuable. There may be differences of opinion as to the extent of its application ; a matter, however, on which it is not very essential to dispute, as it will be gradually developed by use and experience.

The old barbette battery, from its unlimited command of lateral range, and its freedom from the damaging effects of the enemy's fire on its partially covering works, possesses advantages that leads to its application in many situations, notwithstanding its great and serious defect of extreme exposure to the enemy's fire.

By this contrivance of Captain Moncrieff's, we retain all its advantages, with the removal, to an enormous extent, of its only disadvantage, that is, from a state of constant exposure, to that of what is only occasional, for periods counted by seconds of time, and that when it is your own pleasure to fire the gun. This, then, is one clear gain.

Then comes the more important question of the practicability of applying it as a substitute for embrasures, which, again, are exposed constantly to the damaging effects from direct fire, from which these guns are exempt, except during the very short periods of pointing and firing the piece, when, certainly, for those short periods, the exposure is greater, not only to a direct fire, but also opens the gun and gunners to a wide ranging lateral fire ; and there may be differences of opinion as to the comparative value of loss or gain in that respect, but all will agree that in many cases it may be applied to advantage in place of embrasures.

It is to be remarked that the getting rid of the embrasures would be attended with much more advantage than might be generally supposed ; for it is not only the embrasures, but to obtain them requires to have the merlons and indeed the whole line of parapet above the height of the genouillère exposed to destruction by the besieger's fire, which is, in fact, one of the regular processes in a siege, and thus not only has the effect of silencing the guns, but of opening, in a great degree, to view the whole terreplein of the work ; whereas, a parapet, as on this principle, prolonged *en glacis*, may be said to be virtually, as a whole, indestructible, except in a work presenting a very small front ; the very partial damage that could be done to it, so little indeed, as not likely to be ever systematically attempted, would be readily repaired.

When we treat of the superior slope of the parapet being *en glacis*, it is not meant as necessarily implying a continuous glacis from the crest of the parapet, but one that may be intersected by a ditch, provided that the same plane as that of the upper slope of the parapet is continued from the crest of the covering counterscarp or covered way.

Many matters of detail have been adverted to which have a bearing in estimating how far such an invention as this may be really valuable ; for inventions, shewing manifest advantages, frequently require sacrifices that more than counterbalance them.

First, then, the efficiency of its mechanical construction and working parts : this is said to have been already proved by adequate trials, up to the scale of the 7-ton gun, and no doubt is expressed but that the principle may be extended to heavier metal; every exertion, however, will, of course, be continued for even further improvements, if possible, on this head, for simplicity and freedom from liability to be put out of order are of the most essential importance ; not only should it be strong, to meet rough usage and wear and tear, but of a construction that in case of defects or accident, would not require the refined means that are only to be found at great manufactories.

Whatever differences of opinion there may be as to the amount of effect of the enemy's artillery on these guns during even their very short period of exposure, there can be no doubt but that the gunners might suffer much from rifled small arms ; but possibly that might be met by some musketry-proof screen applied for the moment ; and, perhaps, even the gun itself might be in some degree concealed from view when raised by a loose canvas curtain. Nothing at all refined or troublesome would be needed for either of these objects.

The question of *cost* has been referred to ; one that just now it is the fashion to enforce somewhat to extremes, that is, without reference to a fair comparison with the value of the benefits to be derived from it. At all events, in this case, there are doubts whether the actual cost will, on the whole, much, if at all, exceed that for which it will be the substitute.

With regard to vertical fire, it would be neither more nor less exposed than any other gun that is not under bomb-proofs, which this is not intended to be. At the same time, vertical fire, when direct and not very close, is of very little effect, on account of the small extent of range on which it must fall, namely, but little more, than the length of the gun and carriage, and only becomes formidable when on an enfilade, which, giving it a far greater mark, would be attended with its usual destructive effects.

Reference is made to its employment in *pits*, that is, sunk, it is presumed, in the earth, to the depth necessary, or nearly so, for its entire cover. This, I apprehend, would, *on service*, be found to be a most inconvenient practice ; first, from its want of command, as the slightest inequalities or obstructions in front, such as almost always exist, except on the brow or descent of a height, would greatly affect its fire ; and again on account of the state of such pits, which frequently it would be most difficult, if not impossible, to drain in wet weather.

In the sieges in Spain, circumstances drove us generally to sink our batteries, and though to a trifling degree compared to what these guns would require, we often suffered from the two causes above mentioned. These difficulties would not be experienced in permanent works. Of course, it is meant that all such pits should have covered communications to them.

I do not know whether it is contemplated to use these carriages in the siege of a place, but I should consider them far too unweildy to be added to the equipment of an army in the field, even in a siege train, or for being brought into the trenches ; the labour of putting them in battery would also be particularly heavy, nor are their special advantages so much required there.

If this mode of mounting guns should have the effect, as I anticipate it may in many cases, of preserving the parapets of a front attacked from any but partial destruction, it will afford in defence additional means of retarding the progress of a siege, for guns may then be brought to bear from time to time suddenly on the trenches, which at present they cannot be ; and as the sap. in particular, is on a principle for security only against musketry, on the assumption that the artillery of the garrison would then be silenced, the very lightest description of pieces, say a *one* pounder, would be quite efficient against it, and thus would require more elaborate and slower proceedings by the besieger.

For such service it will be desirable to adapt the piece to a power of very ready removal from place to place, and consequently not to require fixed curbs for traversing on, which would not be difficult for such small pieces.

On the whole, I hope that this principle of working guns will be actually employed, first on a moderate scale in positions where its advantages are most palpable, whereby partial improvements will, no doubt, suggest themselves ; and that its application will then be further extended.

THE CHAIRMAN : The paper by Sir John Burgoyne having been read, it is now open to any officer to make any remarks.

COLONEL GALLWEY, R.E. : I think, Sir, in the two previous discussions we have lost sight in a great measure of the important subject of shell firing from rifled guns of a certain calibre. We have spoken about penetration of shot, which is absolutely ineffective against an earthen battery ; and as to shell firing from mortars some people seem to place value on it, and others do not. However, it is nothing compared with the fire from a rifled gun firing shell horizontally. I think one of the great reasons why we do not understand it is that, with the exception of some experiments carried on by the Ordnance Select Committe about five years ago, we have hardly ever seen a shell burst in earth. We cannot fire them at Shoeburyness as there is no suitable range. When we see blind shells fired at earth, and turning all sorts of ways after impact, we imagine that shells do no harm. I should like, therefore, to draw the attention of this meeting more closely to what was done at Newhaven. I shall shortly describe these experiments, and I am glad General Lefroy is here, as he will be able either to correct or support what I state. The Newhaven experiments were conducted or undertaken to ascertain the penetration of shot and shell from different guns in the service, both rifled and smooth bore, and also to ascertain the quality of the fuses. During the course of the experiments we tried to burst the shells in the exterior slope of the parapet, when, of course, there were a great many grazes and occasional misses. In watching the action of the shells fired from rifled guns, particularly those from the 7-inch gun, we saw several examples of this kind—viz., where the shell struck the superior slope about twelve feet or so from the crest, and after entering a certain way it burst, clearing away a mass of earth, the fragments of the shell passing through into the battery at a high velocity. We could plainly see the matrix of the shell where it burst blackened in the clay. You will see the effect in some photographs on the table. Then the committee, if I remember rightly—I have lost the report, but I was a member at the time—having some hundred rounds left, it was thought advisable to expend them in making a breach. In order to effect this, instead of "plumping" the shell into the exterior slope, we fired at the crest of the parapet, and that breach which you see in the photograph was thus formed. It is 33 feet wide, 5 feet deep, and the parapet was 25 feet thick, made of very good stuff.

THE CHAIRMAN: What was it made of?

COLONEL GALLWEY: Of sand and clay well rammed—a very good parapet indeed. I think there are some officers here to-night who had the digging out of the shot. The penetration was very good. The result was, that breach was made at 1,060 yards, with about seventy 7-inch shells in about two hours and-a-half, many of those shells being blind, and a good many bursting prematurely. In fact, it made a great impression upon the committee, especially upon me, who looked upon shell firing generally as not injuring the parapet materially, as the earth could not be got rid of; whereas, here with rifled shells it was literally blown away. There have been remarks made here that a parapet *en glacis* is superior to an ordinary parapet as regards protection from fire. As long as you begin to work at the top it is no matter whether it is *en glacis* or whether it is of a certain thickness, 20 feet, or 30 feet, or 40 feet. I think it was Sir William Gordon who put the case well, when he compared a gun on a Moncrieff carriage behind an earthen parapet to a gun behind a shield as regards exposure. That is a fair comparison. Now as to the vertical exposure, there (see Pl. II. fig. 1) is the gun in the firing position, and there is the gun in the loading position. Supposing the top of the parapet to be disintegrated by the first hour's fire, which it certainly must be, there is a vertical exposure of three feet six inches multiplied by the length of the parapet. That bears out what Colonel Jervois said in the last evening's discussion. Therefore, it seems essential where an accurate fire of rifled guns may be expected (and we know how very accurate this fire is up to 1,000 yards and further) that something must be done to protect the crest of the parapet. A perpendicular revetment is necessary, in order to give proper cover to the gun and carriage. Fig. 2, Pl. II., shews approximately a construction affording this protection, consisting of a revetment of masonry on brickwork, counter-arched (so as to give storage) and iron plating to that portion of the superior slope which, according to our present experience, would inevitably be cut away if unprotected. Fig. 3, Pl. II. shews the Newhaven breach in elevation with two guns on Moncrieff carriages; this I think, demonstrates the necessity for something beyond a mere pit, thus adding greatly to the expense. That breach was made by one 7-inch gun in two hours and-a-half. Of course, there must be a co-efficient put in for another battery firing at it. At all events, the gun would be discovered after a certain time, and when discovered it would afford a very much larger mark than a gun ordinarily mounted. I think it is only due to Captain Moncrieff and his system to say that this result can only be obtained when guns are fired from a rigid platform, and laid with great accuracy. I would conclude by adding my testimony to that of everybody else to the mechanical ingenuity and the great importance of the invention. I only hope that Government will go a little faster than they have done in applying it to larger guns, because it is to larger guns that, to my mind, the system ought to be applied.

The Chairman: It is the same with any gun?

Colonel Gallwey: Just so; but what I mean to say is this, that it is peculiarly applicable in coast defences, and therefore to our heaviest ordnance. We have heard from good authority—Captain Selwyn amongst others—that when a ship is coming into harbour her fire cannot be very accurate in consequence of her having to slow, and of her having now-a-days to hunt about for torpedoes, and, therefore, I think you may have these guns in support of forts, like the forts at Portsmouth, in pits or behind a bank without any protection, relying on the inaccuracy of the fire from the ships. But in land attacks, where you know your range and can fire as accurately as possible, the crest of the parapet becomes damaged; you see the thing, and its specific value is all gone. I think Colonel Pasley, and also Captain Selwyn, remarked that sand was excellent for parapets. So it is—the best material you can get; but then, it should be remembered, you are obliged to make use of the material close at hand. Sand is also excellent for foundations when incompressible. The experience of the American works has been taken as an example of the excellence of sand. Now, the immunity enjoyed by American works was entirely due to the fact that the Americans had not a fuse in their equipment that would burst in earth at moderate ranges. I saw this at Fort Wagner and other places. The parapets at Fort Wagner and the celebrated bombproofs were studded with unburst shells, simply because there was no fuse sensitive enough to burst in earth.

Colonel Lennox, R.E.: Colonel Gallwey has shown us some very interesting diagrams of the breaches made by heavy rifled guns in the Newhaven Battery, but I think we should take into account what would be the condition of such a battery if it were armed not with guns on Moncrieff carriages, but with guns on ordinary carriages. We must compare the two. Now, a battery exposed to such a fire would have been shut up bodily if armed with guns not mounted on Moncrieff carriages. I think also we should bear in mind that the breach shewn in Colonel Gallwey's diagrams was made by guns that were not being fired at; none were returning the fire at all. But the facts of the case would really be, that these guns on Moncrieff carriages are only exposed for a few seconds, and are fired at by an enemy whose guns are constantly exposed through embrasures. The guns on the ordinary carriage can be seen steadily the whole time, and therefore the guns on Moncrieff carriages would be much more likely to shut up the gun firing at them from an embrasure battery, than guns firing from an embrasure battery would be to shut them up. The circumstances of the two batteries are widely different. It is only a question as to which guns are best protected. As long as we have got the guns working there is little doubt in my mind that the Moncrieff guns must be much better protected than the others. It is only a matter of which will last the longer; guns, whether on Moncrieff or ordinary carriages, may be disabled by a good shot, but the gun on the Moncrieff carriage will be exposed a shorter time, and therefore will last longer.

MAJOR GENERAL SIMMONS, R.E.: I am reluctant again to occupy the attention of the meeting, but as no one else has risen, I venture to offer a few observations with reference to the point that has been brought before us by Colonel Gallwey. I take it that those diagrams have special reference to land defences, and that they are not applicable to sea defences, for reasons which I will explain hereafter. With reference to land defences, I think we may look forward to an adaptation of the Moncrieff system or of some other system, so that the guns shall be capable of being moved along the parapet; and I fully anticipate that a gun when once placed in a position will not remain always in that position, but that by being placed upon rails, or by some other means, it will be capable of being moved along the parapet, so that it may appear at one moment at one place, and shortly after at another. Well, then, with regard to those experiments at Newhaven they prove incontestably that an earthen parapet, 25 feet thick, may be breached by 7-inch guns at a certain range, but they do not prove the same thing with regard to a parapet of double or treble that thickness. That diagram (Pl. II, fig. 1), which I have only seen since I came into the room, will explain what I mean. If a shell arrives in the position in which it is there shown to have exploded, it will undoubtedly throw a mass of material into the work; but if, instead of having six or eight feet of earth in front of it, it had thirty or forty feet, it would not have had sufficient power to throw the earth into the work, but the force of its charge would have acted in the direction of the line of least resistance, which is upwards, and the effect would have been similar to that of the old spherical shell which used to form a small crater, this being often filled by the crater from the next shell that lodged near the first one. Well, then, with regard to the superior slope of that parapet, I think this is a subject which we shall have to attend to very closely. We shall not give the slopes that we have been in the habit of giving, but we shall carry our *glacis* up very much higher, so that they shall be in prolongation of the superior slope, or very nearly so. By doing this we place before the Artillery an exceedingly difficult problem. Unless they see the parapet and the work they are firing at they cannot ascertain their range. I cannot forget having witnessed some experiments at Shoeburyness in which, with a screen battery, the Artillery, knowing the range within fifty yards, were scarcely able to hit the parapet of that battery at all, because they could not see whether their shot struck the parapet or the screen, or lodged in the space between the parapet and the screen. I think out of a large number of rounds with one of their best shooting guns, the 40-pounder, with the most experienced gunners at Shoeburyness, and the best shots in the regiment laying the gun, they could scarcely hit the parapet at all. There are gentlemen present who will bear me out in what I say with regard to that practice. I do not see why we should not adopt the same system in our works of raising the *glacis*, keeping the superior slope as flat as possible, so that the parapet shall be scarcely seen, and in some cases be even hid altogether, because as the path of the shot rises all that you want is the line of vision clear to enable you to lay your gun. Well, then, to go on with the subject and apply Colonel Gallwey's reasoning to coast defences, I think here it breaks down altogether. I have taken the trouble since the last meeting to refer to the work of a committee of which I was a member some years ago—the Armstrong and Whitworth Committee—and I have made a note or two of the practice carried on by that committee, which I think very instructive. This practice was carried on in April, 1864, with 12-pounders at targets nine feet square, with solid shot. In those experiments the object was to get the relative accuracy of the guns which were being tried competitively. In order to attain that, it was agreed after some discussion by the two competitors that they should fire at targets nine feet square; that they were to be allowed five rounds in order to ascertain the range, the results of those five rounds not being registered; and that, subsequently, five rounds should be registered, upon which was to be determined the relative accuracy of their guns. I should say that in order to attain accurate practice during the five trial rounds they corrected the deflections of their guns to seconds, with as much accuracy as a theodolite can be laid. These corrections were made with the greatest care, under conditions which can never be realized on service; on each round being fired, the exact spot where the shot fell was reported by the range party. Now, I find on the records of those experiments that at 200 yards, 300 yards, 400 yards, and 500 yards all the shot hit; at 600 yards there was a miss; at 800 yards they all hit; at 900 yards there were two misses; at 1,300 yards there were eight misses out of the five rounds from each of the three competitive guns. The consequence was that we were obliged to abandon that method of testing the accuracy of the guns, because, we could not assign a value to a miss. Of course, one could not tell whether the shot just grazed the target or went ten, or twenty or fifty feet from it. Out of a total of 120 rounds fired in that way there was only one bull's eye. If you will allow me I will read an extract from the report of the committee. I am anxious it should be clearly understood with what trouble we tried to attain accuracy with the guns; and I think I shall be able to show you the bearing it has upon the discussion in question. The extract from the committee's report which I wish to read is as follows:—"It being exceedingly difficult to employ targets for practice at longer range than 900 yards, of such dimensions as would catch all the shot, and thus ensure a complete record of the practice; and it having been found impossible, on account of the difficulty of assigning an exact value to a miss, to make a comparison of the accuracy of the various guns without a record of the position of every shot, the committee decided to test the relative accuracy of the guns by the same series of experiments by which their range was determined. In these experiments, the guns were placed in battery as nearly as possible, under like conditions, and were laid by spirit level. The position in which each shot fell on the sands was carefully noted. The competitors were then allowed to strike out a percentage of the shot from the records, the remainder of which formed a group. These groups were arranged in parallelograms calculated upon the law of probabilities according to the method usually adopted. The committee, however, were not satisfied with this expression of the practice of the guns as a representation of their comparative accuracy, but in order that their accuracy when tried at vertical targets might be compared, the committee, by a simple calculation sufficiently accurate for all practical purposes, based on the angle of descent of the projectiles, transferred the positions at which the shot struck on the horizontal plane of the sands to a vertical plane at the mean range of the group. By this means the horizontal target was, as it were, converted into a vertical target, on which the position of every shot was recorded, and its radial distance ascertained from the centre of the group." Now, we conducted some of that practice with 70-pounders, and the result is exceedingly instructive as to the probabilities of hitting the crest of a parapet. I find that with no elevation the mean range of 20 rounds was 484 yards, the mean radial distance 14 inches. I have roughly calculated what that 14 inches gave of mean horizontal error, and of mean vertical error. I find that it gave a mean horizontal error of 11 inches, and a mean vertical error of 8 inches. In the same manner, I find that with three degrees of elevation, and a mean range obtained from 30 rounds of 1,614 yards, the mean radial distance was 68 inches, the mean horizontal error being 47 inches, and the mean vertical error 49 inches. At 1,805 yards, with 4° of elevation, 30 rounds gave a mean radial distance of 89 inches, the mean horizontal error being 33 inches, and the mean vertical error 83 inches, and so on. At 7°, with a range of 3,025 yards, 34 rounds gave a mean radial distance of 430 inches, the mean horizontal error being 71 inches, and the mean vertical error 424 inches. I believe those figures are correct, but shall be very glad after they are in the shorthand writer's notes, if any gentleman will correct them. I also find that if a shot be fired from a distance of 400 yards from the level of the sea, at a battery 30 feet above the water, the shot when it arrives at that battery will be still ascending, and it will therefore be impossible to strike the superior slope of the battery at all. If it strikes the battery at all, it must strike the exterior slope. It is still ascending.

THE CHAIRMAN : With full charges ?

MAJOR GENERAL SIMMONS : with full charges, which is the condition under which ships fire at the batteries on shore.

COLONEL HUTCHINSON : What superior slope would that be ?

MAJOR GENERAL SIMMONS : About 1 in 20. In the same manner, I find that at 800 yards a shot fired at a battery 30 feet above the level of the water will be descending at an angle of about 1° 56′, or about 1 in 29½. That is a very moderate angle, and it must therefore strike very near the crest of the parapet in order to produce any effect ; and I doubt very much whether, in the case of well-rammed earth, if, falling at an angle of 1° 56′, it would not deflect from it without penetrating at all. If it was fired at 800 yards at a battery 120 feet above the water, the shot would be still ascending, and would not hit the superior slope at all. At 1,600 yards, a shot fired at a parapet 30 feet above the level of the sea would descend towards it at an angle of 3° 56′, and if the superior slope were calculated at that height, to strike a ship at a distance of 200 yards from it, then that shot would strike that superior slope at an angle of 6° 47′, or about 1 in 8, and would I believe if the earth were very well rammed, deflect from it, and not penetrate, because we know that it would deflect from water at that angle, and that earth offering a greater resistance than water will cause deflection at a higher angle. Of course if the shot struck very near the crest of the parapet, the resistance would not be sufficient to cause deflection ; but this only points to the necessity of a material with greater resisting powers for a distance of a few feet from the crest. I need not trouble you with all the figures I have here, but I have taken my calculations up to 3,000 yards, and found that at that range the angle of the descending shot would be 8° 52′ as fired at a battery 30 feet above the water, and would be 8° 16′ as fired at a battery 20 feet above the water. The probability is that these shot would penetrate the earth, because they would strike it at an angle of 11°. But I will ask any gentleman who has watched practice, especially after what I have said with reference to accuracy of fire and vertical deviation, what is the chance of a shot fired from an unstable platform like the deck of a ship, striking a battery at 1,600 yards or 1,800 yards so near the crest as to do any injury to it? I believe myself it would be absolutely throwing ammunition away to attempt it. It must be remembered that ships of war are generally equipped with 100 or 120 rounds of ammunition per gun, and that after an action they must still retain sufficient ammunition to fight their way home again; therefore, I believe, no officer commanding a ship of war would be warranted in throwing away her ammunition at 1,600 yards, on the chance of hitting within two or three feet of the crest of the battery, which is the only practical way of injuring it. I think this is an important consideration, with reference to the Moncrieff gun. I quite agree with Colonel Gallwey, that if a larger number of guns than there are in the defence can be established in batteries to attack a land front, the probability is that their superiority of fire will render it almost certain that the guns of the defence will be overcome, and then an ordinary parapet may be cut down. But I do not think, with the experience of the present day, that one ought to calculate upon parapets only 25 feet thick; on the contrary, they ought to be made very much stronger, and protected in other ways; moreover an attack from the sea is a very different thing from an attack on land. I find that one of the principal considerations which determined the positions of batteries, before the invention of rifled artillery, was the chance of hitting after ricochet. Now this chance with rifled artillery is almost *nil*. The flight of elongated shot after ricochet is so erratic, they cannot be depended upon at all. But it will be interesting to quote the opinion of one of our most experienced officers, Sir John Burgoyne, upon the chances of striking a coast battery, so far as they depend upon accurate elevation. At that time, 1851, there was a double chance of hitting the battery by direct impact, and after ricochet. He says, "The precision required in judging distances, regulating the accurate amount of elevation, &c, may be said to be unattainable afloat, and especially when opposed to fire, so that, practically, the effective exposure on the battery would be trifling." That extract is from a paper published in the Corps Papers, having reference to the height at which batteries should be erected for coast defences, in which he speaks of the elevation of the battery exposed to fire.

Well then, we have heard a good deal of the probabilities of hitting this Moncrieff gun as compared with the probabilities of hitting guns firing through embrasures. Having glanced through the notes of the last meeting, I find I said that the vulnerable area of an embrasure may be taken at 27 feet. That was contested at the last meeting but I think I have strong grounds for maintaining that opinion, and that we are perfectly warranted in considering a space within one foot of the embrasure as vulnerable space. If a 12-inch or 10-inch gun strike within that space of twelve inches I suspect that a large number of fragments would pass into the embrasure. There are Artillery officers present who will correct me if I am wrong, but I think, from what I have seen, that we may take twelve inches round the embrasure as vulnerable space, for the purposes of my argument. Of course, each officer may have his own opinion on that point, but I will go on with the reasoning which I will base upon it. The line I would take is this. A Moncrieff gun was fired the other day at Shoeburyness. I timed it myself, and found that it was exposed for eight seconds during each round. I think that is a *minimum*, the least time that we may calculate upon; a certain amount of time may be required to correct the laying of the gun. We may, therefore, increase that minimum considerably; but in order to be well within the mark I will put the time of exposure at twenty seconds, which may be taken as a *maximum* expression of the time that the gun will be exposed above the parapet. Well, with the gun in its firing position, the area of the target exposed above the parapet to direct fire, is about nine square feet. If the rate of fire be about one round in a minute and a half, it will be exposed for about one fifth of the whole time that the gun is in action. If the rate of fire from other guns is about a round in a minute and a half—and, I believe, when you take smoke into consideration, it will not much exceed that—if you multiply the vulnerable area of an embrasure (27 feet) by 5, it will make a product of 135 to represent the exposure to direct fire of the gun firing through a muzzle pivoting embrasure, as compared with the other, which is nine square feet through one fifth of the period, in fact, the relative exposure to direct fire of the two guns is as 9 to 135. Applying the same reasoning to oblique firing, or taking the most objectionable position in which a gun can be fired at, viz., from abreast, the area of the gun is about 120. Therefore the comparative exposure will be as 120 to 135. But I think there is another point to be claimed for the Moncrieff carriage, which is, that in the one case you have a permanent target upon which the guns may be laid, in the other you have the target only exposed for a very limited time. Therefore, I think, the chances of being missed are much more in favour of the Moncrieff carriage. Next, in considering the application of the Moncrieff carriage I will refer to one or two engineering points. There has been a good deal said about the difficulty of loading the gun; I think that difficulty may be got over. It is a desirable point that we should all endeavour, in adopting an invention of undoubted value, to assist the inventor in bringing it to the greatest perfection. I think this diffculty may be got over by adopting the system tried with great success at Shoeburyness some time ago with a 600-pounder, on an ordinary traversing carriage, by bringing the gun always to the same position to load. If this be done we may have opposite that position a contrivance of the nature of drain pipe, only not circular, laid into the parapet in which the rammer and sponge may remain. The gun being brought opposite to that pipe, the sponge or rammer can be passed down the gun readily, and after it has been loaded, thrown back into the pipe, and remain there until the next round. Then the gun pit being 12 feet deep, the shell recess or shell magazine may be close under the same position, so that the shell may be passed into the gun at once by some mechanical contrivance arranged at that point. I had an idea at one time that the shot or shell might be raised by the recoil of the gun into the loading position; but I now doubt whether that is practicable. At any rate, a mechanical contrivance may be arranged which will permit the loading to be carried on in that position, and thereby accelerate the fire, the gun being very easily traversed, as was the 23-ton gun at Shoeburyness. Then there is another position in which the Moncrieff carriage will be of great use to engineers, and of great advantage to the public by reducing expenditure; that is, as a substitute for cupolas. No doubt the cupola is a very clever invention, inasmuch as the gun is only exposed for a very short time whilst being fired; the cupola being then turned round, the gun is not exposed during the process of loading. But the cupola is as much open to the objection of injury from vertical fire as the Moncrieff carriage.

COLONEL JERVOIS: No, no.

MAJOR GENERAL SIMMONS: You can reply to that presently; it is very nearly as open to that objection, as the Moncrieff carriage. But the cupola has another great disadvantage, and I think we saw that in some experiments that were lately carried on at Gilkicker, when there were great difficulties in bringing up the shot from the magazines with sufficient rapidity to load the gun. If the cupola is not large enough to contain an expense store of 25 rounds per gun the projectiles will have to be brought up through the axis of the cupola. I believe myself from what happened at Gilkicker the other day that the process of bringing the shot up will retard the fire most seriously, and that if a Moncrieff gun be mounted within its recess it will be capable of being fired very much more rapidly than a gun in a cupola, and the expense will probably be little more than one-tenth of that of a cupola. I think that is a point for us, as engineers, to bear in mind when considering the relative advantages of the Moncrieff system.

When the Moncrieff system is exposed to the fire of ships it is very desirable, unless there is a very thick parapet indeed, or one that is well covered in front by a *glacis* or other raised work, that the parapet should be made very solid, and of a good, substantial, resisting material; and although I do not feel that apprehension which some others do as to the chances of the crest of the parapet being tipped by the shot, I should prefer having some hard substance in all cases near the wall that supports the interior of the parapet—concrete, or perhaps even iron concrete at the top—in order to throw the shot off. Although I do not attach that importance to the effects of horizontal fire that others do, still, the object being to keep the guns intact, to keep them in action as long as possible, I should like to see some solid substance of that sort placed for a few feet adjoining the interior revetment of the parapet. I do not know that I have anything more to say, and I apologise for detaining you so long.

General Lefroy: We are all of us rather apt in debate to use arguments that cut both ways, and my friend General Simmons has made that mistake in this instance. He has taken an exceedingly liberal margin of vulnerability round the embrasure of his iron fort, but apparently none at all round the Moncrieff pit. On exactly the same principles on which he makes the area of his embrasure 27 square feet, whereas the actual opening is only 9, so the area of the Moncrieff pit is increased from a diameter of 30 feet to 40 feet, that is from 700 to 1,300 square feet. Whatever it may be exactly, it is a very large margin, all the larger because dealing with a material so impressionable as earth instead of iron; and there can be no doubt that a shell falling on the margin of this earth a good many feet from the nominal crest will produce effects on the interior, when it would not do so in a parallel case against iron. I should like to know what becomes of the earth displaced by these shells. Of course, it is blown in bushels into the work itself, clogging its mechanism. There is nothing, it appears to me, so likely to disable the gun as to have a considerable quantity of well-rammed clay thrown into its delicate cogwork. A very small quantity would for a considerable time suspend the action; and it would require careful cleaning to get it in order. There is another consideration which I think is not quite kept in view in talking of probabilities. I am not going into figures, for it is a difficult problem, and to be of any value, it must be worked out with mathematical precision on sound data, and the results tabulated. It so happens that I have in my pocket an elaborate calculation by Captain Haig, R.A., which, in the original, has gone over a great many sheets of foolscap, to prove what the probabilities of mortar fire are in these cases; I will not, now, however, attempt to go into the question. What I beg to observe is, that probabilities are not distinguishable from certainties if you only fire long enough. We are talking of firing five or ten rounds as at Shoeburyness, but you must multiply that by 50 or 60, and then where is your security. We must contemplate a whole circle of vessels, each of them carrying 100 or 120 rounds of ammunition per gun, firing at the same object all day long, with nothing else to do. In that case, the probability disappears; it virtually becomes a certainty that some shells will take effect, and the immunity of these pieces from the effect of fire of that description disappears. I beg to say I am not here opposing the Moncrieff system, I only oppose those extravagant claims which have been made for its immunity from the accidents and chances of Artillery fire. It may be safer than something else,—I do not venture to say it is not; what I contend is, that it has not that amount of security which will enable us to fold our arms and thank Heaven we are now safe. When you have got your guns into this position you will still not be free from a good many accidents that you are now liable to. That is the whole of my argument. I was present at those experiments at Newhaven which Colonel Gallwey has referred to, and, as he says, we really met with extreme difficulty in ascertaining what was the amount of crater displaced by 10 lbs. or 15 lbs. of powder bursting in a shell. But we saw enough to make it appear that nothing in the world was so easy,—in fact it was an accepted axiom at that time,—that we could cut down any parapet. If you can cut down a six feet parapet, how much easier it would be to cut down a twelve feet parapet? It appears to me, beyond a doubt, that these earthen parapets of Captain Moncrieff would melt down and disappear, exposing the carriages behind them, if subjected to anything like a steady fire.*

COLONEL JERVOIS, R.E.: I have only one or two remarks to make. I was about to observe to the same effect that General Lefroy has just done, on the remarkable difficulty that General Simmons finds in hitting the crest of a Moncrieff gun pit, which is 22 feet long and 3 feet high, and the remarkable facility with which he hits an embrasure 2 feet 5 inches wide and 3 feet 11 inches high, when it is in iron. I think the elaborate calculations made by him will apply to the one case as well as the other. As regards the immunity from vertical fire, which he considers to be possessed by the Moncrieff gun pit, as compared with the turret, it is only necessary to remark that the turret is covered over with iron, and may be covered with iron to any required extent, whilst the gunpit has no cover at all overhead. I should like to know if shell were to tumble upon the 22 feet area we are speaking of, whether you would not all rather prefer having iron over your head than being without it? As regards the employment of a Moncrieff gun-pit in preference to a turret, upon the ground of expense, where the Moncrieff system is applicable, there cannot be two opinions. There are, however, some cases in which it will be found still desirable to employ turrets notwithstanding the expense. The observations made by General Simmons on the saving that can be effected are gathered from designs which have been prepared in the Fortification Department, and I think he has taken a very correct view as regards the economy which may be effected by them. One other remark, as regards the saving

* It is hoped that Captain Haig will extend and publish his calculations. He found from the result of 60 rounds of a 13-inch mortar, fired on land, that the probability of striking any one of five circles, of eleven yards diameter, grouped round a centre point, which is a point of mean impact at a distance of 24 yards, is 0·0255, for a mean range of 2,000 yards. The chance of striking a single circle at that distance he found 0·0061. The substitution of a rifled howitzer for a mortar (the practice being very limited in extent), gives greatly increased chances, viz.:

At 30 Deg.	Range	2,476	yards	P =	·050
" 35 Deg.	"	2,575	"	"	·030
" 40 Deg.	"	2,704	"	"	·024
" 45 Deg.	"	2,612	"	"	·024

of expense that may in some cases be effected by the employment of Moncrieff gun-pits instead of turrets. I did not quite gather from the remarks of General Simmons with regard to the point started by Colonel Gallwey, what in his opinion is the precise construction of a parapet that he recommends to meet the difficulties suggested by the latter officer. He said that if the parapet is prolonged to the *glacis* beyond it the difficulty is met. I do not admit that that is so. The crest remains the same, and the work must be strengthened by material of some more expensive character than that which he advocates the use of. It appears to me that the criticism started by Colonel Gallwey deserves full consideration.

LIEUTENANT ARDAGH, R.E.: I should like to allude to one portion of the mechanism of the Moncrieff carriage, which has not, perhaps, been sufficiently noticed. If a mass of matter receives a blow in a direction not passing through its centre of gravity, that blow will produce a combined motion of rotation and translation, and for each subsequent position of the mass, there exists a point called *the instantaneous centre of rotation*, around which the particles of the mass at that moment revolve. To represent the carriage in its simplest form, we will suppose that the vertical diameter of this circle is the perpendicular let fall from the centre of the trunnions of the gun to the point of support of the rocking carriage when the gun is in its highest position ; and that the weights of the gun and counterpoise are equal, and are concentrated at the opposite extremities of this diameter. If an impact be communicated to this structure in a line tangential to the circle at its highest point, the tangent at its lowest point will be the locus of the instantaneous centre of rotation, and the circle will roll along the plane without any tendency to slip. In this lies the great beauty of the invention. The stud and rack arrangement on the curve of the carriage has practically no horizontal strain upon it such as that of the recoil on an ordinary platform, and it is only needed to give steadiness to the motion. If the gun were fired on the smoothest ice, it would hardly move from its position, so small is the horizontal strain.

COLONEL GALLWEY : Supposing a gun on the Moncrieff carriage was fired with reduced charges to produce curved fire, would it recoil ? I know that the service charge of a 7-inch breach-loading gun used to be 11 lbs. ; and the reduced charge to produce curved fire was 3 lbs.

GENERAL LEFROY : It could be worked down. If the recoil does not take it under cover it can be worked down with great rapidity.

LIEUT. COLONEL RICH, R.E. : It appears to me that the whole mistake of this discussion is, that we are comparing the Moncrieff carriage with other apparatus to which it is not at all, and ought not, to be compared ; that is to say, we should not compare this invention with casemates, which have protection from vertical fire. The Moncrieff carriage has no protection from above, and therefore it is not a fair comparison. It has also been compared with the cupola. We must admit that where it takes the place of the barbette gun, there is no doubt as to its very great advantage in every respect ; and I do not think anything has been advanced against it when used in that way. Again, when it gets rid of the embrazure, which it will in many of the coast defences, it gets rid of one of the great difficulties we have all met with in the repair of works, not only by the damage done by the enemy, but from the damage done by our own firing. Therefore, it is in that respect of inestimable value. As regards destroying the pit, which has been urged as easy by Colonel Gallwey, and urged as impossible by General Simmons, I think both are perhaps equally wide in their error. I believe if this gun is put as a coast defence, not behind a parapet at all, but if the whole parapet is merely the surface of the ground ordinarily smooth, like a glacis, it will be found almost impracticable to hit the interior crest, just at the place from whence those bushels of earth are to be driven into the cog machinery ; and even if a little earth is blown into the cog machinery, I doubt its interfering at all, or more than a very little, with the movement. If the gun is put behind a *glacis* of that kind, it will be impracticable to blow in the interior crest, for this reason. It is allowed that if the artillery cannot see where their shot drop, so as to be able to correct their fire, their fire becomes very lame indeed, and if it is behind a glacis of unlimited extent, say from 100 feet to 200 feet, they will not know whether their shot drop within 10 feet or 50 feet of the gun, and they will not be able to correct their fire, and the consequence is this interior crest will in all probability remain undamaged. I presume that it is not intended to be made of loose earth, because in that case, the very movement of the men serving the gun would crumble it down. There must be some revetment on the inside to keep it in its proper place. If we take it under these conditions, it appears to me an invention of great value, and of great service to us, but not one to supplant casemates, or iron shields, or cupolas, which are all of great value in their respective places.

CAPTAIN MARSH, R.E. : There appears to be a point in the application of this system as regards the weight of the whole structure. We have only the 7-ton gun, and that with carriage and platform is admitted to weigh about 25 tons. Directly Capt. Moncrieff was challenged to do so, he fitted that gun up, and it is a complete success as regards artillery practice. It has been argued that such a gun might possibly move laterally along the parapet. It may be fairly said that the larger guns will not, but that they will be stationary ; therefore, they must be subjected to all the accuracy of fire that can be brought to bear upon them. I think we may assume that the 7-ton guns and the guns above that weight will not be moveable, but will be fixtures. But to my mind the application of this system is much more important to guns below 7 tons. The effect of the whole recoil being absorbed by the gun carriage itself, renders it very moveable indeed. Taking the 40-pdr. as a type of the siege gun, which weighs about 32 cwt., we then have about 6 to 7 tons for the whole apparatus, the weight of an ordinary locomotive to move it being from 10 to 12 tons. I conceive there will be no difficulty whatever in laying the rails in an enfilade battery, so as to enable a Moncrieff mounted gun to fire from different points within an arc of 60 yards in length at a distance of 600 yards, so as to enfilade a face of a bastion every time. That is why I think it brings the attack up to the level of what it was before. The immense advantage of position that will be given by the use of the Moncrieff gun more than counterbalances the action of such guns in the defence. I certainly think the use of guns of the type of the 40-pdr. in the defence of the land works will be of immense service. The object will be to fight such guns in battery, to concentrate a heavy fire on any point of great annoyance, and then disperse the guns again. I believe that will be quite feasible, and highly advantageous to the defence. I should like to make one remark as regards the gun of position. At the present time it has been stated with very great weight, that there will be no gun of position upon which the Moncrieff principle will be applied. I cannot understand that. I think the very fact of the Moncrieff principle undertaking to give a gun the power to rise up from two to three feet if required, and to do that without any strain or material destructive force upon the carriage itself, is dead against such an assertion. I think if the principle is adapted to the field gun, it opens a very large range of ground which has previously been considered unfit for the action of artillery altogether. Take the case of the 12-pdr. for instance, which weighs some 8 or 9 cwt. When Captain Moncrieff comes to deal with that gun, he has only got to restrain it in the lower position until it is necessary to elevate it. I believe he will do that in some way without adding a pound weight to the gun, and that it can be then either elevated if required, or always lying at the usual height of three feet or thereabouts. I cannot, therefore, but think that Captain Moncrieff has heretofore been in a position of great difficulty. He has had to concentrate the whole of his invention into one type, in order to get it fairly tested or considered. That is a position of great difficulty, and we ought all to hope that he may soon have a much wider field and much greater assistance in interpreting and applying his invention. I may mention my conviction that those large guns of seven tons and upwards will never be applied in their present form. I think the moment we look at that enormous lateral surface which was stated to be 35 square feet, which is composed of a continued structure, we see that the principle there, of Captain Moncrieff's invention, is a series of beautifully applied levers, carrying a great weight in their arms as a counterbalance ; and I think in practice, when it is decided that those guns are immoveable, so to speak, from a certain circle, that the weight will be at once detached and put underneath in a pit ; that it will carry with it the winch and various other things that have to control that weight ; and that then there will be nothing left but a skeleton of the great arms and levers of that carriage, and it will stand up, so to speak, in a naked condition. The whole weight will go below, and then it will appear in a much more favourable form. Captain Moncrieff mentioned at one of the meetings, that he had considered this question of detaching the counterbalance, and I believe that will be the eventual application of the system to these heavy guns.

LIEUT. COLONEL HUTCHINSON, R.E. : I should like to ask General Simmons one question about what he said. He alluded to the difficulty of cutting down the crest of a parapet, if made with a very gentle slope. I do not know whether he applied that remark to land defences, or only to sea batteries, because if applied to land defences, it would, of course, at once do away with musketry fire on the covered way.

MAJOR GENERAL SIMMONS : I have been considering the subject specially with with reference to sea defences. If you arrange the superior slope of a battery at a height of 30 feet above the sea, to strike the water at a distance of 200 yards, it would require a slope of 1 in 20. If a battery were 120 feet above the sea, and arranged for the guns to strike the level of the sea at 400 yards, a superior slope of 1 in 10 would be necessary. But with reference to land defences, adopting the principle of the screen battery, you will certainly lose your musketry fire from the main work on the ground in front, and you will probably have to provide for it by means of a covered way, unless you can obtain it by a flanking fire.

COLONEL GALLWEY : I have only one word to say with regard to General Simmons's remarks. It is a fact that that breach was not made by Shoeburyness gunners, but by a detachment of gunners from Dover, who had never seen a rifled gun before I believe, and the gun was by no means a favourite with many people.

MAJOR GENERAL SIMMONS : It was the 110-pounder.

COLONEL GALLWEY : But a more magnificent shell gun perhaps was never known, certainly not up to that time. The breach shewn in the sketch was made by it. Its shells, containing 8 lbs. bursting charge, tore through a 25 feet parapet in two hours and a half, with an expenditure of 70 shells, of which one fourth were blind. Now, if we are not guided by experiments like this, what are we to look to? The fact is we never see shells bursting. Those blind shells, which were fired near and about the parapets at Shoeburyness, teach nothing at all; but if they had been full of powder hey would have told a very different tale.

ADMIRAL SIR FREDERICK GREY: There is one question I should like to ask Capt. Marsh. As to the advantage of being able to move these guns, does that apply to an ordinary work? I believe the usual practice has been, on the recommendations of committees in 1853 and 1861, to mount guns in pairs, with traverses between. I presume upon any point of attack a work would be fully armed. I am at a loss, therefore, to understand what would be gained by being able to move a gun along a line of defence which is already fully armed, or how guns can be moved along without giving up the protection of the traverses, which are there already, and which have been thought necessary hitherto.

THE CHAIRMAN: Captain Marsh, did you allude more to the attack or to the defence?

CAPTAIN MARSH: I meant the attack and defence.

ADMIRAL GREY: I beg your pardon; I misunderstood you.

MAJOR GENERAL SIMMONS: I think, with reference to the question put by Sir Frederick Grey, one may say this, that granting that the front that is attacked is fully armed with guns firing through embrasures, and is traversed between every two guns, the probability is, that as no attack would be undertaken without a preponderance of Artillery, the assailants would most likely have one-and-a-half or two guns to every one gun in the defence. The probability then is that the guns mounted at the first period of the attack would be very soon silenced. But where I think the Moncrieff gun will be of great value is towards the end of the siege. I took the liberty of saying in the last evening's discussion that I think that towards the end of a siege a single gun in the defence is worth fifty at the beginning of the siege. All that any number of guns in the defence entails upon the assailants in the first stage of the attack is, that they shall have a superiority when they first open fire. Then, when the attack has proceeded, and the period has arrived when it is necessary to resort to the sap, a single gun is of very great value. Now, I believe it would be impossible with the present extended use of rifled guns and small arms to keep a gun to fire through an embrasure. When the works of attack are brought within two or three hundred yards, if you had a Moncrieff gun mounted, you would remove your traverses and lay a rail down, and your single gun so mounted would be of immense value.

ADMIRAL SIR FREDERICK GREY: General Simmons has entirely misunderstood what I said. I made no comparison between the Moncrieff gun and embrasures. I asked a simple question, believing it had been recommended to move guns along a line of defence. I only asked how that was practicable; but I never went into the question of comparing guns fired through embrasures with the Moncrieff guns. I did not see, and I am not yet informed, how you propose to move the guns from one part of the line to the other if you have traverses between them. One word more. I at once say that I misapprehended what Captain Marsh said. I thought this system of moving the guns was considered to be applicable to the defence as well as to the attack.

CAPTAIN MARSH : So I meant. I think it is very applicable to the defence as well as to the attack. I think the whole arrangement of traverses must be modified. In the defence of land works it may be considered whether the guns shall not remain in a totally different position, and then be brought out and massed in batteries where required.

COLONEL JERVOIS : You do away with round pits then ?

CAPTAIN MARSH : Entirely. The French have always attached great importance to the mobility of their artillery in a fortress. It has been argued by distinguished French officers, that nothing should be immovable except the ditch and its defences ; that everything else should be considered movable, and capable of being dealt with according to the development of the attack.

COLONEL CHESNEY : As I was the first person to introduce the subject of "guns of position," let me say that I did it of a purpose, because I believe there are no worse enemies to the Moncrieff system than those who would extend it to any operation of war to which it has no application whatever. You must stop somewhere in using so peculiar a system as this is. It is quite evident no one will apply it to a pocket pistol, or to a breach loader for shooting partridges ; and I would add, that taking into consideration the practical difficulties in war, where you have to move guns frequently over great distances, there can never be any possible instance in which the Moncrieff system, which increases greatly the weight of the carriage, will be of sufficient value to make up for the great extra trouble which it will give you. In the attack of a fortification, you always have to prepare the ground over which you have to move your guns, and you have probably some sort of mechanical means by which to move them to their proper places. In war, you must take the ground rough as it is, and you very rarely can have any means but the simple labour of horses, supplemented more or less by that, in some cases, of men. That being the case, and as far as we know of the system, one of its principle features being certainly to increase greatly the weight of the carriage, and it also being a fact that although nations have been preparing guns of position for centuries past, they have seldom used them ; (for example, in our own last great continental campaign, when we had prepared a battery of that kind, we left it thirty-five miles off the field of battle, because it was too troublesome to bring up) ; taking these joint conditions into consideration, it is not probable, although perhaps it may by some be supposed within the range of possibility, that this system will be applied to any such operations as those of the open field. Having said thus much on a special point, I will add, that I do think it is the feeling of all here that this discussion should now be brought to some kind of a close. Were it in order for some one to move a simple resolution to the general effect,—"That the Moncrieff system has introduced a new principle "into fortification, which is worthy the attention of all who have to erect fortifica-"tions and all who have to attack them."—I believe such a resolution would meet with the approval of a large majority of those who have attended this and the former meetings.

THE CHAIRMAN : I do not think it is in our place to move such a resolution. We meet simply as a *corps* to discuss these questions. We have been favoured by the presence of a number of guests, Artillerists and others, but I do not think it is our place to move a resolution.

COLONEL CHESNEY : I sit down corrected. I only thought it necessary to bring the discussion to a close in some formal manner.

CAPTAIN SELWYN, R.N.: May I ask a question of Colonel Gallwey for information as a naval officer? Is it not generally supposed that we have only to calculate and prepare the line of least resistance, in order to cause the upward bursting of the shell to take place in any direction we please; that it is a matter of the resistance being least in the line in which we wish the shell should form its crater?

COLONEL GALLWEY: I do not quite understand the question put. What I wished to point out was that the action of an old spherical shell falling in earth, and bursting after a short time, produces a very different effect from what I saw at Newhaven, where the shell burst on its passage through the parapet, blowing away the earth. I never saw such an effect produced with spherical shells.

CAPTAIN SELWYN: How far did it penetrate?

COLONEL GALLWEY: About 6 or 7 feet before bursting.

THE CHAIRMAN: What was the range?

COLONEL GALLWEY: 1060 yards. The old idea was that the earth would be tossed here and there, but not altogether got rid of, and such would probably be the case if the fire were directed at the *exterior crest and slope*. The plan adopted by the committee of firing at and near the *interior crest*, realized a very different effect, as, if I remember rightly, the first ten shells produced a breach 12 feet wide, in addition to the damage done by the many fragments of the shell carrying destruction into the work.

CAPTAIN SELWYN, R.N.: With my senior officer's permission I should like to be allowed to continue the remarks that I made at a former meeting, with reference to the naval question as it appears to us. First of all the navy feels very strongly all these delays. Our ships are being built with reference to existing forms of carriages and existing methods of raising and lowering guns, and carrying them; and it is quite possible that as soon as attention is turned to the development of this principle, the present forms may be altered. I do not regard this principle as necessarily to be carried out by the use of weight, with which it has nothing earthly to do. Weight is only one form of power that is applied to counterpoise the recoil of a gun. There are many other forms of power besides this which will come in in their proper place. We are waiting for all this, and we do hope that there will not be any unnecessary delay, or confounding of parsimony with economy; and that although the experimental vote is cut down from £12,000 to £2,000, per annum, it will not be allowed to interfere so much with all experiments that we shall do everthing in the wrong way for want of money to be spent in experimenting. With regard to the modes of attack which have been referred to, those are points which a naval officer may be fairly permitted to take an interest in. I took the pains to go and look at a very excellent model which we have in the United Service Institution, of the harbour of Plymouth, and I saw there an entirely vulnerable point of attack, from which the dockyard can be set in flames from beyond Rame Head without going near the larger forts at all. There is only one small fort near there. If a Moncrieff gun-pit were established at that spot, even as inefficiently as at Shoeburyness, no iron-clad would dare to go in where her deck would be exposed to shot from Rame Head. If on a long line of exposed sea-beach, where an attack might be apprehended, a railway be made with the power of shunting common to all railways, and which consequently may be made to take a gun between the traverses, as well as in any other direction, if on that line of defence we never know where to expect a gun, most undoubtedly, that gun becomes very formidable. It may not be advisable to sacrifice many guns to arm

Fig 1.

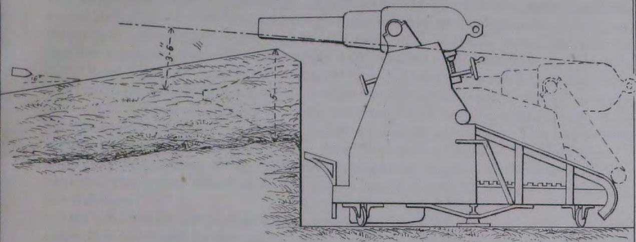


Fig 2.

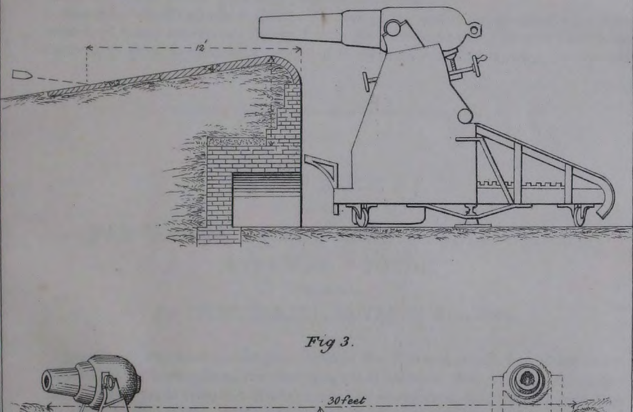
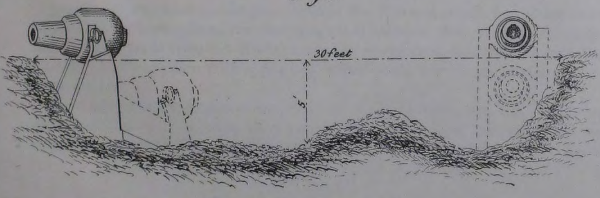
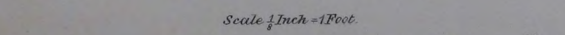


Fig 3.



Scale $\frac{1}{8}$ Inch = 1 Foot.



Lithographed at the Royal Artillery Institution.

the whole work, yet I think one or two guns may be made very efficient and very formidable to a vessel approaching. I was surprised to see in the paper that Lieutenant Ardagh read, that he thinks the gun pits will cost as much as a Martello tower. If anybody will take the tower out of the ditch of a Martello tower, and give me that for a gun-pit, I should be extremely well satisfied ; but I conceive the Martello tower must have cost something to put it there. There are known to this government methods of attack to which all forts situated near the water's edge are specially liable, and against which they have no defence, which require neither ships, shot, nor guns ; and yet which will render the forts entirely untenable. This has become matter of notoriety. It has been for a long time in the hands of the government ; and I do say that these things, however they may be suppressed for a time, in obedience to the policy which rules the nation, ought not to be ignored in preparing our defences.

THE CHAIRMAN : It is about time we should break off for the night. I do not know that there will be any use in having another discussion upon this subject, at all events, not for the present. I think we have elicited many opinions, and rather varied ones, upon this topic, and that we all know so much of it that it is not expedient we should continue the subject by naming another meeting for it, unless something more is likely to be elicited. I do not know whether gentlemen agree with me, but this is my opinion. (Hear, hear.) We are very much obliged to all the officers of the Navy and Artillery for their presence and remarks.

ADMIRAL SIR FREDERICK GREY : Perhaps on the part of the strangers who have come here, I may express our thanks for the great kindness with which we have been received, in being allowed to be present at this discussion and to express our opinions.

PAPER II.

DEMOLITION OF THE IRON PADDLE-WHEEL STEAMER "FOYLE."

BY LIEUT. JEKYLL, ROYAL ENGINEERS.

The Foyle was sunk in the year 1866 in the Thames, about two miles below Woolwich, by having been run into by another steamer. She went down at a distance of 150 yards from the Essex shore, and rested on a bank of hard mud (see Pl. I). She was laden with a cargo of bacon, hams, butter, and similar articles from Ireland.

Soon after the occurrence attempts were made to raise her, but, being conducted on too small a scale, they proved fruitless. After this, a considerable time was permitted to elapse before endeavours to lift her were renewed, and when operations were commenced in earnest it was found that the ship's back was broken amidships. It was, however, decided to continue the works, and, if possible, raise the two pieces separately.

For this purpose divers were engaged, who succeeded after some time in passing chains under her bottom at several places. A number of large lighters were then brought down, and the ends of the chains on both sides of the ship were secured to them, and hove tight at low water. By this means, the rising tide, floating up the lighters, brought a great lifting strain upon the chains.

When a lifting power of 1,000 tons had in this way been gained, the chains gave way; it was then considered impossible to raise the ship by this means, as the largest chains that could be procured had been broken without apparently moving her at all.

As it was now obviously impossible to save the ship, workmen were employed in cutting away all parts of her that were within reach, and in removing as much as possible of the machinery. A good many of the brass pipes were disconnected and brought up at low water, but none of the massive parts of the engines could be moved. Before condemning the ship to be broken up, an attempt was made to lift out the engines and boilers. For this purpose, the large beams which held down the latter were cut through and removed, and lifting power was brought to bear, but they were so firmly secured to the bottom that the chains were again broken.

The wreck being a considerable obstruction to navigation and a constant source of expense, the Thames Conservancy Board resolved to blow her up, as being the easiest and cheapest way of getting rid of her. They accordingly procured suitable powder cases, and began by sinking two charges of 120 lbs. of powder in the after-hold of the vessel. One of the charges got wet, and the other, fired with Bickford's fuze, did very little execution, merely blowing off a portion of the deck, and making a hole in the starboard quarter. Perceiving from this result that destruction of the ship was by no means easy, the Board applied to the War Office to have the work carried out by the Royal Engineers.

On the 18th May, 1868, a party, consisting of one officer, one sergeant, and five Sappers, was despatched from Chatham, taking with them two complete sets of diving apparatus (Siebe's diving dresses) and electrical gear for firing charges under water, consisting of a frictional machine, a small galvanic battery and galvanometer for testing, a quantity of insulated wire, and other stores of a similar nature; these were taken to the wharf at Woolwich, and from thence transported to one of the lighters, which were moored to indicate the position of the wreck.

The party was accompanied by the Admiralty diver at Chatham Dockyard.

The next day an examination of the wreck was made at low water, and the diver went down to ascertain the state of her bottom, and of the mud. At low water, the deck from the break amidships to the bow was nearly all uncovered; towards the stern, however, the ship appeared to have sunk more; still she remained quite upright, and it was said that at dead low water spring tides, the level of the deck was visible all round. The bulwarks had been cut away. On sounding round her sides, it was found that she had sunk very little into the mud, and that the run of the strong tide had scoured a channel on each side of her, raising the mud so removed into a mound a short distance from each side (vide Pl. II., Fig. 3).

The diver went down opposite the engines on the starboard side, and walked from thence both towards head and stern. He found the bottom quite hard and free from obstruction, with the exception of large lumps of peat, which were scattered about at the bottom. He found the chains at intervals which had been used in attempting to raise the ship. On the following day he dived on the port side, finding the same chains as the day before coming under the ship's bottom; the ground was smoother than on the other side.

In this part of the Thames diving is a matter of great difficulty, for, owing to the discolouration of the water, it is perfectly dark at the bottom, and all work has to be done by feeling alone. In addition to this, the tides run so strong at this particular spot that the time during which a diver can work is reduced to two hours at the outside.

As the ship lay to a certain extent across the current one side was always tolerably sheltered from its force, so that the diver always worked on the starboard side with the ebb tide, and the port side with the flood.

The result of the examination showed that the ship was perfectly sound, with the exception of the break and the hole in the starboard quarter, caused by the first explosion. She was somewhat old, having been built in 1848 (at Greenock), but very strong. She was constructed entirely of ½-inch iron plates, riveted, and supported internally by angle irons at intervals of 2 feet, throughout her entire length. There were two strong bulkheads, one forward of the engines, and the other abaft the boilers; the centre of the ship was moreover strengthened with box girders 18 inches square, crossing from side to side, and secured as well to longitudinal girders of the same description, but of smaller size.

The standing part of the engines was secured to these girders, and to similar girders at the bottom, and consisted of heavy cast-iron beams and cross pieces, to which were secured cap squares, sockets, &c., &c., to receive the moving parts of the engines. Being a paddle steamer, the engines were of course double, with oscillating cylinders.

Both the fore and after parts of the ship were nearly full of fine soft mud, which had been held in suspension, and deposited by the water.

The Thames Conservancy Board requested that the after part only might be destroyed, as they were confident of being able to lift the fore part entire, provided the keel was broken through.

The plan for breaking up the after part was, to place 6 charges of 300 lbs. of powder each, in pairs, one of each pair being on either side. The charges were all to be placed outside, and as low as possible; they were to be secured to the chains which were already under the ship's bottom.

For such large charges as 300 lbs., it was necessary to provide special cases. One of these is shewn in Pl. II., Fig. 4, 5 and 6. It was 38 inches long, 24 inches in diameter, cylindrical, and made of $\frac{1}{4}$-inch boiler plate, riveted. The top came off entire, being held down by a number of nuts and screws round the edge, with an india rubber washer to keep it water tight. In the centre of the top was the tube, through which the insulated wires passed out from the fuze; it was made of thin sheet iron $1\frac{1}{4}$ inch diameter, and bell mouthed, so as not to chafe the insulation of the cable. The manufacturer inserted the tube into a small plate 8 inches diameter, which was subsequently screwed down with an india rubber washer; but this arrangement was an unnecessary complication. Two stout bands passed round the case at top and bottom each supporting a ring. A chain shackled between these rings afforded the means of mooring the charge.

The charge itself, containing two Abel's fuzes, was held in a vulcanized india rubber bag, of the form proposed by Captain Steward, R E , and sealed up with india rubber solution, so as to be perfectly water-tight. It was then deposited in the iron case, which was sealed up at the mouth with pitch, tallow, and bees' wax, and was thus probably also water-tight. Thus, a double security against leakage was obtained, the necessity for which was subsequently apparent.

A charge complete weighed as follows:—

	cwt.	qr.	lbs.
Iron Case	3	1	15
Powder	2	2	20
Bag	0	0	5
Total	6	0	12

The charges were all loaded in the second lighter, which was not used for anything else, and in which there was no fire; the pitch, when required hot, was heated in the other lighter and brought over. A charge could be loaded by two men in an hour.

To lift the heavy cases out of the lighter, a pair of sheers was rigged with two 40-feet poles, and a double block-tackle. An anchor boat, provided with a crane at her bow, was used in lowering the charges overboard. Another boat of about the same size contained the diving party, with their pumps and other apparatus; and a small boat was devoted to the electricians. Much trouble was saved by keeping them all separate. When charges had been lowered, the testing and firing were done from one of the lighters.

On the 17th June, preparations were made to lodge the first pair of charges.

These were A and B (Pl. II.,Fig. 2.) A small chain was found by the diver, first on the starboard side, and afterwards, recognized by its size, on the port-side. The ends of this chain did not pass up the sides of the ship, and on to the deck, but lay on the surface of the mud. It was inferred, that like all the rest, this chain passed under the bottom in a direction perpendicular to the keel, and it was not until the charges had been fired that such was discovered not to be the case. The two charges were consequently not opposite, A was by the side of the boilers, and B by the engines.

The charges were moored in the following manner:—

The diver, at low water, attached a snatch block to the chain on each side of the ship. He lashed the blocks as close to the mud as possible. A 2-inch rope having been previously rove through the block, the two ends were secured to a buoy. A powder case was then brought off from the loading lighter, in the anchor boat, and the centre ring of its chain tied to one end of the 2-inch rope. By hauling on the other end, the charge was brought to its proper place. The diver next went down and lashed it to the chain, at the same time, releasing the block by means of which it had been hauled down. The same arrangement was then carried out on the other side.

The time of slack water was just sufficient to enable two charges to be properly lodged.

The electrical connections were then made. From each case two wires proceeded, from A the line wire leading to the lighter, and a piece about 20 yards in length brought up on deck, and from B a short piece going to earth, and a length of 20 yards also on the deck. The two 20 yard lengths were connected with an insulated joint, which completed the connections. There were four fuzes in circuit. The line wire was stapled down to the deck, as far as possible, and then stoppered to a strong rope so as to take all strain off it, for on one occasion a strong cable was broken by the mere force of the tide.

The first attempt to get down the charges A and B was unsuccessful; the olocks had been lashed, and the ends of the ropes buoyed at low water, but as there was then no time to secure the charges, this was left till high water.

The charges were about 150 lbs. lighter than their own bulk of water, and consequently had considerable buoyancy, so that in hauling down A, the upward strain on the chain was sufficiently great to pull a certain length of it through, under the ship's bottom, and when the diver went down to lash the charge he found the block, not where he had lashed it on the mud level, but half way up the ship's side. It was useless to fire the charge in this position, and impossible to put it right in time or to get the other down, so it was hauled up again, and kept until low water in the evening.

At the second attempt the chain was first secured from slipping, and the blocks lashed afresh. The charges were then lodged at low water early on the following morning (19th).

At high water (1 p.m.) preparations were made for firing, and the cable tested for insulation. The galvanometer indicated a considerable leak, which was, however, stopped by generating hydrogen in the leak with the galvanic battery, by the decomposition of water at that spot. The frictional machine was used for firing, and the explosion took place very satisfactorily. Very little disturbance appeared on the surface, owing to the depth of water, 37 feet, but quantities of timbers floated up, and much mud.

The effects of the explosion were examined at low water. At A a breach was found in the bottom, extending for 20 feet, at the level of the mud, and reaching to the gunwale in the form of a rent. The iron plates were much torn and jagged, and whole rows of rivets knocked out at some distance. Charge B had not exploded; there must have been a leak in the cable between the two charges, forming an earth by which the current returned to the battery without reaching the second charge. The wire leading to B being tested, was so unsatisfactory that it was thought advisable to get the charge up and examine the cable along its entire length. No defect could be found. On the charge being brought to the surface it was evident that the iron case was full of water; however the tide would not afford time to open it, and see if the charge was wet, it was therefore determined to lower it again, and trusting to the waterproof bag, to try and fire it. The cable was stapled down as before, and the end brought on board the barge, the indications of the galvanometer being still far from satisfactory. Fortunately the great power of the high tension electricity was sufficient to overcome the leak, and the charge went off as well as the other. The depth of water was 36 feet.

Subsequent examination showed that this charge, though in contact with the ship's bottom, made no hole at all, as not even a crack could be found in the side.

This must have been owing to its position, opposite the strong girders and heavy cast iron work of the engines; still the discovery was almost startling; although no breach had been made the machinery gave unmistakeable signs of having been shaken, the massive cast iron beams were broken across in many places, and portions of the engine-room floor came up; moreover, the ship's side, for a distance of 40 or 50 feet, was sensibly bulged in.

About half of the iron case which held the charge was found and slung by the diver; it seemed to have opened by tearing along its entire length; both heads were blown out.

The next pair of charges were C and D. No blocks were required for these, for the links of the chain were so large that a 2 inch rope would run if rove through a link; this was accordingly done by the diver, and the two charges, 300 lbs. each, were successfully lowered and secured at noon on the 26th. They were fired the same evening, the connections made being as before. At the next low water the effect of these charges was seen to have been very great. Independently of the actual spot where the charges had been, the explosion had lifted the entire stern half of the vessel and let it drop. The machinery, nearly 50 feet away from the charges was greatly shattered, and the beams, cracked by the previous discharge, were separated and contorted and quite removed from their proper positions.

Under the water, charge C had made no break as A had done, but a rent, not much above the mud level, extended from A to within 12 feet of the stern post, running into the hole in the starboard quarter which has been spoken of before.

D had made an immense hole, not less than 25 feet wide, above which the ship's side had fallen outwards, and remained parallel with the bottom, a little distance above it. In examining this part the diver became entangled among the torn plates, and extricated himself with considerable difficulty. In the absolute darkness and strong current of the Thames, diving in such a situation becomes extremely hazardous.

C and D were fired in 38 feet of water.

Two small charges of 130 lbs. each were next prepared and sunk; (*a* and *b* on plan.)

The cases for these were of ordinary sheet tin,* and much too weak, so much so, that it was difficult to handle them when full without tearing them. Of these two, *b* only exploded, *a* was found to be full of water. The fuze had fired. Depth of water 26 feet. These charges were fired on the 30th.

On the following day another charge of 130 lbs. was put down singly on the starboard side (*d* on plan.) It was fired soon after low water, in 24 feet of water, and helped to loosen the starboard side. The port side was sufficiently shattered already.

Another charge of 130 lbs., (E on plan), was placed inside the cabin on the 2nd July; it blew out and almost detached the entire starboard side. Owing to the quantity of broken iron, it was impossible for the diver to go down and examine the effects.

Seeing the small effect of charge B it was determined to try the result of a charge of gun cotton lodged at that spot. One of the iron cases and one india-rubber bag were therefore taken to the Arsenal, where they were loaded with gun cotton by Mr. Brown, assistant to Mr. Abel, chemist to the War Department. The bag, capable of containing 340 lbs. of powder, held 230 lbs. of gun cotton in the form of compressed discs, a charge calculated as nearly equivalent to 1000 lbs. of powder.

This charge was sunk early on the morning of the 3rd, and fired at high water of the same day (noon). The head of water was 37 feet. The explosion was very different from that of powder, being much more sudden and violent. The disturbance on the surface was considerably greater than that caused by the two 300 lbs. charges fired simultaneously (C and D).

The gun cotton appeared to have almost completed the demolition. The engines, weighing 300 tons, were shifted bodily out of their place, and no part of them appeared at low water; the boilers were also moved, and the ship's side was stove in very nearly to the stern.

From the suddenness of the shock, the explosion of gun cotton seems quite irresistible, rendering it peculiarly valuable for demolitions like this, or for torpedo purposes. No doubt the explosion of charge B had weakened the centre of the vessel a good deal, but making all allowance, there can be no comparison between the difference of the effects, and it is improbable that 1000 lbs. of powder, or even more, would have produced such a decisive result. The smallness of bulk of the cotton, compared with its equivalent of powder, also gives it a great advantage.

After firing this charge, one more iron case and bag remained unexpended. A charge of 340 lbs. of powder was loaded and lodged under the stern, the only remaining sound portion. It was fired in 27 feet of water, and was the last of the series, completing the destruction sufficiently to enable the pieces to be removed without difficulty. This operation is being performed by a large dredging machine, employed by the Thames Conservancy Board, which is provided with powerful steam and hydraulic machinery.

* These tins were made under the direction of the Thames Conservancy Board, and from a design prepared by them. They were used with a view to economy, but were ill suited to the requirements of the case.

The fragments are hooked with a large grappling iron, raised with chains worked by the machinery and deposited in lighters, by which they are removed.

The fore part of the ship, in accordance with the request of the Thames Conservancy Board, has not been touched. The explosions, however, especially that of the cotton, appear to have influenced the mud in such a way as to make it sink unequally, for the deck is much contorted, and the port side has sunk at least 2 feet. This part of the ship was full of fine mud, but the gun cotton explosion drove in the great iron bulkhead which separated the fore-hold from the engine room, and the mud will now run out; this will facilitate the operation of lifting.

The demolition was completed on Saturday, 4th July. A charge of 20 lbs. of Mr. Abel's new compound of nitro-glycerine and gun cotton, called glyoxyline, had been prepared, but the destruction was so complete, that it was not required. Being however dangerous to unload this material, it was dropped on the mud, in 24 feet of water, and fired. The concussion and blow were very great, and the column of water was considerable. The strength of this compound is calculated at ten times that of an equal weight of powder.

This compound promises to be of great value in rock blasting, where it is of importance to get as large a charge as possible into a small space.

Some anxiety was felt on account of the tall chimneys of a manufactory distant 150 yards from the wreck. These chimneys were very badly built and much cracked, and it was feared that the frequent concussions might bring them down. No damage was, however, sustained.

13th July, 1868. H. J.

Diving party employed at the wreck of the Foyle:—

Sergeant R. Baker	36th	Company, R. E.
Lance-Corporal T. Apps	35th	"
Sapper J. Falconer	39th	"
" J. Downing	39th	"
" W. Edwards	39th	"
" J. Symons	39th	"

Electrician.—Corporal A. Harley, R.E., relieved by Sergeant-Instructor G. Motley, R.E.

The Admiralty diver was Mr. Hawthorne, a man of great experience, whose services were most valuable. He had with him his own assistant.

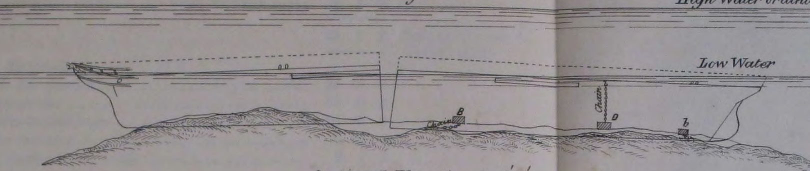
EXPENDITURE.

Royal Engineers.	£	s.	d.	
1 Sergeant, 26 days' pay	2	14	6	
1 Corporal, 8 "	1	3	0	
1 Sergeant, 4 "	0	13	6	
5 Sappers 26 "	6	15	11½	
Transport	2	15	0	
Travelling	6	10	6	
Incidentals	0	4	10	
	20	17	3½	Paid by Thames Conservancy.

DEMOLITION
OF
IRON PADDLE WHEEL STEAMER FOYLE.

DEMOLITION
OF
IRON PADDLE WHEEL STEAMER FOYLE.

Fig 1.



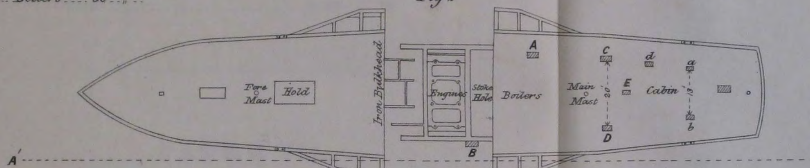
Sectional Elevation on A'B'.

...e Length ... 196' .. 5"
... Breadth ... 25' .. 8"
...Tonnage 704
...in hold ...... 16' .. 8"
...s .... 400 HP.
... of D° .... 300 tons
... Boilers .... 30 .. " ..

SCALE $\frac{1}{480}$ FOR FIGS. 1, 2, & 3.

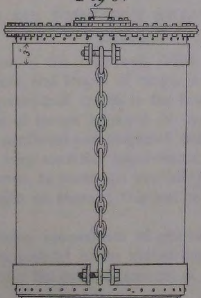
10 5 0 10 20 30 40 50 60 70 80 90 100 FEET.

Fig 2



Deck Plan showing position of the Charges

Fig 5.

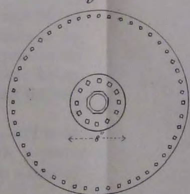


Elevation

WROUGHT IRON CASE.

to contain 300 lbs of Powder.

Fig 4.



Plan of top

SCALE $\frac{1}{20}$ FOR FIGS. 4. 5. & 6.

10 5 0 1 2 3 4 5 INCHES.

Lithographed at the Ro...

	£	s.	d.	
Admiralty diver.				
Board and lodging of diver and assistant	6	6	0	
Pay ditto ditto 21 days......	19	1	9	
	25	7	9	Paid by Thames Conservancy.
Materials.				
1,400 lbs. powder	35	0	0	
6 Iron cases	36	0	0	
6 India-rubber bags	24	0	0	
India-rubber glue	0	15	0	
115 Yards electric cable	2	7	2	
	98	2	2	Supplied by Thames Conservancy.
600 lbs. powder	20	0	0	
230 lbs. Gun-cotton	25	0	0	
	45	0	0	Supplied from Royal Arsenal.
Total	£189	7	2½	

PAPER III.

ON HASTY INTRENCHMENTS IN THE FIELD.

By Field Marshal SIR JOHN FOX BURGOYNE, Bart., R.E., G.C.B.

The increased power of the improved rifled arms of the present day, in accuracy, rapidity of fire, and length of range, will call for many alterations in the tactics and arrangements of troops in the field.

In the case of bodies of troops engaged in open ground, greater rapidity of movement, and more scattered and dispersed order in action will have to be studied; and another very essential requirement will be the best practicable means for obtaining cover, to prevent a possibility of being mowed down before coming into contact with an enemy; this last being our present object for consideration.

Natural cover of banks, inequalities of ground, trees, walls, &c., will more than ever be turned to account in the utmost degree; but what now requires research is how to obtain the greatest amount of cover artificially, in a limited period of time.

Any kind of structure of more rigid materials than earth would require far too long a period for its erection, and would be too costly and wasteful for the very temporary requirements of field service; earth, however, except in rocky or in extremely wet soils, answers the purpose admirably; plenty of competent men to work and put it in shape would be forthcoming; the only absolutely necessary accessory would be a sufficiency of tools; that is, of *pick-axes* and *shovels;* but therein comes the first and leading difficulty.

A few of these, with certain small appendages of carpenters' and smiths' tools, have always accompanied an army; but most grudgingly provided, and in very small quantity, on account of the difficulty of maintaining the amount of transport for provisions, forage, spare ammunition, means for treatment and conveyance of sick and wounded, and other objects, to which intrenching tools have always been considered of minor importance.

The more urgent necessity, however, for having such means at hand for the purpose of obtaining cover, will now cause much more importance to be attached to this demand, and obtain for it more serious attention.

Attempts have been formerly made to remove this difficulty by requiring soldiers to carry intrenching tools on the march. Napoleon, during his great wars, was very anxious to establish that every sapper should carry one of these tools; and, to make it more palatable, offered that, in that case, it should be of superior manufacture and an implement "*de luxe*," as it were, and even gave an order to that effect; but, after much discussion on the objections raised to putting this additional weight on a class of men who frequently had to set to work immediately after a march, (and this will now often be required from all classes of the troops,) he was obliged to abandon the idea.

Something of the kind, however, may hereafter be found absolutely necessary for the army in general, aided perhaps by endeavours to make the articles lighter, and an arrangement by which an intrenching tool may be served out to each two or more men, and carried in turns. This would also be attended by the additional great advantage that they would always be at hand, and would not have to be sought for among the baggage, which might be distant.

Assuming then the troops to be in possession of these implements of first absolute necessity, the next consideration will be how to employ them.

Intrenchments in the field have two objects; first to give protection to the men by a covering mass, shot proof, if possible; and secondly, for defence, by an obstacle or impediment to the enemy's progress.

For the object now under consideration, the first only is the desideratum we are seeking.

The most rapid manner then of obtaining cover is decidedly by the siege trench, sunk in the interior; the excavation and the earth thrown out of it, both tend to fulfil the object required; but it is accompanied by several imperfections.

1.—So far from adding any defensive power, except in the negative quality of giving cover, it does the reverse, by giving the assailants the commanding position when near it, and cover also.

2.—Being sunk, every little obstruction in front, by undulation of ground, or even vegetation, will somewhat impede the fire from it.

3.—Though covering those who are absolutely in the trench, it leaves much exposed those who are in the rear of it.

4.—In wet weather this trench will become more or less a quagmire.

5.—However long it may be occupied it is incapable of improvement.

There are, however, many occasions, as for siege trenches or for rifle pits, where this form of trench is indispensable; and it may generally be adopted with advantage for works hastily thrown up, and not intended for prolonged occupation, or over which it is essential that the defenders should be able to advance with an unbroken front to the attack of an assailing force. At most other times, it will be preferable to excavate on the exterior, leaving the natural surface of the ground for the footing of the defenders; and even although the time should, by circumstances, not admit of a full parapet being thrown up by this means, still to whatever extent it may be done, cover to some degree will be obtained.

To analyze the results of these two modes of obtaining simple cover for the troops, figure 1 will represent the first step, by excavating in the interior; figure 3, the same amount of labour applied to an exterior excavation.

No. 1 may be thrown up in one continuous line in about half-an-hour after the men are laid out to it; and if intrenchments can be carried only to that extent, this method will be manifestly the most advantageous to adopt. Though both give equal cover to the men on the ground, No. 1 gives a far superior position to a *single line* for using their rifles against the enemy.

Figures 2 and 4 will show the next steps in the progress of each, and will require perhaps one or two hours more work, and the method of proceeding by an exterior excavation is brought to a less disadvantageous result; the cover for the troops in the rear remains equal; and though in the one case those absolutely in the trench have cover for their full height, in the other the inconvenience is reduced to working in a kneeling or stooping position, and in consideration of its subsequent capabilities, the latter form is to be preferred; for in the one case the interior trench is at its best and can not be improved, while the other may be added to, until it reaches a parapet of 7 ft. in height, (having a banquette) and it will then afford sufficient cover for all the ground in the rear, while the excavation affords more or less of a defensive obstacle,

Where, as may often be the case, the trench shewn in Figure 1, has been adopted in haste in the first instance, and time becomes subsequently available for improvements, it will generally be preferable to recommence in rear of it a trench on the system shewn in Figure 3 as eventually the best; and even if there should not be time to carry it out to the extreme of 7 feet cover above the ground, the first, which will have cost but very little labour, will always be available.

When mention is made of the advantage of the outside excavation for intrenchments as being subsequently available for the application of obstructions to the advance of the enemy, it must be clearly understood, as only useful in that respect, for flanking redoubts or other limited detached posts, and not in front of the great body of the army ready to meet its enemy at close quarters; before this there must be no obstruction connected with the mere cover to prevent it rushing out freely to the attack in line or column on the near approach of the enemy.

For very hurried or very temporary occupation of ground likely to be attacked then, the simple sunken trench in a continuous line will be the readiest mode for procuring *cover:* the first addition with the object of giving to that or any other line of cover some defensive power, would be to throw up, at intervals of 300 or 400 yards asunder, projections, such as redoubts or redans, to act as flanks; in proportion as these flanking works can be made more powerful, may the intervals between them be greater.

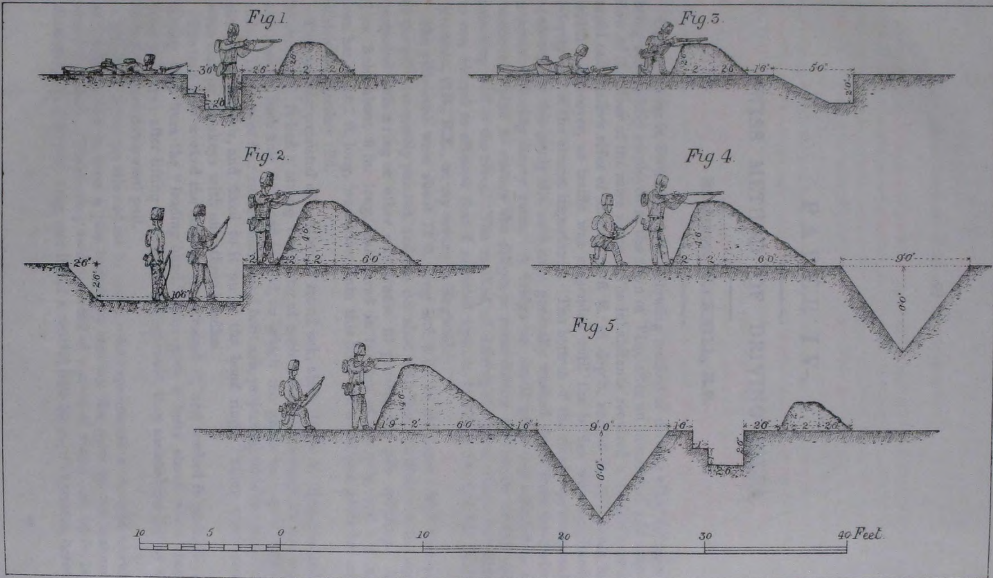
It is very desirable that these at least, as the most important features, should have their parapets entirely raised above the ground.

In addition to any line of cover, natural or artificial, for the mass of the troops, rifle pits in advance, for a couple of men each, may be of great service; these decidedly should be sunk in the interior, on many accounts.

With reference then to this new pressing requirement for providing cover in the greatest degree against the destructive fire of the rifle, the above, and any other points which may be suggested, will be well worthy of consideration, trials, experiments, and practise; first, as to the urgency of the provision of the most necessary implements, with every regulation and arrangement for their transport, care, and preservation; and secondly, as to the means of employing them to most advantage, first for cover, and afterwards where required, for defence; particularly defining the time and means necessary for each distinct operation, not as may be required by accomplished Sappers at Chatham, and under every advantage, but what may be reasonably expected from the soldiers of the line, under all the fatigue, hardships, and deprivations of a campaign.

J. F. B.

HASTY ENTRENCHMENTS



PAPER IV.

SWISS METHOD OF DRIVING PILES.

By Lieut. BUCKNILL, R.E.

During a tour in Switzerland the following method of driving piles was seen being successfully employed at the town of Visp, after an inundation and overflow of the river of the same name. The inhabitants required a bridge over a rapid and shallow river of about 5 or 6 ft. in depth, and 80 to 100 yards in width. Moreover, as traffic was suspended until the bridge was completed, celerity was of the utmost importance. The bottom of the river was composed of stones and fine sandy silt, such as is generally washed down from the Swiss mountains during heavy rains. A bridge on small piles was adopted as a temporary plan to restore the diligence route during the repair of the old retaining wall of the river. The method of driving the piles, which was new to me, seemed so efficient that I reported upon it to Major General Sir John Simmons, C.B., R.E., on my return to England.

The piles used were about 12 ft. long and 5 in. in diameter. The bottom of the pile was merely pointed, and was not shod with iron; neither was the top protected with a ring or other contrivance to prevent the pile splitting. A $\frac{3}{4}$-in. hole, about 9 in. long, was bored in the top of the pile, and a $\frac{3}{4}$-in. iron bar, 6 or 7 ft. long, was driven into this hole, and acted as a guide bar on which the monkey slid.

The monkey consisted of a piece of round oak, about 10 in. in diameter and 30 in. long. It had a strong bond ring at each end, and through its central axis was an inch hole from end to end, in which the guide bar could easily slide. There were four curved handles of bent ash, projecting from the body in the arc of a circle, and fixed to it under the bond rings. There were also some smaller monkeys with only three handles.

The men who worked the monkey stood round it, and worked it vertically, taking time from the "leading hand," who gave a lusty shout when they were to heave; after lifting it as high as they could, they assisted the fall by a strong vertical downward pull.

Sir John Simmons allowed me to make some experiments in the field works at Chatham, and to form a pile bridge, by driving the piles in the manner above described. The monkey used consisted of a piece of round oak, $9\frac{1}{2}$ in. in diameter, and 3 ft. 6 in. long, and it had a central hole $2\frac{1}{2}$ in. in diameter, bored from end to end and then burnt out to get a smooth surface. (Figs. 3 and 4.) It had four handles made of $\frac{3}{4}$-in. round iron; they were flattened out at the ends and a hole made through the flattened part, by which a wood screw fastened the handle to the monkey, the wood being slightly cut away at that part, and the outer part of the handle thus brought flush with the surface; a shoulder, however, was left on the handle to butt against the bond rings. The bond rings were made of $\frac{5}{16}$-in. iron, and were 2 in. broad. They were shrunk on after the handles were attached. Much difficulty was found in making the wooden handles stand the shock of the concussion; but after iron handles, as described, were used, no further trouble was met with. As the $\frac{3}{4}$-in. handles were rather small for the hand, they were served with spun yarn.

I was anxious to devise some method by which the platform, upon which the men who worked the monkey stood, should be fixed to and supported by the pile itself, so that their dead weight should push the pile deeper after the blow had moved it and disturbed the mud and earth surrounding it. I tried several plans, and when $\frac{1}{4}$-in. iron plate can be procured, and a forge and a good smith are at hand, the best seemed to be as follows :—

The platform itself was of wood, formed of planks and battens; it should be circular in shape, and should have a central hole large enough to take the largest pile that is to be driven. (Figs. 1 and 2.) This was supported on two clips of iron which were cut out of $\frac{1}{4}$-in. plate, bent to a right-angle, and again bent at the centre to receive the pile; two of these were then riveted together by similar arms to form one clip, the other two arms being drilled with suitable holes for screw bolts which attached the two clips firmly together, and caused them to grip the pile. When the platform was about 15 in. below the top of the pile, the men could work with the greatest force.

Should there be no forge at hand, the following method can be resorted to if the piles have not to be driven to a greater depth than 4 or 5 ft. Two planks, 20 ft. long, 3 in. thick, and 12 in. broad, had each a hole bored through the centre at a distance of 1 ft. 7 in. from the ends, and a diamond shaped jaw, 9 in. long and 5 in. broad, was made at a distance of 2 ft. 2 in. from one end; (Figs. 5 and 6). The ends of the planks were connected together by four turns of No. 8 iron wire, which passed through the holes at the ends near the jaws. The other ends were connected by a lashing after the planks had been lifted over, and their jaws had embraced, the top of the pile to be driven. In order to prevent the planks slipping down the pile, a lashing was tied round the latter about 15 in. from the top, and some strong iron spikes driven in below the lashing; and to prevent the planks toppling sideways, an iron hanger was made, which is shewn in Figs. 5 and 6. This could be replaced with wire or small strong rope from the pile top to the outside of the planks, where it could be fastened to a projecting batten, or to spikes suitably placed.

The plan that seems the best for bringing the piles into position is as follows: the length of bay should not exceed 10 ft., and it is easier to work with a bay of 8 ft. Two strong poles about 20 ft. long and 5 in. in diameter, are bolted together at one end, about 7 in. apart; they are then lashed down to the last

FIG 7.

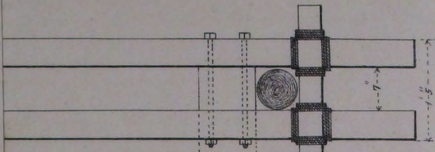


FIG 8.

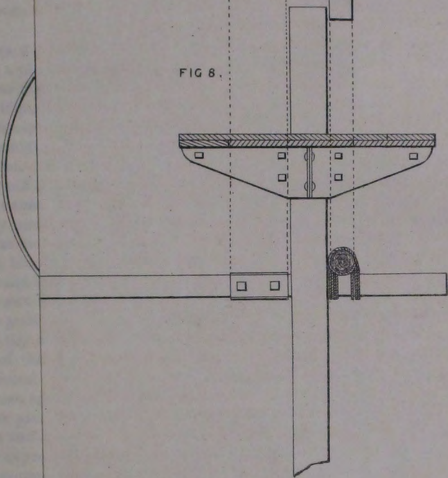
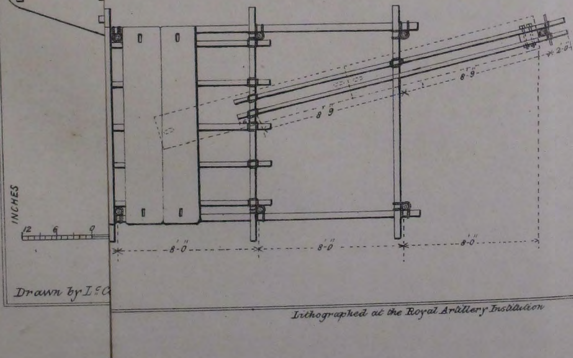


FIG 9.
SCALE $\frac{1}{96}$



Drawn by I. C.

Lithographed at the Royal Artillery Institution

bay as in Fig. 9. Two planks are laid on them and the pile taken out point foremost and dropped into its place. A small cross piece is then lashed on the ends of the spars, to prevent the pile falling outwards. The iron clamp and circular platform, or the plank platform, is then put on, and the guide rod and monkey brought out and placed on the pile by two men; the remainder then follow, and the pile is driven until the bottom of platform is brought down to the poles. The driving party then come in, bringing with them the monkey and guide rod; the platform is next brought in, and the transom and road bearers are then duly lashed in their places.

Experiments.—A Norton's tube-well was driven 14 ft. in less than half-an-hour.

Short piles, 6 in. diameter, were driven in hard ground at the rate of 18 in. per minute, a platform clamped to the piles being used to carry the driving party of four men.

A pile bridge, 90 ft. long and 10 ft. wide, with bays 12 ft. or 13 ft. long, was made by ten sappers in forty-one hours of actual work. The average weight of each pile was 90 to 100 lbs., average diameter 6 in. top and 4 in. bottom, average length 20 feet. The nature of the bottom in which the piles were driven was 12 in. of mud, and then a thick layer of gravel. The weight of the monkey being a little more than 1 cwt., it will be seen that the piles were rather heavy; nevertheless they were driven at an average rate of 1 ft. in four or five minutes, and sometimes as fast as 6 in. per minute.

Sir John Simmons proposed that a lengthening tube of Norton's tube-well should be used as the guide bar; it was tried and answered the purpose admirably. It was found to be important that the hole bored in the top of the piles to take the guide bar should be quite vertical when the pile was being driven, otherwise the friction between the monkey and the bar was apt to pull the latter out of the hole.

It was found that there was no necessity to bind the tops of the piles to prevent them splitting.

The men preferred working on the platform with iron clips, as they had more room and a more stable footing; with the plank platform, also, some difficulty was experienced in lifting the heavy planks over the head of the pile. The time necessary to get them into position was nearly the same.

J. T. B.

PAPER V.

THE ELECTRIC TELEGRAPH AND VISUAL SIGNALLING, IN CONNECTION WITH FUTURE MILITARY OPERATIONS.

By Captain R. H. STOTHERD, R.E.

Electric Telegraph likely to be important in future wars.

Recent experiences seem to indicate that the Electric Telegraph is destined to play a very important part in future campaigns.

Used by the Prussians in campaign of 1866.

No one can read the account of that in Bohemia in 1866, so ably described by Hozier in his book entitled "The Seven Weeks War," without being struck by the masterly strategy of the Prussians, which, on nearly every occasion, gave them an advantage over their less skilfully handled opponents; and that the orders for these strategical movements, emanating from the master mind of Von Moltke, were flashed along the telegraph wires, from his office at Berlin to the several armies and corps concerned, has now become a matter of history. This, though one of the most prominent, is not the only instance tending to prove the immense advantage which would be gained by an army engaged in the operations of a campaign, if provided with an efficient Electric Telegraph; as by this it could communicate directly with its base of operations, or with detached corps operating on lines at a considerable distance from each other, with almost the same speed and facility as if they were within speaking distance.

An Electric Telegraph Equipment will form a part of every modern army.

An Electric Telegraph equipment will, no doubt, form a part of every modern army taking the field, and the question naturally arises, what effect this will produce on future military operations, and what is the best form of equipment to adopt.

Results to be attained by employing an electric telegraph.

In considering these questions let us first examine the results hitherto obtained by the employment of the electric telegraph. Putting aside, for the present, the military telegraphs used by our own forces in the Crimea, and by the Federals while engaged in the attack of Richmond and Petersburg, as required to fulfil conditions not exactly in accordance with those which would occur on a campaign, the forces having on those occasions been stationary, we must turn to the Indian Mutiny in 1857-8, the campaign in Bohemia in 1866, and that in Abyssinia in 1867-8, in all of which the electric telegraph was used, and under conditions which would occur in an enemy's country.

Telegraph employed during Indian Mutiny.

During the Indian Mutiny, Lord Clyde's head-quarters were generally in telegraphic communication with the seat of Government at Calcutta. There appears, unfortunately, to be no detailed account of the instruments and means employed in the operations by which this very desirable result was effected. There is, however, a very short report by the late Lieutenant Colonel Patrick Stewart, R.E. (to whose unremitting energy its success was entirely due), published in the records of the India Office, which gives a general idea of what was done. As far as I have been able to ascertain, it seems that temporary lines were constructed in continuation of the permanent lines of the country, to connect the head-quarters of Lord Clyde's forces. The permanent lines of the country being always along the main lines of road, which formed the communication with the base of operations, and which were consequently, to a considerable extent, guarded and patrolled, interruptions to telegraphic communication, due to the rebels' operations, were extremely rare.

Used by the Prussians during the campaign of 1866.

As regards the campaign in 1866, each of the two main armies operating in Bohemia had one unit of field telegraph equipment attached to it, a third unit was attached to the head-quarters of the King of Prussia, and a fourth was in reserve.

Each unit carried $27\frac{1}{2}$ English miles of wire, with a certain number of Morse recording telegraph instruments and batteries, was complete in all its details, and capable of erecting a line of telegraph as fast as the head-quarters of an army could march. An excellent detailed description of the constitution of the Prussian Field telegraph equipment, by Captain C. E. Webber, R.E., is given in volume XVI. of the "Corps' Papers," and I am indebted to that officer for some further information on the subject, which has been embodied in this paper.

Thus equipped, the head-quarters of each army appear to have been in constant communication with Berlin and, through this latter place, with each other. The system adopted seems to have been to make connections with the permanent lines of the country and to form temporary lines as required, using the field equipment for the latter purpose, as well as to supply any deficiencies occurring in the permanent lines till the latter had been repaired. Till within three or four days before the battle of Sadowa, the telegraphic operations appear to have been always well advanced; and though the wires did not actually extend up to the field of battle, there can be no doubt that the electric telegraph contributed to the Prussian success in no small degree. There appears to have been no difficulty in protecting the line which followed the railways (the main lines of communication) and was consequently well guarded.

Used during Abyssinian Campaign of 1867-8.

For the Abyssinian campaign of 1867-8, the telegraph equipment provided was organised in two divisions, viz.: a light line to be laid as fast as the force advanced, and of which a system of visual signalling formed a part; and a reserve line, partaking more of a permanent character, to be erected at leisure. In consequence of want of transport the light line, with the exception of the visual signalling apparatus, was abandoned altogether; and for the same reason great difficulty was experienced in carrying the materials, especially the poles, required for the semi-permanent line, and its efficiency was, consequently, seriously impaired. From the above causes the progress of erection was much slower than it might have been; and, when the line was erected, considerable inconvenience and interruption to signalling was experienced, principally from the breaking down of the make-shifts, which it became necessary to substitute for telegraph posts, suitable poles not being obtainable in the country. The number of men available for working parties, appears also to have been limited; towards the end of the campaign when more men were employed in the construction of the line, as much as ten miles were erected in a day; there seems to be no doubt, therefore, that with adequate means it might have been carried, if not absolutely to Magdala, very much nearer to it than was actually done. Except at first, there appears to have been very little difficulty consequent upon the interference of the natives with the line; their motives for touching it appeared to be chiefly curiosity, or a wish to become the possessors of the copper wire of which it was formed.* The interruptions experienced were chiefly due to camels, numbers of which were wandering about sick and disabled in the vicinity of some of the halting places; and from the inefficiency of the poles, the line was in many cases not sufficiently high to allow them to pass freely under. Much credit is due to Lieutenant St. John, R.E., and the officers and men under his command, by whom this line was erected, and who, by their zeal and energy, accomplished a very great deal with very inadequate means.

Such are, briefly, the results obtained in the campaigns mentioned, and there seems to be no doubt that military telegraphy is capable of very considerable development, and that greater effect may be easily produced thereby.

A line of telegraph somewhat in the same position as a railway for military purposes.

A line of electric telegraph is in somewhat a similar position to a railway as regards modern warfare. A force, retiring through its own or a friendly territory would be in full possession of both telegraphs and railways, and could use them to the utmost, and by thoroughly destroying them would deprive an enemy of all advantage to be derived from them till reconstructed.

For defensive purposes a line of telegraph would be most advantageous.

For defensive purposes, therefore, we may fairly infer that the electric telegraph would be of very great advantage, as admitting of the transmission of orders and intelligence with a celerity hitherto unattainable.

For the attack all must be formed afresh with materials carried for the purpose.

An attacking force, on the contrary, must be prepared to find everything in the shape of telegraphs and railways at best only in a state of ruin on the line of advance, and must carry the means of re-establishing them with the utmost rapidity, and when re-established they must be thoroughly patrolled and guarded to ensure efficiency. Both railway and telegraph would generally be on the main line of communi-

* It is probable that a sharp electric shock, judiciously administered with a frictional machine to a delinquent caught in the act, would have a salutary deterrent effect in preventing depredations of this nature.

cations, and their value, as bearing upon the conduct of a campaign, would essentially depend upon the efficiency of the protection afforded to them.

Combined operations rendered more certain by telegraphic agency.

From the experience of the Bohemian Campaign, it would seem fair to assume that combined military operations by columns operating on lines at a considerable distance from each other, can be carried on, with the aid of the electric telegraph with infinitely greater precision and certainty of result than has hitherto been possible.

Detached bodies are thereby brought more under the control of the General commanding.

It is again no small advantage that the same head which conceives an idea may, as it were, work it practically out; that, in fact, a General may have within his grasp the power of issuing orders and giving explanations personally for the execution of operations at an almost unlimited distance, and of receiving immediate intelligence as to how his orders are being carried out, or what new combinations it may be desirable to make on the spur of the moment. Hitherto it has, under such circumstances, been necessary to entrust the execution of details to others, and misconceptions must occasionally arise in the communication of ideas from one individual to another, however great may be the care bestowed thereon.

Form of equipment for field service.

Next, with regard to the best form of equipment for field telegraphic operations. To effect the object in view, it would seem necessary to have an equipment organised in two divisions—viz., a light one, capable of laying a line of telegraph as fast as infantry can march; and a reserve, provided with everything necessary for the construction of a line of telegraph of the most substantial description.

Prussian equipment.

The Prussians in the campaign of 1866 possessed a light equipment, but nothing corresponding to the reserve above referred to. Their light equipment consisted of four units, each carrying 27½ English miles of conducting wire, or a total of 110 miles in all, with a certain proportion of instruments, batteries, &c. Two of these units were fitted with an electric cable, insulated with gutta percha, with an outer protecting covering of copper tape, to be laid on the ground, as described by Captain Webber. This form of cable was tried at Chatham, in connection with some experiments during the fitting up of our own field telegraph equipment, and failed badly. It is not surprising, therefore, that it has been condemned by the Prussians, and that the other two units of equipment were differently organised. The latter were fitted to construct an aerial line, carried on light poles. This is, no doubt, an improvement on the cable protected by the copper tape, but it would be extremely conspicuous, be sure to attract the attention of an enemy during a cavalry raid, and be very susceptible of injury. It would only be necessary to throw a rope over the wire and pull it down, or to break or pull down the poles with a lasso, to render the line inefficient.

Abyssinian equipment. Light line.

For the Abyssinian equipment a light and a reserved line were provided. The light line consisted of an insulated conductor, to be laid on the ground. The insulation in this case was Hooper's core, (a combination of Indian rubber, as described in Volume XVII of the Corps Papers, pages 68 and 72.) For the reasons already stated it was never used, but it was found to stand the great heat, while in store at Zoulla, without any apparent deterioration to the insulation. Gutta percha is easily damaged by dry heat, it melts at a lower temperature than Hooper's core, and when the heat is not sufficient actually to melt it, it becomes brittle and cracks, exposing the conductor; it is, moreover, not so applicable generally as Indian rubber to a cable which has to be frequently payed out and reeled up, as is the case with any field telegraph equipment.

Visual signalling apparatus. The visual signalling apparatus belonging to the light Abyssinian equipment was carried forward and proved most valuable.

Reserve equipment. The reserve Abyssinian equipment consisted of a light conducting wire, of No. 16, copper, carried on poles. Bamboos were shipped at Bombay for this purpose, but many of them never reached their destination, having been washed or thrown overboard during a gale of wind; and it was found difficult to carry those that did arrive up the country. These were a serious loss, and the equipment was in addition, as already stated, much crippled by want of transport.

Both the Austrian and Italian governments possess a field electric telegraph equipment. The former, (the Austrian), is described in Volume XVII. of the Corps Papers, and does not seem to differ from that of the Prussians in any very essential particulars. It is unnecessary to describe the Italian equipment which, though slightly differing in details, is precisely similar in general arrangements.

Austrian field telegraph.

Italian field telegraph.

Having had the benefit of the experience of the Prussians and Austrians, as well as a very good description of the Italian equipment, the task of organizing a field electric telegraph equipment was undertaken at Chatham, and we now possess specimens of carriages and apparatus, which seem well adapted for the purposes required to be fulfilled in a light equipment. The instruments employed are Morse recorders and Saunders, arranged in a very portable form. The batteries are a modification of Daniell's, and the conductor is Hooper's core. A few light, tubular, iron telegraph poles are also carried for special purposes. The instruments, batteries, &c., are fitted in travelling offices, which are simply telegraph offices on wheels, and the conducting wire, poles, &c., are carried in waggons, adapted for the rapid construction of a line of telegraph. The conducting wire is arranged to be laid on the ground, at a minimum rate of two miles an hour; with well practised men a line has been constructed from Brompton Barracks to Rainham, a distance of four miles, in an hour and thirteen minutes. This insulated cable is not, like the Prussian, susceptible of injury by the passage of heavy waggons over it, and it has stood some very severe tests, in that and other respects, without injury. The light iron poles are for use at road crossings, where continuous heavy traffic would in time produce injury, if it were allowed to pass over it. Spikes of a peculiar form are also carried, to enable the conducting wire to be suspended

Field telegraph equipment organized at Chatham in 1867-8.

Instruments.

Batteries.

Waggons.

Conducting wire.

Poles.

Spikes.

to trees or walls, in order to meet the contingency of passing through a town or village.

Visual signalling apparatus.

Visual signalling apparatus, consisting of flags for day and lamps for night use (similar to, though somewhat improved upon, that used in Abyssinia), forms a part of the light equipment. This is worked on the approved system for army and navy signalling, and forms an extension of the electric telegraph, while it gives the means of temporarily bridging over a fault, should one occur in the electrical system, and of communicating with the navy in combined operations.

Light equipment.

The organization of a unit of light equipment has been drawn up on paper, but has not yet received the sanction of the authorities. At present we possess a very limited amount of line wire, only eight miles.

Reserve equipment.

In addition to the light equipment, it would seem necessary to provide a reserve, for the construction of a more permanent line, in order to carry out the requirements of a campaign. Where the nature of the country admitted of such a course the insulated wire might be buried by digging a trench, in which to place it, or by running a light plough along the line. Where an aerial line would be preferable, and transport comparatively easy (for example, if a railway were available), it would seem desirable to provide the means of erecting an ordinary telegraph line of the most substantial description. Everything flimsy or make-shift should be avoided, and ample depôts of materials for repair should be established at intervals along it, in whatever way it may be constructed.

Light equipment used at Aldershot during summer of 1869.

The light equipment above referred to was used during the past summer, in connection with the strategetical operations instituted at Aldershot, with very good results.

Electric telegraph.

The electric telegraph was attached to a flying column on two occasions, and used to keep up a communication with the base of operations while actually on the march, and to connect the various points where camps were formed with the nearest telegraph stations. This entailed a very great variety of work, from the simple formation of a line along a road, to the passage of a river at a point where there was no bridge.*

The instruments and apparatus worked remarkably well; the lines were rapidly formed and dismantled, and several improvements in minor details were elicited in the course of the work, which also gave good practice to the officers, non-commissioned officers, and men employed.

Used to connect an outpost with head-quarters.

The electric telegraph was also used on the 2nd of August, to connect an advanced force, thrown out towards Frimley and Hawley to watch the enemy's movements, with head-quarters near the North Camp at Aldershot, a distance of nearly four miles. As the enemy advanced, the telegraph was dismantled and reeled up, piece by piece, as required, signalling communication being re-established when the enemy's advance had

* A line, to connect the Camp at Bushey Park with the Hampton Court Telegraph Office, was formed through the Thames on the 19th of July, and worked satisfactorily for two days, while the column remained at the former place.

been sufficiently left behind to render it safe to do so. No difficulty was experienced in executing this retrograde movement; the office waggon was easily moved along the road at a trot, and the line was reeled up at the rate of about four miles an hour. The very great advantage in increase of speed, over the ordinary system of mounted orderlies, attained by this method of communicating with an outpost, even at the comparatively short distance tried on this occasion, was very strongly exemplified.

Visual signalling.

The visual signals were employed on several occasions to communicate between columns of troops when on the march, as well as to connect outposts with the main body, while feeling for an enemy, and the rapidity with which the information collected was, through their agency, transmitted to head-quarters, gave the force employing them a very marked advantage on two occasions, viz., at the Pirbright field day on the 22nd of July, and at the Bizley field day on the 6th of August.

Balloons for signalling purposes.

From the experience thus gained, it would seem probable that balloons might be very usefully employed in connecting outlying signalling parties with the main line of communications. Should this be found practicable, much difficulty which now occurs in the selection of stations, affording a good view from point to point, would be eliminated.

Officers of all arms should be familiarised with the use of telegraphs and signals.

It is manifest, however, that to work either the electric telegraph or visual signalling to advantage, it is necessary that officers and men of all arms of the service should be familiarised with the use of the apparatus employed, in so far as its application to the rapid transmission of orders and intelligence is concerned.

Telegraphs of a more stationary nature

With regard to the employment of telegraphs of a more stationary nature, we have examples in those used by the allies during the siege of Sebastopol, and by the Federals during their operations against Richmond and Petersburg. In both these cases the electric telegraph, and in the latter visual signalling also, were found most useful. In such cases rapid locomotion, construction, and dismantling are not required, and the lines may be made of a more permament character.

Telegraphs (electric and visual) in fortresses.

Still more permanent should be the electric and visual signalling arrangements, which will in future be necessary, to connect the main works with head-quarters, in all large fortresses. Unlike those already referred to, these may be carefully designed and constructed at leisure, and long before they are actually required for use. Without them the systems of submarine mines and other appliances of modern warfare, which must now form a part of the defence of every first-class fortress, could not be worked to advantage.

R. H. S.

PAPER VI.

HOW EARTHQUAKES CAN BE OBSERVED AND REGISTERED

By LIEUTENANT T. FRASER, R.E.

Owing to the great importance of being able to foresee the eruptions of Vesuvius, the late government of Naples was led to put up an observatory to watch its signs. The house, built in 1844, stands near the Hermitage, 2080 ft. above the sea, being placed on a ridge of the mountain which has turned aside many a lava current, without being itself submerged. It is founded on vaulted arches, above which is a large hall for specimens of lava and volcanic minerals. Steps lead up from this hall to the observatory proper. The whole is in the charge of Professor Palmieri, of the Royal University of Naples, who, by his ingenuity and zeal, has brought the instruments to a state of great perfection; to his kindness I am indebted both for a personal explanation of the working of the apparatus and also for a description of it.

The seismographic or shock-recording instruments are in a separate room, and are worked by electricity. There are also instruments for observing the electricity of the air, and the pressure of the wind and amount of rain-fall, as well as the diurnal variations of the magnetic needle.

All former attempts at measuring and recording earthquakes depended directly on the shocks making their own marks; slight ones thus escaped notice, but by the use of electricity the certainty of record is invariable. The instruments are made to record the horizontal and vertical oscillations, the time of their occurrence, and their duration and direction, in the following manner:—

In Fig. 1, E is a helix of brass wire, (gauge about 1 millimetre); the helix consists of 14 or 15 turns, and has a diameter of from 20 to 25 millimetres; it hangs from a fine metal spring, and can be raised or lowered by a thumb screw. From the lower end of the helix hangs a copper cone with a platinum point, the latter is kept close to the surface of mercury in the iron basin *f*, which rests on an insulating column of wood or marble (G). The distance of the point from the surface of the mercury remains constant, as the metal pillar (T) is of such a length that its expansion or contraction compensates that of the helix; the latter is in connection (by T) with one pole of a Daniel's battery of two cells, and the basin *f* is connected with the other pole. Any vertical movement, however slight, makes the platinum point dip into the mercury, and thus completes the circuit. In this circuit are included two electro-magnets, C and D; these, during the circulation of a current, attract their armatures, which are connected with levers. The action of C's lever is to stop the clock A, which thus records, to a half second, the time of the occurrence of the shock, at the same instant that the clock strikes an alarm bell. The lever, attached to the armature of D, at the first instant of the current, frees the pendulum of the clock B, which was before kept from swinging, in a position out of the vertical; the clock then acts as a time-piece, and its motion unrolls a band of paper, K, K, K at the rate of three metres an hour. At the same time the armature of D, while attracted, presses a pencil point against the band of paper which passes over the roller *m*, marking on it, while the earthquake lasts, a series of points or strokes which occupy a length of paper corresponding to its duration, and which record the work of the shock. After it is over, the paper continues to unroll from the drum *i* and passing round the clock, rolls on to the drum *l*. If a fresh shock occur, the pencil indicates it, as before, on the paper, and the length of blank paper between the two sets of marks is a measure of the interval of time between the shocks. By way of additional check, several helices, *h*, *h*, *h*, are hung from a stand, with small permanent magnets suspended from their ends; below and close to these latter are small basins, holding iron filings; into these the points of the magnets dip, when their helices oscillate vertically, and some filings remain sticking to the magnets as a record of the shock. One of the magnets has a shoulder on it which moves an index hand along a graduated arc, as shown in Fig. 2, thus again registering the amount of the vertical movement.

The following arrangements are more specially for registering the horizontal motions:—On the stand to the right of the clock A, are set four bent glass tubes, open at their ends. One of each pair of vertical branches must have a diameter at least double that of the other. These pairs, with their supporting columns, are shewn in plan, where one pair lies N and S, another E and W, a third NE and SW, and the other NW and SE. It will be observed that metallic bars pass from the pillar P, over the ends of all the long branches, and similar bars pass from R over the ends of the short branches; the pillars themselves, as in the case of the other instrument, are each connected with one pole of a Daniel's battery, the connections including the electro-magnets C and D. The description of the tube *n* will apply to all the others; *n* is partly filled with mercury, and an iron or platinum wire *o*, suspended from the bar above the short branch, dips into the mercury therein, while another platinum wire, hung from the bar over the mouth of the longer branch, has its end very close to the surface of the mercury in that branch. Any shock which is not perpendicular in direction to the plane of the pair of branches, will cause the mercury to *oscillate* in the tubes and more sensibly in that with the smaller diameter; when it rises up in the latter, so as to touch the platinum point, the connection between P and R is made and the circuit completed, starting the action of the electro-magnets C and D, which record the shock as already described. By having the tubes set in the different directions already mentioned, one or more of the pairs is sure to be acted upon, and by observing in which the oscillation takes place, the direction of the shock can be ascertained. Besides this, each long branch has a small ivory pulley q fixed above it, over which passes a single fibre of silk, with an iron float at one end, resting on the surface of the mercury : at the other end of the fibre hangs a counterpoise x: fixed to the pulley is a fine index hand capable of moving along a graduated arc. When the shock takes place, the mercury rising in the long branch, raises the float on its surface, the silk fibre at the same time makes the pulley revolve with its index hand, which afterwards remains stationary, as the counterpoise x prevents the float from sinking again with the mercury. The reading on the graduated arc is thus a measure of the magnitude of the shock. It will be seen that in all these instruments, shocks however small can be recorded with certainty, by adjusting the distance between the platinum points and the mercury.

In addition to the above, some instruments of a rougher description are used; for instance, at the foot of the pillar G there is a wooden trough with eight holes (two of them shewn in section) round its inner circumference; mercury is poured into the basin till its level is nearly up to the lips of the holes. The effect of a shock is to throw some of the mercury into one or more of these holes, and the greater the oscillation the more mercury is thrown in. The screws shewn outside are for drawing off the mercury from the holes, when its quantity can be measured. The direction of the shock is shewn by seeing which holes are filled with mercury. The following is another method. From the arm of the pillar G, a fine metal wire hangs, with a metal ball at its end, which, by its oscillation, thrusts out one or more light glass tubes, set horizontally in a stand as shewn in figure 3. The two rings are of wood, and the glass tubes pass through holes in them of the shape shewn in the sketch; small leather washers are placed outside the outer rings: the displacement of a tube measures the shock. It has been shewn then, that by means of this apparatus, the astronomical time of the first shock is recorded, as well as the interval between the shocks, and the duration of each; their nature, whether vertical or horizontal is given, as also the maximum of intensity and, in the case of horizontal shocks, their direction is indicated. Professor Palmieri has it examined three times a day, and an assistant observer is always at hand to hear the bell, and put back the apparatus to its normal position for fresh observations. It appears that it records all the violent shocks that occur in the Mediterranean basin—thus on the occasion of the late eruption in the Greek Archipelago, Pr. Palmieri was able to announce to the Neapolitans that a great disturbance had taken place, long before the news reached Italy. The shocks in connection with Mount Etna are readily observable.

It is recommended that where earthquakes are frequent the observatory should be founded on solid masonry, bedded in the earth, and should consist of a wooden house not liable to be overthrown.

The following signs of an approaching eruption are considered reliable.

First.—When the crater fills up and the vapour from it diminishes in quantity.

Secondly.—When the vapour from the crater gives much deposit of iron or sodium.

Thirdly.—When the water sinks in some of the springs of the neighbourhood.

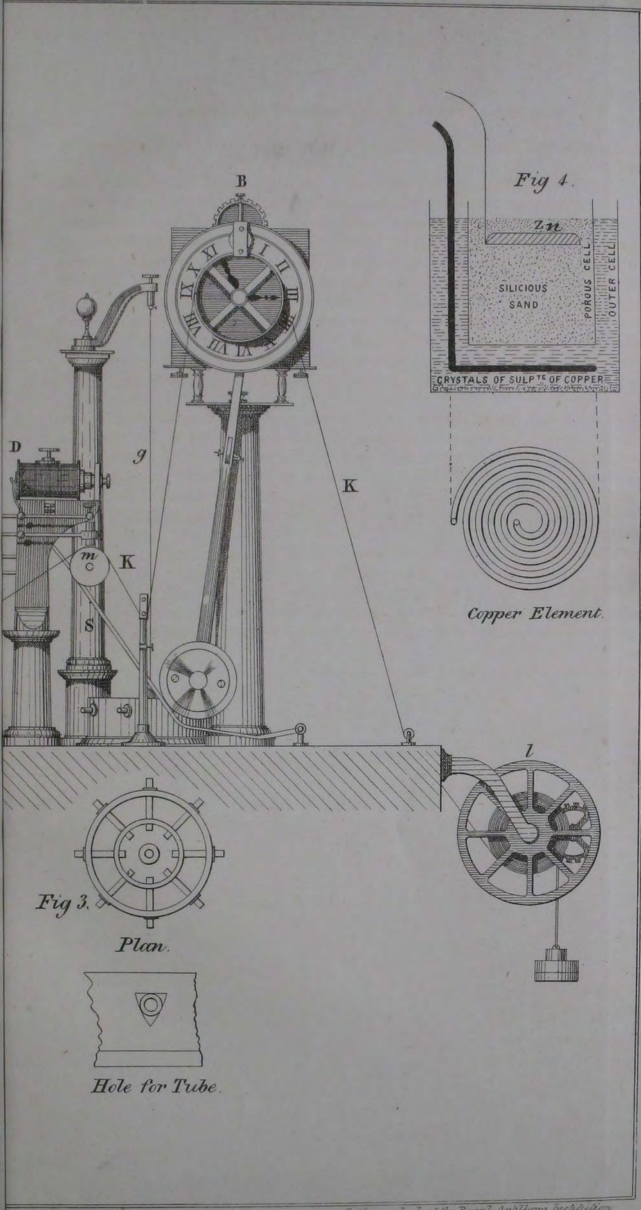
The phenomena more nearly preceding an eruption are the occurrence of earthquakes, increasing in intensity and frequency for some days beforehand, also the irregularity of the diurnal variations of the magnetic needle. One of the remarkable attendants of an eruption (which may be observed to a lesser degree whenever the mountain is steaming much), is the frequency of lightning flashes, considered by Pr. Palmieri to be due to the condensation of the vapour of water from the crater; just as in an ordinary thunder storm, lightning occurs at the time the vapour is condensing, as is proved by the rain that follows; this too would explain the action of Armstrong's hydro-electric machine, which has been thought to be due to the friction of the particles of vapour escaping through an orifice.

In addition to these phenomena of Vesuvius, the volcanic activity of the district is shown by a gradual rising of part of the coast of the bay near Torre dell' Annunziata, where there is already an alteration of several feet; while on the other side of Naples, at Pozzuoli, the pavement at the edge of the harbour is sinking below the level of the water, and the pavement of the temple of Jupiter Serapis had in the spring of this year (1869) sunk about 16 inches lower than in 1858.

The arrangement of Daniel's battery used for the seismograph, is shown in Fig. 4, where, for convenience of cleaning, the copper element is made of wire (about 8 B.W.G.) coiled flat without touching. Crystals of sulphate of copper are placed at the bottom of the outer cell, into which water is poured; and the inner cell, into which the zinc plate goes, is filled with silicious sand.

T. F.

Chatham, 28th August, 1869.



Lithographed at the Royal Artillery Institution

PAPER VII.

STATISTICS

Relative to the Size, Weight, Capability, &c., of Beasts of Burden in India, collected by Lieutenant F. Bailey, Royal Engineers, and communicated by Colonel Lennox, R.E., C.B., V.C.

	Average weight	Weight able to carry, inclusive of gear.	Proportion of weight borne by fore legs.	Ditto hind legs.	Distance between fore and hind legs, centre to centre.	Distance between fore or hind legs, centre to centre.	Superficial area occupied by a single animal. [4	Ditto occupied by each in a crowd unloaded. [5	Ditto ditto loaded. [6	Height to be allowed for passage of a loaded animal.	Width to be allowed for passage of a loaded animal.	Space required for a single animal when sitting down to receive load.		Rate of travelling when loaded —good road.	Number of hours which can be travelled per diem in a continuous march.
	tons cwt.	cwt.			ft. in.	ft. in.	sq. ft.	sq. ft.	sq. ft.	feet	feet	length ft. in.	breadth ft. in.	miles per hour	
Elephants.	[1] 3 0	13	·6	·4	6 6	2 0	55	60	100	15	12	13 0	5 0	2½	6
Camels.	10	3½ to 4½	[2] ·67	·33	4 6 to 5 0	1 4	25	33	70	11	10	9 3	2 2	2½	6
Pack Bullocks.	4	1½	[3] —	[3] —	3 6	0 9	15	10	13½	6	5	not applicable		1½	7

1.—A very large one might weigh 4 tons.

2.—A camel is much slighter made behind.

3.—Could not be ascertained owing to unsteadiness of animal.

4.—Greatest length by greatest breadth.

5.—This was ascertained by driving into an enclosure of certain dimensions as many animals unloaded as could be got in. Elephants and camels cannot be packed to the same extent as bullocks, who will crowd to any extent and stand with their heads over the backs of others.

6.—This will be very variable according to nature of load. Tents with their poles, &c., occupy a great deal of space, grain very little, but the above is a fair average.

PAPER VIII.

FRENCH TELEMETERS,

At the Paris Exhibition of 1867.

BY LIEUT. MACGREGOR GREER, R.E

We are at present engaged in building very expensive forts along our coast, and arming them with powerful guns, manufactured with such beautiful precision that they are capable of hitting objects at *known* distances with a certainty scarcely credible. The ranges too at which these guns can be effectively used are very great, and the difficulty of guessing these longer ranges or accurately determining them by the old methods of land marks or buoys is proportionately increased. This being the case, it only remains for us to find the means of measuring rapidly, and with a certain amount of accuracy, the distance to any object, such as a distant ship, which the defenders of a fort may wish to hit. This may be done in either of the following ways :—

1st.—By measuring simultaneously two angles from the extremity of a measured base and then solving the triangle.

2nd.—By observing from a point of known altitude above the sea, the inclination of a visual ray directed upon the line of floatation of a ship.

3rd.—By employing an instrument adapted for one observer, consisting of a telescope, and of a base, receiving at its extremities rays coming from the same point of a ship.

The advantages and disadvantages of most instruments employed for the above purpose have been investigated thoroughly by Captain Gautier of the French Artillery, and those decided upon by him as being the best are the following .—

1st. Arrangements required for measuring simultaneously two angles from the extremities of a measured base, and then solving the triangle.

This method of measuring distances is called "telemetrography," and is employed when the coast batteries are sufficiently close to each other to observe the same ship. The distance between the batteries must be known, they must be connected by at least one telegraph wire, and two observers are required to take the angles. We will first describe the principle by which the distance is obtained, and then show how it is carried out in practice.

Let A and B Fig. 1, be two coast batteries close together; the former being that from which we wish to measure the distance of a ship. Let *a* and *b′* represent two telescopes which turn round their centres on vertical limbs, placed at two ends of the measured base; let the line *a b* represent a certain proportion of the whole length of the base, say $\frac{1}{1000}$th, and suppose that there is an index arm at the point *b*, capable of revolving in a horizontal plane round its centre, and so constructed that it always moves parallel to the telescope at *b′*; then it is evident that if observations be made at the same moment from both ends of the base upon the same point of a ship, the triangle *a b c* will be determined, of which the side *a c*, will be $\frac{1}{1000}$th of the distance required.

The problem therefore simply resolves itself into finding the means by which the index arm *b* at the fort A can be made to move, so as always to keep parallel to the telescope *b′* at the fort B.

Now we know that if the handle of a manipulator, arranged with a simple electrical combination, at M be moved round the fractional part of a turn, the needle of the indicator at R will, in virtue of the series of short currents thus passed along the conducting wire, turn through the same quantity or arc of a circle, so that if the handle of the manipulator can occupy 20 equidistant positions on its dial plate, the needle of the indicator may be made to occupy 20 corresponding positions.

Again, if the handle of the manipulator be connected with the telescope *b′* by an arrangement of toothed wheels, so that each twentieth of the total circumference described by the handle produces a movement of two minutes of a degree in the telescope, and the needle of the indicator R be connected with the index arm *b* by means of a similar arrangement of toothed wheels to that employed at the fort B, it is evident that any motion given to the handle of the manipulator M will produce a similar movement in both the telescope *b′* and the index arm *b*, with the difference that the latter will perform its angular movement by a series of small angles of two minutes each.

We have thus an arrangement by which the index arm *b* can be made to move parallel to the telescope *b′* as long as the handle of the manipulator is turned in one direction; it only remains, therefore, for us to show how it can be made to move in the opposite direction. This is done by passing the current through a system of two electro-magnets, with their contrary poles opposite one another, and having a permanently magnetized armature playing between them, as shewn in Fig. 2; by changing the direction of the current the polarized armature moves from one electro-magnet to the other, and alters the reversing gear of the machinery, connecting the indicator with the index arm *b*, thus causing the latter to move in the opposite direction.

To complete a description of the apparatus, it is only necessary to say, that the telescopes *a* and *b′* and the index arm *b* should move upon circular graduated plates, numbered in the same direction, and that the similar numbers of each should be in the same relative position with reference to the meridian.

We will now suppose that the two forts A and B, between which the base is measured are connected by two wires, that they each have an electric battery, indicator, and manipulator, and an alarum, and that the arrangement described above has been completed.

If the observer at Fort A sees a ship the distance to which he wishes to ascertain, he signals to B the description of the ship, and the part of it on which he is to direct his telescope;* to avoid taking several turns of the handle of the manipulator, B places the telescope roughly in the direction of the ship, and telegraphs to A to place the index arm *b* on the corresponding number of its graduated arc, so as to get it parallel to the axis of the telescope *b′*.

The observer B then follows the movement of the ship through the telescope *b′* by turning the hand of the manipulator, if the ship moves to the right he puts the wire to the positive pole of the battery, if to the left, to the negative pole. At the same time, the observer at A also follows the movement of the ship through his telescope, so that at each moment the triangle *a b c* (and consequently the required distance) is determined, and is found on a scale that is drawn out beforehand.

2nd.—We now come to the second method alluded to, viz., by means of an instrument for observing from a point of known altitude above the sea, the inclination of a visual ray directed upon the line of floatation of a ship, and thus determining her distance.

It is not worth while to describe any of the instruments proposed for measuring in this way, as they are all so very imperfect. It is almost impossible to construct an instrument capable of measuring the amount of refraction, which should be taken into account in calculating the distance, owing to the fact of its varying so much under the ever varying conditions of the atmosphere.

As regards the 3rd method; by means of an instrument adapted for one observer, consisting of a telescope and a base, receiving at its extremities rays coming from the same point of the ship.

Telemeters, as at present made in this country, are very faulty in construction, for the following reasons:—1st. They consist of mirrors or triangular prisms producing only one reflection; consequently, if the instrument happens to be bent either by irregular expansion or contraction (which, to a certain extent, always takes place on a sunny day) or by a fall, the angles of inclination of the faces of the extreme mirrors or prisms with the base become changed, as shewn in Fig. 3, producing anything but a correct result, when a distance is measured in this way. 2nd. The micrometric arrangements adapted by opticians for measuring the angles are mechanical, and cannot be depended upon for any length of time. 3rd. Any disarrangement of the object glasses produces an enormous error in the length of the line measured.

The French telemeters, as recommended by Captain Gautier, avoid the above disadvantages (and consequently all adjustments) by the employment of prisms

* Some general rule with reference to the part of the ship to be observed is usually adopted in such cases, as for example, all angles may be taken to the foremast.

TELEMETERS.

Fig 1.

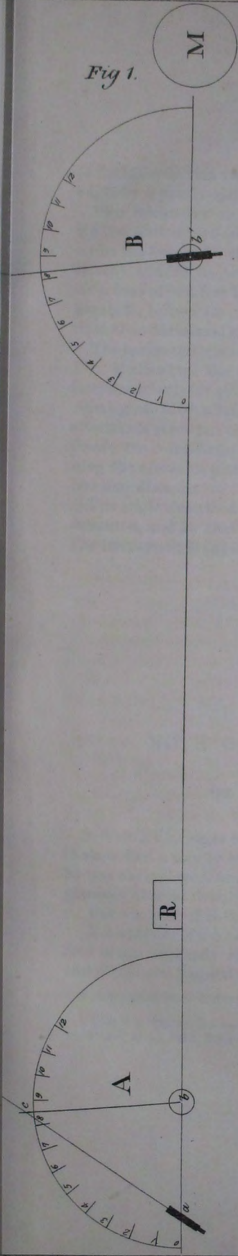


Fig 2.

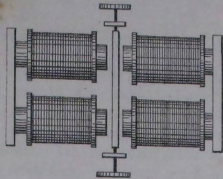
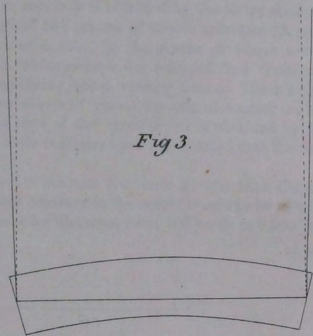
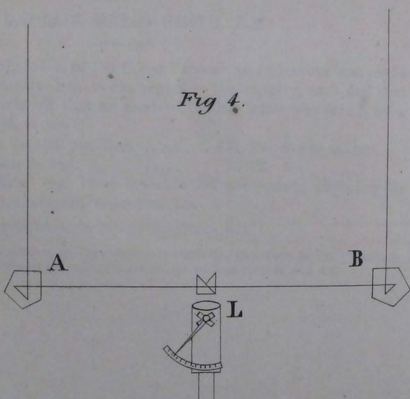


Fig 3.



INSTANTANEOUS TELEMETER.

Fig 4.



Lithographed at the Royal Artillery Institution.

of double reflection instead of mirrors, and by the enlargement of the measured angle by a purely optical arrangement, instead of a mechanical one.

Two telemeters on the above principle have been constructed in France, the one with a vertical base, the other with a horizontal one. We will not describe the former for the following reasons. 1st. In consequence of the errors already alluded to, which arise from refraction, these are much greater even for a base of ten feet than is generally supposed. 2nd. Because masts of ships, flagstaffs, houses, &c., in fact, vertical lines generally, being usually more distinct than horizontal ones, greater accuracy is obtained by the latter method.

The horizontal telemeter consists of two prisms of double reflection (A and B) Fig. 4, placed at the extremities of a tube, in the centre of which are two isosceles triangular prisms. The luminous rays are reflected from these to the object glass L of a telescope magnifying about twenty times. These rays are afterwards conveyed through two sheets of glass, the one moveable, the other fixed; the coincidence of the two rays of the same object is obtained by inclining the moveable plate, and a needle indicates upon a graduated limb the corresponding distance.

The angle described by the needle is about 250 times greater than the angle measured, and for that reason great accuracy in the result is said to be obtained. The instrument is capable of measuring distances from 100 yards to 6,000 yards.

M. G.

PAPER IX.

NOTE ON THE COST OF A SOLDIER.

By CAPTAIN PERCY SMITH, R.E.

In Vol. XVI., pages 87, 101-4, of the Corps Papers* an endeavour was made to shew that a soldier employed on works repaid to the country, each day that he was so employed, nearly all that he received, which latter was found, by a process † therein detailed, to be—

For a soldier of R.E. 2s. 10d. per diem	£51 18 6	per annum.
For a soldier of the Line 2s. 4½d. „	43 12 5	„

And it was expressly stated that these amounts did not include anything for cost of officers, hospitals, transport, recreation, &c.

* Notes on military and convict labour, by Captain Percy Smith, R.E.

† This was merely the calculation by Quartermaster Connolly, published in the "Military Opinions" of Sir John Burgoyne, expanded and corrected for modern rates of pay, &c.

In fact, they represent only the pecuniary value to the soldier of his situation.

It has been objected that these sums appear too low, and an officer writes—"Everyone knows that a soldier costs £100 a year."

This appears by the newspapers to be a general idea; it is arrived at by dividing the total amount of the army estimates (about 14 millions) by the number of soldiers in the *regular* army (about 140,000).

Such a rough calculation leads, however, to an erroneous impression, as the army estimates include provision not only for *regular* soldiers, but also for Militia, Yeomanry, Volunteers—stores for all these—heavy guns—the manufacturing departments, and even for the civilians on the ordnance survey!

In order to check the accounts given in the paper above referred to the writer has made an analysis of the army estimates for 1866-7, thus arriving at the information by an entirely different process, and as the subject may be of some general interest he appends the result. (See Appendix.)

The estimates for 1866-7 have been chosen as representing the normal condition of the army estimates, being clear from expenditure connected with the Abyssinian War and other complications.

From the analysis in the appendix it will be seen that the items composing the army estimates may be divided into four classes.

1. Those forming the direct emolument received by the soldier—the pecuniary value of his situation.

2. Those connected with administration, discipline, &c., necessary for the soldier, but from which he derives no pecuniary advantage.

3. The charges for fortifications, heavy guns, &c., which, though part of the defence of the country, hardly form a portion of the cost of the soldier himself.

4. The charges for the auxiliary forces, the ordnance survey, &c., which really do not bear on the cost of the regular soldier at all.

The statements in the succeeding paragraphs show in the first column the heads of expenditure as grouped in the analysis (see appendix), and in the second column the amount of this expenditure per man when divided among the *combatant* non-commissioned officers and rank and file of the regular army.

The items of the 1st class are—

Heads of Expenditure.	Amount per Combatant Soldier of Regular Army. £	s.	d.
Pay, non-com. officers and rank and file	27	12	9
Food (beyond what the soldier pays for rations, including cost of issuing)............................	4	3	9
Clothing	3	7	3
Pensions of non-com. officers and rank and file	9	5	0½
Lodging-money, fuel, light........................	2	12	0
	£47	0	9½

This is the average pecuniary value of a soldier's position, taking all regiments together, from the senior sergeant-major to the youngest drummer in the army. It will be seen that this amount does not differ materially from the mean between the cost of a sapper and that of a Line soldier, as given in the paper above referred to. The value of the position of a private in the Line has been estimated at about £39, but the estimate given above includes all non-commissioned ranks and all branches of the service, which accounts for the difference.

The items composing the second class are—

Heads of Expenditure.	Amount per Combatant Soldier of Regular Army. £ s. d.
Pay of officers	10 12 0¾
Pensions &c., of officers	5 12 8
Recruiting	0 11 6
Horses	3 8 10
Instruction, recreation	0 16 10
Hospitals and medical officers	3 1 8
Divine service	0 6 3
Martial law (after deducting soldier's forfeited pay)	0 3 0
Arms and accoutrements	0 4 7
Lodging-money, fuel, light, for officers, both regimental and departmental; additions and repairs to barracks	5 6 4
Allowances in colonies for officers of regiments and departments to cover high price of provisions, &c.	0 15 5
Miscellaneous	0 13 1½
Movement by land	0 18 11
Administration (War Office and Horse Guards)	1 12 6
Superannuation of civilians	1 0 8½
Total	£35 4 4¾

The third class comprises the following items :—

Heads of Expenditure.	Amount per Combatant Soldier of Regular Army. £ s. d.
Fortifications and military store buildings	2 8 9
Manufacturing Departments	7 8 9
Military Store Department and stores	2 12 10
Total	£12 10 4

The items totally unconnected with the cost of the *regular* soldier, and forming the fourth class, are—

Heads of Expenditure.	Amount per Combatant Soldier of Regular Army. £ s. d.
Auxiliary forces	10 4 2½
Non-effective Auxiliary Forces	0 4 2
Ordnance survey	0 12 2
Total	£11 0 6½

Taking all the items together, we find that the total amount voted divided by the number of combatant non-commissioned officers and soldiers in the regular army, gives £105 16s. $0\frac{3}{4}$d, as the cost of each, including his proportion of everything in the estimate—auxiliary forces, heavy guns, surveys, &c.

It will be seen, moreover, that the $13\frac{1}{2}$ millions of the estimate provide for

129,347	Regular troops exclusive of officers and non-combatant branches.	
130,243	Militia	ditto
15,991	Yeomanry	ditto
155,216	Volunteers	(efficient)
13,242	Pensioners	(enrolled)
62,733	Out pensioners of Chelsea Hospital.	
759	Pensioners from auxiliary forces,.	
x	Superannuated civilians, pensioned officers, widows, &c.	

Therefore £105, instead of representing the cost of one combatant regular soldier only, really covers the expense of—

1	Regular soldier.
$1\frac{1}{8}$	Soldier of militia or yeomanry.
$1\frac{1}{5}$	Volunteer.
nearly 1	Individual (being either a retired officer, a pensioner, superannuated civilian, or widow).

P. S.

APPENDIX.

In the following table the amounts voted are grouped, for convenience, under different heads from those given in the estimates.

In the fourth column are shown the sums repaid from various sources, for example, by cadets for their education.

If the total expenditure be divided by the number of men, including non-combatants, in the regular army (which is the usual way of arriving at the sum of £100, as the annual cost of a soldier), we have a sum of £104 7s. $0\frac{1}{2}$d., as the proportionate charge for each man, including his share of everything in the estimates, auxiliary, forces, survey, &c.

The table shows how much of this charge of £104 7s. $0\frac{1}{2}$d. is due to each of the great items on which expenditure is incurred.

ANALYSIS OF ARMY ESTIMATES FOR 1866—7.

		Officers	7,150	
Numbers of regular army ...	Combatant	Non-commissioned officers	13,091	131,145.
		Rank and file	116,078	
		Native troops at Labuan	178	
	Non-combatant	Non-commissioned officers	363	
		Rank and file	1,435	

	Vote.	Amount voted.	Repaid from various sources during the year, see A. E. for 1867—8.	Nett expenditure during 1866—7.	Expenditure per man *including non-combatants* of regular army, being nett expenditure divided by 131,145.	Remarks.
		£	£	£	£	
Pay non-com. officers and men, including regiments, depôts, departmental corps, 'good conduct pay, good shooting pay, gratuities, miscellaneous pay, &c.	1	3,725,023	96,821	3,628,202	27 13 5	
Food non-com. officers and men, beside what the soldier pays for rations, (including pay of Commissariat for issuing, but not including Commissariat Staff Corps)	2	501,460	....	501,460	3 16 5	
Allowances to officers to cover high price of provisions	2	101,100	......	101,100	0 15 5	
Clothing, including cost of clothing establishment	3	454,400	13,551	440,849	3 7 3	
Officers, Regimental and Staff, including pay, command pay, mess allowance, and education	1 & 15	1,457,546	86,073	1,371,473	10 9 2	
Barracks, including lodging money, fuel, and light for all ranks, regimental and departmental; barrack department; also new barracks and repairs, with cost of civil superintendence	4 & 14	1,130,013	91,897	1,038,116	7 18 4	Of this £2 12s. is for lodging money, fuel, and light, for n.c.os. and rank and file.
Recruiting	1	78,207	2,518	75,689	0 11 6	
Horses, including regimental and staff veterinary surgeons, purchase of horses, medicines, and forage	1 & 2	457,120	11,947	445,173	3 7 10½	
Instruction.—Schools of gunnery, engineering, musketry, regimental schools and libraries	1	110,680	541	110,139	0 16 10	
Carried forward	...	8,015,549	303,348	7,712,201	58 16 2½	

	Vote.	Amount voted.	Repaid from various sources during the year, see A. E. for 1867—8.	Nett expenditure during 1866—7.	Expenditure per man *including non-combatants* of regular army, being nett expenditure divided by 131,145.	Remarks.
		£	£	£	£	
Brought forward............		8,015,549	303,348	7,712,201	58 16 2½	
Hospitals, medical officers, (staff and regimental,) and their education; Purveyors, and medicines, (not including Army Hospital Corps)	1, 7, 15	339,022	2,293	336,729	2 11 4	
Divine service	5	41,100	......	41,100	0 6 3	
Martial law (after deducting the forfeited pay of prisoners)	6	22,000	2,991	19,009	0 3 0	
Miscellaneous	17	94,800	3,788	91,012	0 13 1½	
Movement by land. Commissariat pay and transport	2	136,021	15,301	120,720	0 18 11	
Administration, including War Office and Horse Guards ..	18	212,800	....	212,800	1 12 6	
Fortifications and military store buildings	14	315,505	....	315,505	2 8 1½	
Stores.—Manufacturing departments	12	965,800	3,246	962,554	7 8 9	
Arms and accoutrements	13	30,510	....	30,510	0 4 7	
Military Store department, and military stores, (not including Military Store Staff Corps)	13	397,490	69,290	328,200	2 8 2	
Auxiliary forces.—Disembodied Militia	8	842,600	....	842,600	10 1 5	
Yeomanry	9	85,200	....	85,200		
Volunteers	10	348,100	239	347,861		
Pensioners	11	45,000	......	45,000		
Non-effective.—Officers	19 23 5	738,800	......	738,800	5 12 8	
N.c.o.s., rank and file	19 24 2	1,213,600	629	1,212,971	9 5 0½	
Civilians.......................	26	135,900	.....	135,900	1 0 8½	
Auxiliary	27	27,000	......	27,000	0 4 1	
Ordnance survey	16	88,300	8,549	79,751	0 12 2	
Total....	....	£14,095,097	£409,674	£13,685,423	£104 7 0½	Expenditure per man, including non-combatants.

The foregoing statement shows the expenditure on the different items divided among the whole of the non-commissioned officers and rank and file in the regular army, including the Army Hospital Corps, the Commissariat Staff Corps, and the Military Store Staff Corps; but as these are not combatants their cost should be charged to hospitals, food, and stores respectively.

When this is done* the proportion of the items of expenditure to be borne by each *combatant* soldier of the regular army will be as follows:—

Heads of Expenditure.	Amount per Combatant Soldier of Regular Army.		
Pay (non-com. officers and men)	27	12	9
Food (including cost of Commissariat Staff Corps)	4	3	9
Allowances to officers in lieu of provisions	0	15	5
Clothing	3	7	3
Officers' pay	10	12	0¾
Lodgings, fuel, light, barracks, &c.	7	18	4
Recruiting	0	11	6
Horses	3	8	10
Instruction and recreation	0	16	10
Hospitals (including Army Hospital Corps)	3	1	8
Divine service	0	6	3
Military law (deducting forfeited pay)	0	3	0
Miscellaneous	0	13	1½
Movement of troops inland	0	18	11
Administration; War Office and Horse Guards	1	12	6
Fortifications and Military Store Buildings	2	8	9
Manufacturing department	7	8	9
Arms and accoutrements	0	4	7
Stores, including Military Store Department and Military Store Staff Corps	2	12	10
Auxiliary forces	10	4	2½
Non-effective; Officers	5	12	8
Non-com. officers and rank and file	9	5	0½
Civilians	1	0	8½
Auxiliary	0	4	2
Ordnance Survey	0	12	2
Total amount per Combatant Non-com. Officer and private of regular army	£105	16	0¾

* This double operation is necessary, in order that the whole cost of the Army Hospital Corps, Commissariat Staff Corps, and Military Store Staff Corps, including clothing, lodging, &c., may be charged to hospitals, food, and stores respectively.

PAPER X.

ON THE STATICAL PRESSURE PRODUCED BY THE IMPACT OF A FALLING WEIGHT.

BY LIEUTENANT ENGLISH, R.E.

1.—In the course of the year 1867, it was found, by the officers of Royal Engineers engaged in the construction of iron defences, that armour bolts, although made of iron which well withstood the ordinary tests, sometimes failed in an unaccountable manner; and it was determined to try whether they could be tested in a way more reliable, and more resembling actual practice, under the blow given by a falling weight.

2.—After some experiments, the apparatus shewn in Figs. 1 and 2, plate I, was devised, and erected at the various contractors' works. It consists of a cross-bar, supported firmly except at the centre, and provided there with a hole fitting the head of the bolt E, to be tested, which hangs vertically from it. A block, D, also with a hole through the centre, surrounds the lower part of the bolt, and is supported by the nut; vertical pieces, C, C, rest one on each end of this block, and these rise up above the level of the cross-bar. Another block, B, resting on the upper ends of the vertical pieces, completes the apparatus; and a weight, A, moving between guides, is allowed to fall vertically upon the last mentioned block, the impact being transmitted through this and the vertical pieces, to the lower block, and thence through the bolt to the supports. The bolts tested are generally about two feet long and nearly three inches diameter, and when of good quality, it is found that a weight of one ton, falling through a height of thirty feet, will pull one of them in two in six or seven blows. This apparatus is now regularly employed for testing samples of all armour bolts made for the War Department, and a copy of it, recently erected by the Admiralty, is, I believe, to be seen in Chatham Dockyard.

3.—In the course of the experiments made with this apparatus, it was, however, noticed that many more foot-tons of work were always applied to break a bolt, than the number which it would give out before breaking, under the steady strain of a hydraulic testing machine. It was also noticed that the work accumulated in one heavy blow was much more effective than the same amount applied in a number of light ones; and that any increase in the mass of metal interposed between the falling weight and the bolt appeared to lessen the effect upon the latter. From these, and various other indications, it was judged that a considerable amount of the work applied was absorbed in the mass through which the blow was transmitted to the bolt.

4.—In order to obtain a more accurate knowledge of the amount of work and of the greatest pressure applied to a bolt under this test, it appeared desirable to attempt a mathematical investigation of the subject, and the calculations in the sequel were made to obtain, approximately, the conditions of motion of a body struck by another, moving with a known velocity. It is hoped that, if they should be borne out by experience, results may be deduced from them which will be useful, not only in the construction of armour bolts, but also in questions relating to the resistance of armour plates, and, generally, to the effect of a live load on any piece of construction, such as a girder or bridge.

5.—In order to obtain the approximate results in as simple a form as possible, several assumptions, not strictly correct, have been made, as follows :—

(1.)—The mass of each body is supposed to be collected at its centre of gravity, thus assuming that a body of any length consists of that length of an elastic substance without weight, with a heavy particle of the same mass as that of the body, at the centre of its length.

(2.)—The transverse elasticity of bodies has been left out of consideration.

(3.)—The elasticity of wrought iron, which is the only substance referred to in this paper, has been taken from experiments made for the War Department in Mr. Kirkaldy's hydraulic testing machine; the compressions or extensions under similar pressure or tension, however, naturally vary in every sample tested, as shown by the thin lines in plate II, where the ordinates represent pressures or tensions applied, and the abscissæ represent the corresponding alterations of length.

The mean values assumed in this paper are shewn by the thick lines in the same plate, and are obtained by supposing the ratio of alteration of length during extension or compression to the force applied, to be constant up to a certain force, whilst, on the application of any greater force, the amount of alteration of length, added to a constant quantity, is assumed to bear another fixed ratio to the force applied.

(4.)—The elasticity of iron is assumed to be perfect, as far as the calculations are concerned; that is, all the work which disappears in the form of heat is assumed to be lost during the return of the extended or compressed body towards its original shape. As the calculations to obtain the greatest pressure under impact are only concerned with the change of a body from its natural shape, and not with its return, no account has been taken of the work which disappears in this manner.

6.—If a rigid mass, moving with a given velocity, strike an elastic body of known mass, which is perfectly free to move, so as to compress or extend it, it is required to find the alteration in length of the elastic body at any time after impact, and also the velocity of such body; first, on the assumption that the compression or extension of the elastic body varies directly in a given ratio with the pressure or tension applied.

Let the velocity of the striking body be..... U_0
„ the mass of the striking body „ ... m
„ the mass of the body struck „ .... n
„ the area of the body struck „ .... A
„ the extension or compression produced in the body struck by a force E per unit of area „ l
„ the velocity of the striking body at any time t after impact „ .... u
„ the velocity of the body struck at the time t „ v

Then the compression of the elastic body at any time t after impact is $\int_0^t (u - v)\, dt$

The pressure at any time t tending to accelerate the mass n is $n\frac{dv}{dt}$, and this must be equal to the pressure retarding the mass m, $-m\frac{du}{dt}$, and also equal to the pressure produced by the compression or extension of the elastic body.

$$\text{Hence } -m\frac{du}{dt} = n\frac{dv}{dt} \qquad (1)$$

$$\text{and } n\frac{dv}{dt} = \frac{E\,A}{l}\int_0^t (u - v)\, dt \qquad (2)$$

Integrating (1),

$$m(U_0 - u) = nv$$

$$\text{and } u = \frac{m\,U_0 - nv}{m} \qquad (3)$$

Substituting this value in (2)

$$n\frac{dv}{dt} = \frac{E\,A}{l}\int_0^t \left\{\frac{m\,U_0 - (m+n)\,v}{m}\right\} dt$$

or,

$$\frac{dv}{dt} = \frac{EA}{nl}\int_0^t \left(U_0 - \frac{m+n}{m}\cdot v\right) dt$$

differentiating,

$$\frac{d^2v}{dt^2} = \frac{E\,A}{nl}\left(U_0 - \frac{m+n}{m}\cdot v\right) = \frac{EA}{l}\cdot\frac{m+n}{mn}\cdot\left(\frac{m}{m+n}U_0 - v\right) \qquad (4)$$

which is of the form

$$\frac{d^2v}{dt^2} = c^2(a - v)$$

but if

$$v = a - b \cos ct$$

$$\frac{dv}{dt} = bc \sin ct$$

$$\frac{d^2v}{dt^2} = c^2\, b \cos ct$$

$$= c^2\,(a - v)$$

hence equation (4) will be satisfied if

$$v = \frac{m}{m+n} \mathrm{U_o} - b \cos \sqrt{\frac{\mathrm{EA}}{l} \frac{m+n}{mn}} \,.\, t$$

and since when $t = o$, $v = o$,

$$b = \frac{m}{m+n} \mathrm{U_o}$$

and

$$v = \frac{m}{m+n} \mathrm{U_o} \left(1 - \cos \sqrt{\frac{\mathrm{E\,A}}{l} \frac{m+n}{mn}} \,.\, t\right) \qquad (5)$$

substituting this value of v in (3)

$$u = \mathrm{U_o} - \frac{n}{m}\left\{\frac{m}{m+n} \mathrm{U_o} \left(1 - \cos \sqrt{\frac{\mathrm{E\,A}}{l} \frac{m+n}{mn}} \cdot t\right)\right\}$$

$$= \frac{\mathrm{U_o}}{m+n}\left(m + n \cos \sqrt{\frac{\mathrm{E\,A}}{l} \frac{m+n}{mn}} \cdot t\right) \qquad (6)$$

also

$$u - v = \mathrm{U_o} \cos \sqrt{\frac{\mathrm{E\,A}}{l} \frac{m+n}{mn}} \,.\, t$$

And the compression or extension

$$\int_o^t (u - v)\, dt = \int_o^t \left(\mathrm{U_o} \cos \sqrt{\frac{\mathrm{E\,A}}{l} \frac{m+n}{mn}} \,.\, t\right) dt$$

$$= \mathrm{U_o} \sqrt{\frac{m\,n\,l}{(m+n)\,\mathrm{E\,A}}} \,.\, \sin \sqrt{\frac{\mathrm{E\,A}}{l} \frac{m+n}{mn}} \,.\, t \qquad (7)$$

this is a maximum, when

$$\mathrm{Sin} \sqrt{\frac{\mathrm{EA}}{l} \frac{m+n}{mn}} \cdot t = 1 = \sin \frac{\pi}{2}$$

hence maximum alteration of length $= \mathrm{U_o} \sqrt{\dfrac{mnl}{(m+n)\,\mathrm{EA}}}$ (8)

and time from impact of maximum alteration of length

$$= \frac{\pi}{2}\sqrt{\frac{mnl}{(m+n)\,\mathrm{EA}}} \tag{9}$$

the pressure produced by the maximum alteration of length $= \frac{\mathrm{EA}}{l} \times$ max. alteration

$$= \mathrm{U}_0\sqrt{\frac{m\,n}{m+n}\;\frac{\mathrm{EA}}{l}} \tag{10}$$

It is evident that at the time of greatest alteration of length the two bodies must be moving with the same velocity ; hence $u = v$, and substituting in (3)

$$\text{common velocity} = \frac{m\,\mathrm{U}_0 - n \times \text{common velocity}}{m}$$

$$\text{common velocity} = \frac{m}{m+n}\,\mathrm{U}_o\,. \tag{11}$$

When the body, supposed to be perfectly elastic, returns to its original shape, after alteration, we have

$$\text{alteration} = \mathrm{U}_0\sqrt{\frac{m\,n}{m+n}\;\frac{l}{\mathrm{EA}}}\cdot\sin\sqrt{\frac{\mathrm{E\,A}}{l}\;\frac{m+n}{m\,n}}\cdot t$$

$$= 0$$

$$= \sin\pi$$

Hence,

$$\sin\sqrt{\frac{\mathrm{E\,A}}{l}\;\frac{m+n}{m\,n}}\cdot t = \sin\pi$$

$$t = \pi\sqrt{\frac{m\,n}{m+n}\;\frac{l}{\mathrm{EA}}} \tag{12}$$

substituting this value in (5) and (6)

$$\text{velocity of } n = \frac{m}{m+n}\;\mathrm{U}_o\,(1-\cos\pi)$$

$$= \frac{2\,m}{m+n}\,\mathrm{U}_o \tag{13}$$

$$\text{velocity of } m = \frac{\mathrm{U}_o}{m+n}\,(m + n\cos\pi)$$

$$= \frac{m-n}{m+n}\,\mathrm{U}_0 \tag{14}$$

These values agree with those found by experiments on the impact of elastic bodies.

If the elastic body have any velocity V_0 before impact, the value $U_0 - V_0$ must be substituted for U_0 in all the above equations, and the common velocity will become

$$= \frac{m}{m+n}(U_o - V_o) + V_o$$

$$= \frac{m}{m+n} U_o + \frac{n}{m+n} V_o \qquad (15)$$

7. If, in the last section, the elasticity of the body struck be assumed to be such that the extension or compression varies directly as the force applied in a given ratio, up to a force E, per unit of area, which produces an extension or compression l, whilst beyond this point the alteration added to a constant quantity varies directly in another ratio with the force applied, as in Plate II.

If U_o be such that the maximum mutual pressure is less than E A, the problem will be the same as in section 6, but if the maximum pressure is greater than E A, let t_l be the time elapsed from impact before the mutual pressure becomes equal to E A.

Let the velocity of m at this instant be .... u_l

and the velocity of n .... v_l

Then by equation (7) of section 6,

$$U_o \sqrt{\frac{m\,n\,l}{(m+n)\,E\,A}} \cdot \sin\sqrt{\frac{E\,A}{l}\;\frac{m+n}{m\,n}} \cdot t_l = l \qquad (1)$$

and substituting the value of t_l obtained from this in equations (5) and (6), section 6.

$$v_l = \frac{m}{m+n} U_o \left(1 - \cos\sqrt{\frac{E\,A}{l}\;\frac{m+n}{m\,n}} \cdot t_l\right) \qquad (2)$$

$$u_l = \frac{U_o}{m+n}\left(m + n\cos\sqrt{\frac{EA}{l}\;\frac{m+n}{m\,n}} \cdot t_l\right) \qquad (3)$$

If, now, k be the sum of the constant quantity already referred to and of the actual compression of n under a force EA, the condition of n will evidently be the same as that of an ideal body of the same mass and dimensions, in which the alteration of form varies directly as the force applied, a force, EA, producing an alteration, k; and the problem will be solved by determining the original velocities of m and n, which will on this supposition produce, at a certain point, the respective velocities u_l, v_l, and the alteration of length k.

If U_1, V_1, be the required original velocities, t_k the time which has, under the above supposition, elapsed from impact, before the alteration of length k is produced,

$$k = (U_1 - V_1)\sqrt{\frac{k}{EA}\frac{mn}{m+n}} \cdot \sin\sqrt{\frac{EA}{k}\frac{m+n}{mn}} \cdot t_k$$

or,

$$\sin\sqrt{\frac{EA}{k}\frac{m+n}{mn}} \cdot t_k = \frac{k}{U_1 - V_1}\sqrt{\frac{EA}{k}\frac{m+n}{mn}} \qquad (4)$$

but from equation (6) section 6

$$u_l - v_l = (U_1 - V_1)\cos\sqrt{\frac{EA}{k}\frac{m+n}{mn}} \cdot t_k$$

$$= (U_1 - V_1)\sqrt{1 - \sin^2\sqrt{\frac{EA}{k}\frac{m+n}{mn}} \cdot t_k}$$

squaring, and substituting from equation (4).

$$(u_l - v_l)^2 = (U_1 - V_1)^2 - EA \,.\, k \,.\, \frac{m+n}{mn} \qquad (5)$$

from which $U_1 - V_1$, can be determined. The time t_k can be found by substituting this value in equation (6) section 6.

If v_k be the velocity which n would have had if V_1 were nothing, from equation (5) section 6

$$v_k = \frac{m}{m+n}\left(U_1 - V_1\right)\left(1 - \cos\sqrt{\frac{EA}{k}\frac{m+n}{mn}} \cdot t_k\right) \qquad (6)$$

but the actual velocity of n at this point is v_l, hence $V_1 = v_l - v_k$ (7)
and U_1 can be obtained by substituting this value in equation (5).

$$\text{The maximum mutual pressure will} = \left(U_1 - V_1\right)\sqrt{\frac{mn}{m+n}\frac{EA}{k}} \qquad (8)$$

and the common velocity accompanying this will

$$= \frac{m}{m+n}U_1 + \frac{n}{m+n}V_1 \qquad (9)$$

8. If the striking mass m in sections 6 and 7, instead of being rigid, be composed of a substance which is compressed or extended by a length h on the application of a force G to each unit of area, the other conditions being the same as in sections 6 and 7, let B and A be the respective areas of the masses m and n. Then if u, v, w, be the respective velocities of the centres of gravity of m and n and of their touching surface, at any time t after impact

$$-m\frac{du}{dt} = n\frac{dv}{dt} = \frac{GB}{h}\int_0^t \overline{u - w}\,dt = \frac{EA}{l}\int_0^t \overline{w - v}\,dt \qquad (1)$$

Hence $\mathrm{GB}l \int_o^t udt - \mathrm{GB}l \int_o^t wdt = \mathrm{EA}h \int_o^t wdt - \mathrm{EA}h \int_o^t vdt$

$$\mathrm{GB}l \int_o^t udt + \mathrm{EA}h \int_o^t vdt = (\mathrm{GB}l + \mathrm{EA}h)\int_o^t wdt$$

and

$$\int_o^t wdt = \frac{\mathrm{GB}l \int_o^t udt + \mathrm{EA}h \int_o^t vdt}{\mathrm{GB}l + \mathrm{EA}h} \qquad (2)$$

and substituting this value of $\int_o^t wdt$,

$$\frac{\mathrm{GB}}{h}\int_o^t (u - w)\, dt = \frac{\mathrm{ABEG}}{\mathrm{GB}l + \mathrm{EA}h} \int_o^t (u - v)\, dt$$

and from equation (1)

$$- m\frac{du}{dt} = n\frac{dv}{dt} = \frac{\mathrm{ABEG}}{(\mathrm{GB}l + \mathrm{EA})h}\int_o^t (u - v)\, dt \qquad (3)$$

From this it appears that the equations giving the conditions of motion in this case may be obtained from those found in sections 6 and 7, by substituting for the expression of the form $\frac{\mathrm{E\,A}}{l}$, one of the form $\frac{\mathrm{ABEG}}{\mathrm{GB}l + \mathrm{EA}h}$

Making this substitution, we obtain from section 6, where the elasticity of the body struck follows a uniform law,

$$v = \frac{m}{m + n}\,\mathrm{U}_o\left(1 - \cos\sqrt{\frac{\mathrm{A\,B\,E\,G}}{(\mathrm{G\,B}\,l + \mathrm{E\,A}\,h)} \cdot \frac{m + n}{m\,n}} \cdot t\right) \qquad (4)$$

$$u = \frac{\mathrm{U}_o}{m + n}\left((m + n\cos\sqrt{\frac{\mathrm{A\,B\,E\,G}}{(\mathrm{G\,B}\,l + \mathrm{E\,A}\,h)} \cdot \frac{m + n}{m\,n}} \cdot t\right) \qquad (5)$$

$$u - v = \mathrm{U}_o \cos\sqrt{\frac{\mathrm{A\,B\,E\,G}}{(\mathrm{G\,B}\,l + \mathrm{E\,A}\,h)}\,\frac{m + n}{m\,n}}\;.\;t \qquad (6)$$

$$\int_o^t (u - v)\, dt = \mathrm{U}_o\sqrt{\frac{m\,n}{m + n}\,\frac{\mathrm{G\,B}\,l + \mathrm{E\,A}\,h}{\mathrm{A\,B\,E\,G}}}\;.\;\sin\sqrt{\frac{\mathrm{A\,B\,E\,G}\,(m + n)}{(\mathrm{G\,B}\,l + \mathrm{E\,A}\,h)\,m\,n}} \cdot t \qquad (7)$$

$$\text{maximum pressure} = \mathrm{U}_o\sqrt{\frac{m\,n}{m + n} \cdot \frac{\mathrm{A\,B\,E\,G}}{(\mathrm{G\,B}\,l + \mathrm{E\,A}\,h)}} \qquad (8)$$

From section 7

$$l = U_0 \sqrt{\frac{m\,n}{m+n} \cdot \frac{GBl + EAh}{ABEG}} \cdot \sin \sqrt{\frac{m+n}{m\,n} \cdot \frac{ABEG}{GBl + EAh}} \cdot t_l \quad (9)$$

$$v_l = \frac{m}{m+n} U_0 \left(1 - \cos \sqrt{\frac{ABEG}{GBl + EAh} \cdot \frac{m+n}{mn}} \cdot t_l \right) \quad (10)$$

$$u_l = \frac{U_0}{m+n} \left(m + n \cos \sqrt{\frac{ABEG}{GBl + EAh} \cdot \frac{m+n}{m\,n}} \cdot t_l \right) \quad (11)$$

Also the force EA will produce an alteration of length k, in the mass n; and at the same time an alteration $\frac{EAh}{GB}$ in the mass m. Hence, for k, the expression $k + \frac{EAh}{GB}$ must be substituted, and

$$\sin \sqrt{\frac{ABEG}{GBk + EAh} \cdot \frac{m+n}{m\,n}} \cdot t_k = \frac{GBk + EAh}{GB\,(U_1 - V_1)} \sqrt{\frac{ABEG}{GBk + EAh} \cdot \frac{m+n}{m\,n}}$$

$$= \frac{EA}{U_1 - V_1} \sqrt{\frac{GBk + EAh}{ABEG} \cdot \frac{m+n}{mn}} \quad (12)$$

$$(U_1 - V_1)^2 = (u_l - v_l)^2 + E^2A^2 \cdot \frac{GBk + EAh}{ABEG} \cdot \frac{m+n}{m\,n} \quad (13)$$

$$v_k = \frac{m\,n}{m+n} (U_1 - V_1) \left(1 - \cos \sqrt{\frac{ABEG}{GBk + EAh} \cdot \frac{m+n}{m\,n}} \cdot t_k \right) \quad (14)$$

$$\text{maximum pressure} = (U_1 - V_1) \sqrt{\frac{ABEG}{GBk + EAh} \cdot \frac{m+n}{m\,n}} \cdot \quad (15)$$

9. If a mass m, of area A, and which undergoes an alteration of length l, under a force E per unit of area, strike a fixed rigid mass,

Let U_0 be the original velocity of m, u the velocity at any time t.

$$\text{Then } -m\,\frac{du}{dt} = \frac{EA}{l} \cdot \int_0^t u\,dt$$

differentiating

$$\frac{d^2u}{dt^2} + \frac{EA}{ml} \cdot u = 0\,.$$

This equation, and the other conditions of the problem, are satisfied if

$$u = U_o \cos\sqrt{\frac{E\,A}{ml}} \cdot t \qquad (1)$$

$$\text{The alteration} = \int_o^t u\,dt$$

$$= U \cdot \sqrt{\frac{ml}{E\,A}}^{\,2} \cdot \sin\sqrt{\frac{E\,A}{ml}} \cdot t \qquad (2)$$

$$\text{and this is a maximum when} = U_o\sqrt{\frac{ml}{E\,A}} \qquad (3)$$

The greatest mutual pressure, accompanying the greatest alteration

$$= U_o\sqrt{\frac{m\,E\,A}{l}} \qquad (4)$$

If the ratio of the alteration of length to the pressure applied changes beyond a pressure E A, as in section 7, and if the maximum pressure is more than E A, let u_l be the velocity, and t_l the time from impact at which the pressure becomes equal to E A, and the alteration of length equal to l

$$\text{then } U_o\sqrt{\frac{m\,l}{E\,A}} \cdot \sin\sqrt{\frac{E\,A}{m\,l}} \cdot t_l = l$$

$$u_l = U_o \cos\sqrt{\frac{E\,A}{m\,l}} \cdot t_l \qquad (5)$$

As in section 7, assuming m to be a body in which a pressure E per unit of area produces an alteration of length k, let U_1 be the original velocity, t_k the time which would on this supposition have elapsed from impact,

Then,

$$k = U_1\sqrt{\frac{mk}{EA}} \cdot \sin\sqrt{\frac{EA}{mk}} \cdot t_k \qquad (6)$$

from which t_k can be determined ; and

$$u_l = U_1 \cos\sqrt{\frac{EA}{mk}} \cdot t_k \qquad (7)$$

$$U_1^2 = u_l^2 + \frac{E\,A}{m} \cdot k \qquad (8)$$

$$\text{The greatest pressure will} = U_1 \sqrt{\frac{m\,E\,A}{k}} \qquad (9)$$

If, as in section 8, the fixed body be elastic, and suffer a change of length h under a pressure G per unit of its area B. Then, as before, substituting for $\frac{E\,A}{l}$ the expression $\frac{A\,B\,E\,G}{A\,E\,h + B\,G\,l}$

we have

$$u = U_0 \cos \sqrt{\frac{A\,B\,E\,G}{A\,E\,h + B\,G\,l} \cdot \frac{1}{m}} \cdot t \qquad (10)$$

$$\left.\begin{matrix}\text{alteration of} \\ \text{length} \;..\end{matrix}\right\} = U_0 \sqrt{\frac{m\,(A\,E\,h + B\,G\,l)}{A\,B\,E\,G}} \cdot \sin \sqrt{\frac{A\,B\,E\,G}{(A\,E\,h + B\,G\,l)m}} \cdot t \qquad (11)$$

$$\text{greatest alteration} = U_0 \sqrt{\frac{m\;(A\,E\,h + B\,G\,l)}{A\,B\,E\,G}} \qquad (12)$$

$$\text{greatest pressure} = U_0 \sqrt{\frac{m\,.\,A\,B\,E\,G}{A\,E\,h + B\,G\,l}} \qquad (13)$$

Whilst, for pressures beyond E A

$$U_1^2 = u_l + E^2 A^2 \cdot \frac{G\,B\,k + E\,A\,h}{A\,B\,E\,G} \cdot \frac{1}{m} \qquad (14)$$

$$\text{and greatest pressure} = U_1 \sqrt{\frac{m\,.\,A\,B\,E\,G}{A\,E\,h + B\,G\,k}} \qquad (15)$$

10. The following calculation, to determine approximately the distribution of pressure and work among the various parts of the bolt-testing apparatus, described in section 2, will serve to shew the application of the preceding formulæ.

The solution is approximate only, on account of the complex nature of the action of a series of elastic bodies, striking one another, rendering it necessary to assume some arbitrary conditions; and it is accordingly supposed that the whole expenditure of work in each impact is confined to the two impinging bodies alone, and does not extend to the others of the series; and further, that each body, after being struck, and before striking the next, regains its original length.

The falling weight, and the whole of the apparatus, except the bolt, are made of armour plate iron, and are of the following dimensions—

Falling weight	A	$3{\cdot}0 \times 1{\cdot}\dot{5} \times 1{\cdot}0$ feet.
Block	B	$1{\cdot}5 \times 0{\cdot}\dot{6} \times 0{\cdot}\dot{6}$,,
Vertical pieces	C	$0{\cdot}\dot{6} \times 0{\cdot}\dot{6} \times 1{\cdot}2$,,
Lower block	D	$1{\cdot}5 \times 0{\cdot}\dot{6} \times 0{\cdot}75$,,
Bolt	E	$0{\cdot}2\dot{3}$ diam : $\times\ 2{\cdot}0$,,

The weights being	Tons.
A	1·00
B	0·1424
C	0·114
D	0·161
E	0·0184

And the consequent masses, that of 32·2 tons being the unit, for

A	0·031
B	0·0044
C	0·00354
D	0·005
E	0·00057

Then we have, first, A striking B, with a given velocity of 44 feet per second, and consequently with an energy of 30·06 foot-tons.

From plate II, it will be seen that armour plate iron is compressed 0·00868 of its length, by a pressure of 1000 tons on each square foot of area. (This corresponds to a compression of 0·01 of its length, under a pressure of 1152 tons to the square foot, or 8 tons to the square inch.)

By equation (8) of section 8

$$\text{maximum pressure on common surface of A and B} = U_o\sqrt{\frac{m\,n}{m+n} \cdot \frac{ABEG}{GBL + EAh}}$$

$$\text{and in this case } \frac{m\,n}{m+n} = 0{\cdot}0039$$

Also, the distance of the centre of gravity of A from the surface struck is 1·5 feet, and the corresponding distance in B is $0{\cdot}\dot{3}$ feet; and the areas of A, B are $1{\cdot}\dot{5}$ and 1·0 square feet respectively. Hence, calculating dimensions in feet, and pressures in tons,

$$\frac{A\,B\,E\,G}{G\,B\,l + E\,A\,h} = \frac{1{\cdot}0 \times 1{\cdot}\dot{5} \times 1000 \times 1000}{1000 \times 1{\cdot}\dot{5} \times 0{\cdot}00868 \times 0{\cdot}\dot{3} + 1000 \times 1{\cdot}0 \times 0{\cdot}00868 \times 1{\cdot}\dot{5}}$$

$$= 88778.$$

$$\text{maximum pressure between A, B,} = 44{\cdot}0 \times \sqrt{0{\cdot}0039 \times 88778}$$

$$= 821{\cdot}04 \text{ tons}$$

Also, from equation (11) section 6

$$\text{common velocity} = \frac{m}{m+n} U_o$$

$$= 38{\cdot}5 \text{ feet per second}$$

$$h = 0{\cdot}0513 \; \frac{0{\cdot}0208 \times 49{\cdot}3}{20}$$

$$\frac{E^2 A^2}{m} \cdot \frac{G B h + E A h}{A B E G} = 728{\cdot}4$$

$$U_1^2 = 865{\cdot}183 + 728{\cdot}4$$

$$U_1 = 39{\cdot}9$$

From equation (15) section 9

$$\text{Maximum pressure} = U_1 \sqrt{m \cdot \frac{A B E G}{A E h + B G h}}$$

$$= 72{\cdot}89 \text{ tons}$$

$$\text{Extension of bolt} = {\cdot}02 + (0{\cdot}4 - 0{\cdot}02) \; \frac{72{\cdot}89 - 49{\cdot}3}{80{\cdot}12 - 49{\cdot}3}$$

$$= 0{\cdot}31 \text{ feet}$$

Foot tons absorbed $= 18{\cdot}21$

$$\text{compression of supports} = \frac{72{\cdot}89 \times 0{\cdot}0208}{20} = 0{\cdot}075 \text{ feet.}$$

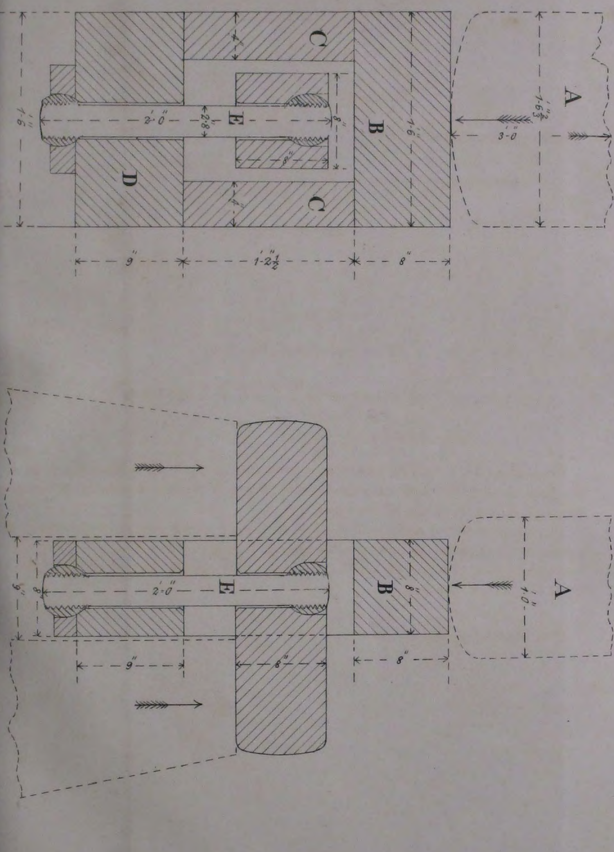
Foot-tons absorbed $= 2{\cdot}73$.

From Plate II, it will be seen that a pressure of 72·89 tons upon the area o the bolt, or of 1,703 tons upon the square foot, will produce a permanent exten sion in a bolt 2 feet long, of 0·13 feet.

The mean of ten experiments in the bolt-testing apparatus gives an observe permanent extension, in bolts similar to that shewn in Plate I, of 0·12 feet, cor responding to a pressure of 1,640 tons upon the square foot, or of 70·19 ton upon the area of the bolt.

T. E.

27th September, 1869.



Lithographed at the Royal Artillery Institution.

PAPER XI.

THE FRENCH ATLANTIC ELECTRIC TELEGRAPH CABLE.

By CAPTAIN VETCH, Royal Engineers.

French concession and formation of a company.

On the 6th July, 1868, a concession was obtained by the Baron Emile d'Erlanger and Mr. Julius Reuter from the French Government, for the laying telegraphic communication by a submarine cable between France and the island of St. Pierre, a French fishing station off the coast of Newfoundland; and a further arrangement was made with the state of Massachusetts to continue a submarine cable on from St. Pierre to Duxbury Cove, near Boston, Massachusetts; and on the 10th August, the same year, a company, having the title of the "Société du Câble Transatlantique Français (Limited)," was incorporated in London, with a capital of £1,200,000 sterling, to carry out the project.

Contract with the Telegraph Construction and Maintenance Company.

Before the formation of the company, the concessionaires had already entered into a contract with the Telegraph Construction and Maintenance Company, for the manufacture, shipping, transport, and laying of the whole line of cable, at a cost of £920,000; and the new French Company was, therefore, formally substituted for the concessionaires in this contract. The whole work of constructing and laying the cable was thus placed in the hands of the Telegraph Construction Company, which was bound by its contract to hand over the line laid complete, and in good working order after one month's testing. The Telegraph Construction and Maintenance Company was formed some five years back to combine the works of the Gutta Percha Company, in the City Road, London, with those for cables, of Messrs. Glass, Elliott, & Co., at Greenwich. These firms had carried out the construction and laying of the Atlantic cables of 1865 and 1866, and, therefore, the Telegraph Construction Company, as their successor, was most fitted for successfully laying the new cable.

Description of cables.

The whole line was divided into two sections, separately contracted for, No. 1 comprising the length between Brest and St. Pierre; and No. 2, that between St. Pierre and Duxbury, Massachusetts. In each section three descriptions of cable were used; those in No. 1 section, designated A, B, and C; and those in No. 2 section, D, E, and F. A and D were the main cables of their respective sections; B and E the intermediate cables, or portion between the main cables and the shore ends; and C and F were the shore ends.

1st Section—Brest to St. Pierre.

Brest shore end cable,	C.	length	8	knots	—	weight	163	tons.
Brest intermediate cable	B.	„	107	„	—	„	668	„
Main cable	A.	„	2643	„	—	„	4366	„
St. Pierre intermediate cable	B.	„	20	„	—	„	125	„
St. Pierre shore end cable	C.	„	10	„	—	„	205	„
Total No. 1 section		„	2788	„	—	„	5527	„

2nd Section—St. Pierre to Duxbury.

St. Pierre shore end cable,	F.	length	11	knots	—	weight	182	tons.
St. Pierre intermediate cable	E.	„	33	„	—	„	207	„
Main cable	D.	„	700	„	—	„	2013	„
Duxbury intermediate cable	E.	„	21	„	—	„	133	„
Duxbury shore end cable	F.	„	11	„	—	„	186	„
Total No. 2 section		„	776	„		„	2721	„
Grand total		„	3564	„		„	8248	„

The length of the main cable of No. 1 section (A) was considerably in excess of that actually required in order to provide for accidents. A much smaller margin was allowed in the main cable of No. 2 section (D), as it was to be in comparatively shallow water, but for this same reason it was made proportionally heavier and stronger than cable A.

Description of cable A, section No. 1. Core.

The core of cable A, the main portion of the Atlantic cable, consists of a copper conductor, covered with four coverings of gutta percha and Chatterton's compound, alternated. The copper conductor is a strand of seven wires, the diameter of each wire being 0·054, and of the whole strand 0·168 of an inch. The copper conductor is laid up with Chatterton's compound, and covered with four separate gutta percha coatings, alternated with coverings of Chatterton's compound; the thickness of the four coatings of gutta percha and compound is 0·148 of an inch, and the diameter of the core is, therefore, 0·464 of an inch.

Jute serving.

The core is covered with a serving of twelve strands of well tanned jute, about 0·103 of an inch thick, making the total thickness of the cable 0·67 of an inch.

Outer sheathing.

Over the jute-serving is an outer sheathing composed of ten homogeneous galvanised iron wires, each served with five Manilla hemp strands steeped in tar; the diameter of each wire is 0·1, and of each served wire 0·245 of an inch. The average diameter of the cable is 1·1 inches.

Abstract of weights in one knot (from a specimen one foot long).

Core	Copper conductor	402	lbs. or	0·180	tons.
	Gutta Percha and compound	385	„	0·172	„
	Jute serving	234	„	0·104	„
Outer sheathing	Iron wire	1589	„	0·709	„
	Hemp strands	1091	„	0·487	„
	Total	3,701	„	1·652	

Total weight and breaking strain. The total length of cable A is 2,643 knots, and its weight 4,366 tons; the approximate breaking strain was found from experiment to be from 6·75 to 7 tons.

Description of cable B, section 1. Core and jute serving. The core of cable B is precisely similar to that of cable A, and is covered with a serving of well-tanned jute, 0·2 of an inch thick, and making the cable 0·864 of an inch in diameter.

Iron sheathing. The jute serving is surrounded by an iron sheathing composed of 12 B. B. iron wires, galvanized, and of No. 4 B. W. G.

Clark's outer covering. Outside the iron sheathing is a double serving, with right and left lay, of Clark's compound and yarn; the compound consists of mineral pitch and silica, in the proportions of 60 and 40 parts respectively, with sufficient mineral tar to give the requisite consistence; this is laid on after the first coating of yarn, and again after the second coating of yarn. The thickness of this covering is 0·125 of an inch. The average diameter of cable B is 1·5 inches.

Abstract of weights in one knot (from a specimen one foot long).

Core	787	lbs.	or	0·352	tons.
Jute serving	824	„	„	0·368	„
Iron sheathing	10,317	„	„	4·605	„
Clark's outer covering	2,064	„	„	0·921	„
Total	13,992	„	„	6·246	„

Total weight and breaking strain. The total length of cable B is 127 knots, and its weight 793 tons. The breaking strain is about 14·73 tons.

Description of cable C, section 1. Core, and 1st, or inner serving. The core of cable C, shore end cable, is precisely similar to that of A and B cables. Around the core is a serving of twelve strands of well tanned jute, 0·085 of an inch thick, making the thickness of the cable 0·634 of an inch.

1st, or inner iron sheathing. Over the first, or inner serving, is an iron sheathing, composed of twelve galvanized B. B. iron wires, of No. 6 B.W.G., making the diameter of the cable 1·062 inches.

2nd, or outer serving. Over the first, or inner iron sheathing, is a serving, composed of hemp steeped in tar, in two layers, with right and left lay, and 0·447 of an inch thick, making the diameter of the cable 1·956 ins.

2nd, or outer iron sheathing. Outside is a heavy iron sheathing of twelve strands, each strand consisting of three galvanized B. B. iron wires, of No. 3 B.W.G., or 0·237 of an inch in diameter. The average diameter of cable C is 2·5 ins.

Breaking strain. The approximate breaking strain is calculated at about 44 tons.

Abstract of weights in one knot (from a specimen one foot long).

Core -	787 lbs.	or	0·352	tons.
Inner serving	484	„	0·217	„
Inner sheathing	7,618	„	3·398	„
Outer serving	4,730	„	2·113	„
Outer sheathing	32,250	„	14·397	„
Total ...	45,869	„	20·477	„

The total length of cable C is 18 knots, and its weight 368 tons.

Description of cable D, Section 2. Core. The core of cable D, the main cable of the 2nd section, consists of a copper conductor covered with three coatings of gutta percha and Chatterton's compound alternated. The copper conductor is a strand of seven wires, the diameter of each wire being 0·030, and of the whole strand 0·087 of an inch. The conductor is laid up with Chatterton's compound, and covered with three separate coatings of gutta percha, alternated with three coverings of Chatterton's compound. The thickness of the three coverings of gutta percha and compound is 0·099 of an inch, making the diameter of the core 0·285 of an inch.

Jute-serving. The core is covered with a serving of well tanned jute, 0·0825 of an inch thick, making the diameter of the cable 0·45 of an inch.

Iron sheathing. Over the jute-serving is a sheathing of ten galvanised B. B. iron wires, of No. 8 B.W.G.

Clark's outer covering. Outside the iron sheathing is a double serving, with right and left lay, of Clark's yarn and compound, as before described. The thickness of this covering is 0·161 of an inch, and the total average diameter of cable D is 1·1 ins.

Approximate breaking strain. The approximate breaking strain is about 4·27 tons.

Abstract of weights per knot (from a specimen one foot long).

Core	Conductor	109 lbs.	or	0·0482	tons.
	Gutta percha and compound.	153 „	„	0·0683	„
Jute-serving -		244 „	„	0 1093	„
Iron sheathing -		4,367 „	„	1·9495	„
Clark's outer covering		1,568 „	„	0·7000	„
Total		6,441 „	,	2·8753	„

Total length and weight of cable D. The total length of cable D is 700 knots, and its weight 2,013 tons.

Description of cable E, section 2. Core and serving.

The core of cable E is precisely similar to that of cable D. It is covered with a serving of well tanned jute, 0·297 of an inch thick, making the diameter of the cable 0·879 of an inch.

Iron sheathing.

The jute-serving is surrounded by a sheathing, composed of 12 galvanized B. B. iron wires, of No. 4 B.W.G.

Clark's outer covering.

Outside this sheathing is a double serving, with right and left lay, of Clark's yarn and compound, as before described. The thickness of this covering is 0·12 of an inch, and the total average diameter of cable E is 1·5 inches.

Breaking strain.

The approximate breaking strain is about 11 tons.

Abstract of weights per knot (from a specimen one foot long).

Core	262 lbs.	or	0·116	tons.
Jute-serving	1,184 „	„	0·528	„
Iron sheathing	10,648 „	„	4·753	„
Clark's outer covering	1,965 „	„	0·879	„
Total	14,059 „	„	6·276	„

The total length of cable E is 54 knots, and its weight 340 tons.

Description of cable F, section 2. Core, inner serving, and inner sheathing.

The core, jute inner serving, and inner iron sheathing of cable F are precisely similar to those of cable D.

Outer serving.

Around the inner iron sheathing is an outer serving of hemp steeped in tar, in two layers, with right and left lay, and 0·441 of an inch thick, making the diameter of the cable 1·66 inches.

Outer iron sheathing.

Outside is a second iron sheathing of twelve strands of wire, each strand consisting of three galvanised B. B. iron wires of No. 4 B.W.G. The average diameter of cable F is 2·5 inches.

Breaking strain.

The approximate breaking strain is 41 tons.

Abstract of weights per knot (from a specimen one foot long).

Core	262 lbs.	or	0·116	tons.
Inner serving	244 „	„	0·109	„
Inner iron sheathing	4,367 „	„	1·949	„
Outer serving	3,501 „	„	1·563	„
Outer iron sheathing......	29,169 „	„	13·023	„
Total	37,543 „	„	16·760	„

Total length and weight of cable F.

The total length of cable F is 22 knots, and its weight 368 tons.

Manufacture.

The manufacture of the core of the cable was carried on at the Gutta Percha Works in the City Road, London, and the core was then sent to Greenwich to receive the external coverings.

"Great Eastern." The efficiency and special adaptation of the "Great Eastern" steamship as a cable vessel having been tested in laying the Atlantic cables of 1865 and 1866, her services were secured for this expedition, and it was arranged that she should lay the greater part of section 1. She was accordingly moored off Queenborough in the the Medway, where all the necessary alterations in her were made, and the cable sent down from Greenwich and coiled on board. Three large iron tanks were constructed to hold the cable, and to keep it under water until paid out. These tanks were of the following dimensions :—

Fore tank	51′ 6″ diameter,	20′ 6″ deep,	holding 720 knots.
Main tank	75′ 0″ ,,	16′ 6″ ,,	,, 1,113 ,,
After tank	58′ 0″ ,,	26′ 6″ ,,	,, 920 ,,

In order to build the main tank one mast of the ship had to be cut away, and stepped into a girder, and yet, notwithstanding the great size of these tanks, they occupy but an insignificant portion of the big ship.

The same picking up gear and paying out machinery, as were used for the 1866 cable, were refitted in the "Great Eastern."

Cable tanks. The end of cable A was placed in the testing room, and the cable then carried to the bottom of the main tank, and coiled there for 868 miles, when it was led to the after tank, in which 920 miles were coiled, and then to the fore tank, where 720 miles were coiled; from the fore tank it was then brought back to the main tank, and the remainder of cable A, about 135 miles, coiled over the original coil, then 107 miles of cable B over this, and, finally, 2½ miles of cable C over this again. The tanks were filled with water, which was always kept at the level of the top of the coil. The floors of the tanks were all above the water line of the ship, and by the arrangement of the cable described above, it was expected that the vessel would keep in good trim throughout the voyage.

The eye of each coil in the tanks was occupied by two telescopic square frames, one over the other; the lower one was extended upwards, and the upper one downwards; the cable passed out from the tank through the centre of the upper telescope by a series of rings, which confined its centrifugal tendency; when the tank was full of cable, the upper frame was contracted like a closed telescope, and the lower one extended to the level of the top of the coil; as the cable was paid out the upper frame was extended, and the lower one contracted, downwards, so that the top of the lower frame was always kept a little above the level of the top of the coil, while the bottom of the upper frame was kept a little higher still. A stout iron ring was fastened round the lower part of the upper frame; the cable passed under this, and up through the telescopic upper frame over a light iron wheel above the tank, and some seven feet above the deck; an iron ring prevented the bight of the cable, as it was drawn out of the coil, from lashing out under the influence of centrifugal force; from this ring, iron rods or spokes radiated to the circumference of the tank, where they were joined by another large iron ring; this light iron frame extending over the tank, and attached to the central ring, was called the "crinoline," and was lowered by pulleys from above with the upper telescopic frame; in the event of a foul "flake," * or any other accident, it pre-

* "Flake" is the name given to one layer of the coil in the tank.

vented the cable from rising above the level of the "crinoline," except through the telescope.

Conducting trough. From the light wheel over the tank, the cable passed into a wide wooden trough, lined with sheet-iron at the bottom, and having light wheels at intervals to lessen the friction against the bottom of the trough; this trough was some three feet above the deck, and conveyed the cable to the paying out machine.

Paying out machinery. The paying out gear was arranged in such a manner that no extra strain could be put on the cable in excess of that previously arranged, but the extra strain could, if necessary, be either reduced or removed by means of hand wheels. The cable first passed over six leading V wheels, and was pressed down into their grooved rims by a small weighted wheel, or jockey pulley, around the circumference of which there was a band of India rubber. The jockey more or less restrained the speed of the cable, according to the weights it carried, and the strain from these weights could be reduced or removed by turning a hand wheel. From the V wheels the cable passed four times round a large drum, about six feet in diameter, to which a constant restraining friction was applied, in the form of an "Appold" break. In this break both ends of the break strap were attached to one lever, so that when the drum began to turn, the lever with the weights attached to it was lifted, but as the weights were lifted the strap was slackened, and thus a constant friction, equal to the weights employed, was obtained. These weights could be attached or removed at pleasure, and a man was detailed to carry out any orders on this head. From the drum the cable passed under the dynamometer, or strain gauge-wheel. This was a very simple and extremely useful machine; a V wheel was attached by its axle to a frame fastened on the top of a vertical rod, the frame slid on vertical iron bars, the wheel, frame, and rod were a known weight, and weights could be added if necessary. The cable passing under the V wheel raised it more or less, according to the strain, which it registered by a pointeron a vertical scale. An indicator, worked by cogs, was attached to the drum, and showed on a dial, by means of three hands, the number of revolutions, up to 300,000. From the dynamometer the cable passed over a V wheel in the stern bulwarks, and glided into the sea.

Picking-up machinery. The machinery in the bow, intended for picking up and for grappling, was similar in character to that used for paying out, but was more simple, stronger, and heavier, as the strains met with in grappling are frequently very high. There was an auxiliary engine of 70 horse power to work the drum in the bow.

Other vessels employed. In addition to the "Great Eastern" three other vessels were employed, viz., the "Chiltern," of some 900 tons register, the "William Cory," of about 1,100 tons register, and the "Scanderia," of about 1,400 tons register. The "Chiltern" carried a portion of the Brest shore end, cable C, part of main cable D, and the Duxbury intermediate and shore end portions of cables E and F. The "William Cory" carried the St. Pierre portions of cables B, C, E, and F, and part of the main cable D. The "Scanderia" carried the remainder of main cable D. Each of these three vessels was fitted with tanks, in which the cable was coiled, as in the "Great Eastern," round central telescopic frames. These tanks were securely decked over to prevent the cable from shifting its position during the voyage to the point where paying out was commenced. The paying out and picking up machinery were similar to the machinery in the "Great Eastern," though on a smaller scale.

Table No. 1.

A table, showing the description, length, weight, and distribution of the cable carried by each vessel is attached.

Steam steering gear.

Since the laying of the Atlantic cable of 1866, the "Great Eastern" has been fitted with steam steering machinery, by which one man at the wheel, either on the bridge or astern, has perfect control over the vessel in any weather, whereas it formerly required eight men to steer her, and in bad weather the wheels were double manned. The helm can now be put hard over, and by turning the paddles astern, and the screw ahead, the great ship can be made to turn in her own length.

By the terms of contract the cables were all to be completed by the 22nd of June, and the expedition was to be ready to start not later than the 25th June. This was easily accomplished; the "William Cory" left for St. Pierre at the beginning of the month, and the "Chiltern" went round to Brest a little later. The "Great Eastern," accompanied by the "Scanderia," left the Medway on the 12th June, and went round to Portland to coal, and at 8.30 a.m. on the 19th she finally left the shores of England on her third great cable-laying expedition.

Having received instructions from the Secretary of State for War to report on the laying of the French Atlantic Cable, and permission having been obtained from the Directors of the Telegraph Construction and Maintenance Company for me to accompany the expedition, I joined the "Great Eastern" at Portland.

Members of the expedition.

The principal members of the expedition were Sir Daniel Gooch and Mr. Rawson, on behalf of the Telegraph Construction Company, and Sir James Anderson, as Director General of the French Company. The contractor's staff consisted of Sir Samuel Canning, as Chief Engineer, assisted by Messrs. Temple, Bell, and London, with Messrs. Willoughby Smith and Laws as electricians-in-chief. The staff of the French Company consisted of Messrs. Fleeming Jenkin, Latimer Clark, and Charles Hockin, with Messrs. Cromwell Varley and Birtsch, as consulting electricians. The ship was commanded by Captain Halpin.

Arrival at Brest.

During the passage to Brest the cables in the several tanks were joined up in circuit, and the shore end prepared for splicing to the piece already laid by the "Chiltern." We arrived outside Brest about 4.30 p.m. on the 20th, and brought up close to the buoy marking the end of cable C, laid by the "Chiltern" from Point Minou. The "Chiltern" and the "Hawk," the latter with the Managing Director of the Construction Company on board, were awaiting us, and a dozen steamers from Brest crowded with passengers were soon steaming round and round us, in spite of a very fresh breeze blowing.

No time was lost in preparing to make the splice, as it was necessary to get away shortly after midnight, before the tide again turned. The "Chiltern" picked up the end of the shore cable, and then slowly worked up to the "Great Eastern" till her bow was close to our stern. Our end of the shore cable was then passed over, and hauled on board the "Chiltern," where the splice was made.

21st June. About two a.m the splice was completed and the bight thrown overboard, and the "Great Eastern," having weighed her anchor, steamed slowly ahead and commenced paying out, followed by the "Chiltern" on the starboard, and the "Scanderia" on the port quarter. The course the cable was to take was the shortest line between Brest and the tail of the Great Bank of Newfoundland, or that portion of a great circle passing through those two points. A special survey of the line for soundings had been made for the French Company in the spring of the year by Navigating Lieutenant V. F. Johnson, R.N., and a chart is attached, Pl. I, showing these soundings and the course of the cable. On leaving Brest the "Great Eastern" was in very good trim, carrying about 7,000 tons of coal, and over 5,000 tons of cable, and drawing about 32 feet of water forward and 34 aft, and until her trim was considerably altered by loss of cable and coal, she was remarkably steady even in bad weather. But although the arrangement of the cables in the several tanks already described tended to preserve the vessel's trim and steadiness for as long a time as possible, yet this arrangement had its disadvantages, for the manner in which the cable was disposed in the main tank tended greatly to confuse the signals, and for this reason; when a signal was sent from the ship, the current passing through the lower coil in the main tank at once induced a current in the upper coil, so that there was a double signal, that by the induced current being more rapid than the other, and it was some time before the telegraphists were able to distinguish and read the signals. The weather for the first week was most beautiful, bright warm days, with a perfectly calm sea, and all went well. The staffs of the Engineers and Electricians were divided into watches, kept by Greenwich time, and the most assiduous and unremitting attention was paid to the cable and every part of the machinery. In the testing room the same unwearied solicitude was shown, and from the commencement of paying out until the cable was laid (except when the cable was buoyed), there was always someone anxiously watching the little spot of light from the reflecting galvanometer on the scale. A description of the testing arrangements, with abstracts of some of the tests made during the voyage, is attached.

The heavy shore end was all paid out about half-an-hour after starting; at the junction of cable C with B, and, again, of B with A, one quarter of a mile of taper was allowed, so that the cable of thicker diameter gradually assumed the size and description of that of smaller diameter.

22nd June. The intermediate, or B cable, was all paid out about 12.30 a m. on the 22nd. (The hour must always be understood to be Greenwich time unless specified to the contrary). The speed of the paying-out ship, it was arranged, should not exceed six knots per hour, and the slack cable paid out was to be kept, as nearly as possible, at the same rate as in laying the Atlantic cable of 1866, *i.e.*, between 12 and 14 per cent.

23rd June. At 1.25 a.m. the speed of paying out was reduced to three miles per hour, and at 1.50 a.m., the upper coil of cable in the main tank was all paid out, and the change made to the forward tank. This was done without any difficulty whatever, the plough in the drum was shifted to suit the diminished size of the cable, and at 1.55 a.m. the splice between the main and fore tanks passed overboard. The signals hitherto had on shore appeared to have been those made by the induced current, and as this ceased on the removal of the upper coil, the telegraphists on shore were again somewhat puzzled.

24th June. At 3.27 a.m. a gong, which was suspended near the testing room, was sounded, a signal that the little spot of light had left the scale, and, therefore, that a fault must have occurred. In accordance with instructions previously issued the engines at once reversed full speed astern, and as soon as the ship's way was stopped, rope and chain stoppers were put on the cable; the cable was then cut, and the end passed round the forward drum through the machinery in the bow. The auxiliary engines in the bow turned the bow-drum, and hauled the cable back through the machinery in the stern, which was simply reversed. Hitherto faults had always been recovered by shifting the cable from the stern to the bow, steaming ahead, and hauling in, and this was the first time that it had been done by going astern and hauling it back through the paying out gear, reversed; manifestly a much more simple arrangement. Captain Halpin took up a position close to the stern V wheel of the paying out gear, where he was able to observe the position of the cable, and also the strain shown by the dynamometer, and as the helmsman was now shifted from the bridge to the stern wheel he was close to the captain, and by means of pneumatic tubes, the latter could also communicate with either engine room, and thus had complete control of the ship, and could regulate her movements as circumstances required. In this way, sometimes stopping when the cable was being cut and tested, sometimes going astern and picking up, some $2\frac{1}{4}$ knots were picked up. The cable had been cut three times, with the hope of finding the faulty piece, which at length really was recovered and cut out. The strain on the dynamometer previously to the fault was about 8 cwt., while during its recovery it had risen to 83 cwt. The depth of water was about 2,400 fathoms. At about 8.40 a.m. the joint was commenced, and the splice was finished and paying out resumed about 10 a.m.

The term "joint" it should be observed, applies only to the junction of the cores of the cable, *i. e.* of the conductors, gutta percha and compound. The term "splice" applies to the junction of the servings and outer coverings. To form a joint the gutta percha and compound round the copper wire are cut away for some inches, and the copper wire strands are filed to a long bevil, and made perfectly bright with emery paper. They are then soldered together and are firmly bound round with fine wire, which is soldered to the conductor only at the ends, so that should the conductor become separated by any strain on the cable, the fine wire would still maintain the conduction. This binding with fine wire is repeated, then rubbed bright and coated with Chatterton's compound. The gutta percha adjacent is heated by a spirit lamp, and pushed forward, first from one side to cover the joint, and then from the other side so as to overlap the first; three or four pieces of gutta percha are then heated and applied separately as coverings, with a coating of compound between them; they are firmly pressed together and then placed in ice to cool quickly before the splice is commenced. The joint is tested, and the splice then made by untwisting alternate wires and the jute serving, and having re-covered the joint with the serving from the opposite side, twisting in the alternate wires. The wires are cut so that the joints shall not coincide, and where the joints occur the cable is firmly bound round with yarn.

At about 11.30 a.m. the gong again sounded the alarm, and caused great consternation at the prospect of so speedy a repetition of the morning's work. The ship had, however, hardly been stopped when the spot of light returned to the scale, and it was afterwards ascertained that this, and several other temporary disappearances were caused by the carelessness of a clerk at Brest.

On examining the piece of cable cut out this morning it was impossible, with the closest scrutiny, to detect any injury to the outside wires or hemp, or to the jute serving. In the core itself, however, there was a small puncture, barely extending to the copper; the hole was of the shape and size that would be made by a small tack. It was impossible to say how it could have happened, nothing remaining in the hole to shew its origin, as in the 1866 cable, when a small piece of outside wire was found stabbing the cable on each occasion of a fault occurring.

26th June. About 9.17 a.m. the gong again sounded and the engines were reversed, and by 9.35 a.m. the stoppers were put on the cable, which was cut, and passed round the forward drum. At 10.37 a.m. the picking up ceased, the fault was cut out, and, on the completion of the joint and splice, about 12.14 p.m., paying out re-commenced. The weather continued so fine that the faults, although causing the most tiresome delays, gave no real cause for anxiety. On examining the faulty piece of cable no mark could be discovered on the exterior or on the serving. The position of the fault in the piece cut out was ascertained by joining one end of the piece of cable to a battery and insulating the other, and bringing a wire from the other pole of the battery in connection with a wet sponge, which was passed along the serving until the exact spot was indicated by the galvanometer on the completion of the circuit. The serving was then taken off very carefully, and was found slightly stained on the inside, as if by chemical action, and some of the fibres were cut, but this was only seen on very attentive examination. In the gutta percha there was a little hole, and the instrument with which it had been made had indented the copper wire and brightened it a little. As with the previous fault, no explanation could be given to account for its origin. The amount of cable picked up and cut out was about one knot, and occupied about 45 minutes.

29th June. Shortly after midnight the cable in the fore tank was all paid out, and the change made to the after tank. The distance between the two tanks being considerable, some care was required to effect the change without mishap. The engines were stopped and went astern, so as to stop all the ship's way as the bight passed out of the forward tank. As the last turn left the fore tank, the rings of the telescopic frame, which are hinged, were opened, and the bight passed out of the tank, and was seized by some of the men on deck, who walked away with it steadily to the after tank, near which the strain became too great to allow the men any longer to hold it, and it pulled itself out of their hands, straightened, and commenced paying out from the after tank. The cable in circuit at the time the change of tanks was made was :—

"C" cable, laid by "Chiltern"	-	5·58	knots.
"C" " " "Great Eastern" from main tank		2·41	"
"B" " " " " "		106·96	"
"A" " " " " "		135·59	"
"A" " " " " fore "		719·81	"
"A" not laid " " after "		919·70	"
		1890·05	"
Deduct for cable cut out	-	3·14	"
Total cable in circuit	-	1886·91	"

The main cable left in the main tank is not included in the above, as it was cut out of circuit on the 25th instant, to facilitate the signalling.

In the afternoon a breeze sprang up, which freshened towards evening; the barometer had been falling fast all the afternoon, and by night it was blowing half a gale.

30th June. It continued to blow all night, and at 5 a.m. this morning, there was a heavy gale from the east-south-east. The "Great Eastern" cut her way through the heavy sea with remarkable steadiness, and scarcely any rolling, and the paying out continued without any great increase of strain, the dynamometer ranging from 14 to 16 cwt. Every one was on the alert in case of any contre-temps in such wild weather. Our consorts, the "Scanderia" and "Chiltern," suffered a good deal, the sea appearing frequently to sweep right over them, and the latter vessel lost her starboard lifeboat. At 7 a.m. the sound of the gong, rising above the howling of the storm, announced that a fault had occurred. In rather less than thirty seconds the ship's way was stopped, and both screw and paddles turning astern full speed. The tests showed that the fault was close to the ship, and it was at once determined to back the vessel, and endeavour, notwithstanding the gale, to pick up the cable from the stern as before. Captain Halpin and Sir Samuel Canning took up their usual positions on the little platform projecting beyond the stern, where the cable, passing over the last V wheel, glides into the sea; the stoppers were put on the cable, which was cut, and passed round the bow drum, and the auxiliary engines commenced hauling in, while the ship was driven astern full speed in the teeth of the gale. By this time the fault was some way astern; the strain on the cable at once rose to 31 cwt., and after a few minutes to 47 cwt., and in the course of another twenty minutes, during which time some 70 yards were recovered, it rose to 65 cwt. Still the fault was overboard; it was slow work, and the picking up continued for a whole hour, putting the stoppers on occasionally when the strain was high, and driving astern till it fell, when picking up was resumed. It was certainly a bold attempt, and one attended with much difficulty, and demanding great judgment and experience—to haul in a cable in soundings of over two miles, by driving the ship astern against a heavy gale—and the strains registered were watched with the most anxious attention; during the last hour the strain varied from 45 to 90 cwt; the strain had not been excessive, and the fault once on board all would be well, and the excitement became intense. About three quarters of a mile had been recovered, and the strain had varied from 70 cwt. to 110 cwt.; the latter strain was caused by a heavy sea striking the stern, and suddenly raising it; picking up was discontinued for a few minutes, and on recommencing, another sea caught the vessel in the stern as before, and smashed the platform on which the captain was standing, deluged every one at the stern, and nearly washed the captain overboard. This sudden strain caused the cable to part, but very fortunately in-board, and nearly amidship. As it parted it lashed itself out along the deck, but injured no one, the stoppers were immediately put on at the stern, and the end seized in several places and secured. Large buoys constructed of iron, expressly for cable work, and fitted with flagstaff and flags, were always kept ready, and buoy ropes placed from the bow to the stern on each side of the ship to attach at once to the cable, should it be necessary to buoy it. As it was now quite evident that any further attempt to recover the fault in such weather would end still more disastrously, the cable was at once made fast to the buoy rope, and in about a quarter of an hour, the huge buoy was riding out the storm with the end of the cable attached to it.

The arrangement for fastening the cable to the buoy with a view to its easy recovery is ingenious. The buoy has an eye in the centre of its base, through which a riding chain is passed; one end of this chain is secured to a trigger catch in the side of the buoy above the line of flotation, and the other end hangs down; a hemp rope is fastened to the top of the buoy, and again to the free end of the riding chain below the eye in the base of the buoy. To this hemp rope is attached chain-shackling, and the cable is very securely fastened to this; about 50 fathoms of spare cable are allowed beyond the fastening, to form a bight, and this hanging end, when in the water, twists itself round the fastenings, and increases the security of the cable.

As soon as the cable was overboard, the "Scanderia" was directed to drop a mark-buoy about two miles to the eastward, and the "Great Eastern" proceeded herself to drop another about two miles to the south-east. These mark-buoys, like the cable-buoys, are very large, are painted red, and provided with flagstaffs and flags; their moorings consist of a Manilla hemp and steel wire cable of about 3,000 fathoms length, and a mushroom anchor, weighing 5 cwt. The three ships endeavoured to keep the buoys in sight all day, and at night stood off in a definite course to return at daylight.

1st July. This morning the wind had moderated, and the weather became quite fine; the buoys were sighted early, but the sea continued much too high all day to lower a boat, and attempt the recovery of the cable; the buoys were again, therefore, kept in sight till dusk, when the ships once more stood off on a course.

2nd July. At about 8 a.m., the recovery of the cable was commenced, the buoys having again been found without difficulty at about 6 a.m. Two boats were lowered, one from either side of the ship. The first made at once for the buoy, carrying a line from the "Great Eastern" to secure to the buoy, which was then hauled close to the ship; the crew of the second boat unfastened the hemp rope from the top of the buoy, and made it fast to a line from the "Great Eastern;" the trigger holding the riding chain was then struck, the chain and cable thereby at once freed, while the buoy, relieved from all restraint, bounded up, and was towed away by the first boat to the side of the ship, to be raised to its old place on deck; the cable with the riding chain hanging to it was hauled on board and passed round the bow-drum; the ship went astern, and the picking up of the cable for the recovery of the fault commenced.

About 10.30 a.m., the fault was cut out, one quarter of a mile of cable having been hauled in; the strain during the picking up ranged from 40 to 50 cwt. The joint was commenced at 10.43 a.m., and the splice finished, and paying out recommenced about 12.30 p.m. Immediately on the recovery of the cable a message was sent to Brest, stating what had occurred. While the splice was being made, the "Chiltern" and the "Scanderia" were sent to pick up the mark-buoys.

Upon investigating the cause of the fault, it was found to be almost precisely similar in character to the other two; the hole through the jute-serving was rather more distinct, and the cross section of the hole through the gutta percha was half moon shaped, instead of circular. A general opinion seemed to exist that these faults must have been the work of some malicious person employed to destroy the cable. There was no satisfactory way of accounting for them, and their discovery having always taken place as they passed into the sea, almost precluded the possibility of their existence in the cable while it was under water in the tank; (the water in the tank is generally kept at the level of one or two "flakes" below that being paid out) certainly a more opportune time for the destruction of the cable could not have been chosen than during such a gale, and having failed then, there seemed little chance of the accomplishment of any further malicious designs. However, after this, two of the officers of the ship were always placed on duty in the tank, and whatever may have been the cause, no more faults occurred in the cable.

6th July. The fine weather continued until this morning, when it blew very hard from the west and north-west, and there was soon a heavy sea on with the wind increasing; the barometer had been unusually low since the gale of the 30th ultimo, and was now rising rapidly. The "Scanderia" could not keep her position against the head wind, and was left far behind; she, however, made very good weather, and so did the "Chiltern;" but the "Great Eastern," being considerably lighter (by nearly 6,000 tons) than when she started, rolled very much, on one or two occasions as much as 27° each way, but the average amount was from 10° to 15°.

7th July. In spite of the heavy weather experienced yesterday and to-day, all went well, and the highest strain registered was only 17 cwt., clearly demonstrating that, in the event of no fault occurring, it is as easy for a ship like the "Great Eastern" to lay a cable in water three miles deep, and in half a gale of wind, as in water under 100 fathoms deep, and in calm weather.

At about 8 p.m. the cable in the main tank was again joined up in circuit, that in the after tank was all paid out, and the change to the main tank took place about midnight. It was very easily accomplished, the ship's way was stopped from slow speed in 8 seconds, which, when the momentum of this great mass is considered, shows no small power of control; it was done so quickly that the cable had to be hauled over the drum to get it to pay out. After the splice was made at 8 p.m., between the cable in the after and main tanks, great difficulty was experienced in getting the continuity signal, owing to the rolling of the ship, and a shunt of $\frac{1}{4}$ was required to keep the spot of light on the scale.

8th July. Last night was very wet, and the temperature was decidedly becoming colder, that of the sea having sunk during the night from 67° to 48° Fahrenheit, and there was a general expectation that we should fall in with ice before reaching the tail of the Great Bank.

9th July. The "Scanderia" and the "Chiltern" were sent forward on an early hour to look out for ice, and to take soundings. About noon we arrived at the point off the tail of the Great Bank of Newfoundland, (marked A on the chart, Pl. I. showing the course), latitude 42° 50′ N, longitude 49° 19′ W, and stood on, on the same course for three miles, and the "Chiltern" having, in accordance with previous instructions, found the tail of the Great Bank by sounding, and taken up a position off it in about 500 fathoms, we rounded her, and steered due west for 65 miles.

11th July. Yesterday there was a dense fog for the greater part of the day, and fog-horns and whistles were sounding incessantly; it cleared up in the afternoon, and the "Scanderia" and "Chiltern" went on in advance to take soundings. This morning between 4 and 5 a.m., a kink occurred in the main tank, the vessel was at once stopped, but fortunately it had disentangled itself before reaching the paying out gear, and the man stationed at the drum observed nothing of the kind pass through. The weather was again very foggy, and there was a high wind. Yesterday afternoon a telegram was sent to Brest, to be transmitted by Anglo-Atlantic telegraph to St. Pierre, to direct the "William Cory" to come to meet us at point B, (see Pl. I,) the entrance to the channel between the St. Pierre and the Green Banks, and pilot us through the channel. We had heard on the 25th ultimo of the arrival of the "William Cory" at St. Pierre, and since then she had been engaged in laying the St. Pierre portions of cables B and C, had buoyed the end, and had then placed a mark-buoy at point C (see P. I,) latitude 46° 16′ N., longitude 55° 12′ W., the other end of the Channel between the St. Pierre and Green Banks. About 6 p.m. the fog gradually rose, the sun shone, and there, about two miles ahead of us, were two steamers, which proved to be the "William Cory," and the "Gulnare," an Admiralty surveying vessel, in charge of Commander Kerr, R.N., who had come to render any assistance. Our position was very near point B, or latitude 45° 15′ N., longitude 55° 15′ W., and we shortly changed our course to the north, following the "Gulnare," and the "William Cory." At this time the "Scanderia" was close to us, but the "Chiltern" had not been seen since the fog cleared off, nor her whistle heard since early in the morning.

12th July. At 4 a.m., the wind freshened considerably, and there was lightning at intervals, and soon after we rounded the mark-buoy at point C, and made for the buoy to which the shore end laid by the "William Cory" was attached. About 5.30 a.m. a dense fog set in, and the accompanying vessels were lost sight of. The soundings gave about 74 fathoms. The wind was strong from west by north, and at 12.40 p.m., the ship having run the correct distance to the shore end buoy, and the weather being much too thick to allow us to find it, and too rough to allow of our making the splice if it were found, the ship was stopped, and the cable cut, sealed, and buoyed, the buoy having a mushroom anchor attached to it by a hemp cable. Sealing the end of the cable consists in heating the gutta percha, and drawing it over the copper conductor, so as not to leave it exposed, and then binding the whole of the end over with yarn.

13th July. The fog had all cleared off, and the sun rose clear in a cloudless sky; the sea was quite calm, and around us lay the "Scanderia," "William Cory," and "Gulnare," but the "Chiltern" was still missing. Stretched out before us, some seventeen miles away, were the islands of St. Pierre and Miguélon, with their rugged broken outline sharply defined against the clear sky, and with some brilliant patches of snow still left in one or two deep gulleys. On the north lay the coast of Newfoundland, with the large round top of Chapeau Rouge looming in the distance, and there close beside us was the main cable buoy. The shore end buoy was soon found, about two miles off, and it was determined to join the two ends with a piece of cable A from the "Great Eastern." The "Scanderia" proceeded to pick up the shore end, and to splice it to the end of a piece of cable A sent on board from the "Great Eastern;" while this splice was being made, the "William Cory" was sent to pick up the end of the main cable, and the "Great Eastern" steamed towards her, paying out as she went; but on arriving close to the "William Cory," the unwelcome intelligence was received, that some 70 fathoms of rope and chain had been picked up, a broken shackle discovered, and no cable could be found. At this juncture, the "Chiltern" arrived from St. Pierre, where she had gone, on losing us in the fog; the "Scanderia" had by this time completed the splice and thrown the bight overboard, so that the "Great Eastern" was in possession of the shore end, and the end of the main cable was at the bottom of the sea. The "Scanderia," "William Cory," and "Chiltern" now set to work to grapple for the lost cable, and as time went on, and the cable was not hooked at 6.30 p m., it was determined to take the "Great Eastern" to her anchorage before dark, and to leave the other vessels to complete the cable; the shore end was therefore sealed and buoyed; hardly had this been done, when a gun from the "William Cory" announced that the main cable had been recovered, and the "Chiltern" went at once to pick up the shore end, just buoyed by the "Great Eastern," and as there was sufficient slack, dragged it to meet the "William Cory," when the splice was completed, thrown over, and the first section thereby finished. Altogether, the completion of this section was rather a complicated manœuvre.

The "Great Eastern," on the recovery of the cable, steamed away for her anchorage, passing between the two Islands of St. Pierre and Miquélon, and bringing up in a large open bay formed by the long line of pebble bank joining Grand and Petit Miquélon, a bank longer and higher, but otherwise just such another as the Chesil Bank, at Portland, which we had left 25 days before. The splice was completed about 8.30 p.m. (ship's time), and the other vessels anchored near us about 11.30 p.m. (ship's time).

The total distance from Brest to St. Pierre, following the course of the cable, was 2,327 knots, and the total amount of cable used, and in circuit, was 2,575 knots, showing the per centage of slack to have been 10·65 on the whole distance.

Cable C paid out by "Chiltern"	5·5	knots.
" C " "Great Eastern"	2·5	"
" B " "	107·0	"
" A " "	2,430·0	"
" B " "William Cory"	20·0	"
" C " "	10·0	"
Total cable in circuit	2,575·0	"
Cable A cut out in faults	4.0	"
" left in main tank	209·0	"
Grand total	2,788·0	"

A small hut had been erected at the place where the shore end was landed at St. Pierre, and a trench was cut across the island to the town to take a subterranean cable, as the offices were to be in the town.

14th July. About 10 a.m. (ship's time), the "Gulnare," with the staff of electricians and clerks to be left at St. Pierre, and with the principal members of the expedition, left the "Great Eastern" and proceeded to the town of St. Pierre, about twelve miles from the anchorage. Having visited the Governor of the island, who received us most cordially, we went to the cable house, and remained there some time while the tests were being made. The expedition was now transferred from the "Great Eastern" to the three vessels,—the "Scanderia," "Chiltern," and the "William Cory"—about to lay the second section between St. Pierre and Duxbury.

15th July. A rendezvous of all the vessels was held about 3 p.m. (ship's time), off the cable house, when Sir Daniel Gooch landed, and formally handed over the 1st section to Sir James Anderson, as the representative of the French Company, the electricians having certified the line to be in good working order. The contractors continued liable for the cable for another month, and left an electrician in charge at St. Pierre, while Mr. C. Hockin remained there during the month to carry on tests and experiments for the French Company. About 3.30 p.m. (ship's time), the "William Cory" anchored as close as possible to the cable house, and commenced landing the shore end of the second section. Ten boats from the different ships were ranged at equal distances between the "William Cory" and the shore, a coir rope having first been stretched from the ship to the shore; a larger boat took on board a sufficient quantity of shore end cable properly coiled from the "William Cory," and made for the shore hauling on the coir line; as she went she paid out cable to the different boats, where it was at once secured at the bow and the stern of each boat; the end piece was then dragged up the rocks and rising ground to the cable house; when the end was secured the word was passed to cut the lashings, by which the cable was hanging to the boats; this was done simultaneously on firing a gun, and the cable sank to the bottom. An officer and two men were in each boat, and the landing of the shore end was thus very easily and quickly accomplished. The "Great Eastern" only waited to see the shore end landed, and to hear that it tested satisfactorily, when she steamed away on her return voyage to England.

The "Gulnare" towed the "William Cory" away from the shore, and then led the way out between the banks, and so as to avoid the other cables lying in these waters. The paying out commenced about 7 p.m. (ship's time), or 10.50 p.m. Greenwich time.

16th July. About 12.20 a.m. the "William Cory" was suddenly stopped, one of the outside wire strands of the shore end being paid out having broken and turned outwards, and on this part of the cable reaching the ring of the frame in the tank, it was caught, and the wire stripped off the cable for some way; this caused an entanglement, which jammed in the machinery; the ship was, however, stopped, and moved astern in time to prevent an excessive strain being brought to bear on the cable, which was repaired, and the ship proceeded. The weather was alternately fine and foggy all day, but at 11.30 p.m.. it came on very thick, and the "Chiltern," being unable to make her signals known, came alongside us to communicate; in doing so, she came a little too close, and although the two vessels appeared to be steering parallel courses, yet while the captains were engaged in hailing one another from the bridges, the vessels appeared to draw together sideways, as if by some powerful, but unseen, attraction; when Captain Edington, of the "Chiltern," perceived this, he went ahead full speed, but it was a little too late, and, while shooting ahead, the "Chiltern" continued to draw towards us, and before she had got quite clear the vessels came into collision; the great cable buoy on board the "William Cory" smashed the captain's gig on board the "Chiltern" into splinters, and bent the davits like pins; then the bow of the "William Cory" smashed the "Chiltern's" bulwarks, and also the stern girders and wheel of the paying out machinery, and if she had been a second later in clearing herself, her stern would have been broken in, and the vessel probably sunk. This incident showed the great imprudence of bringing large vessels close to one another to speak, when by a judicious system of signaling, and expert signallers, they could so easily communicate by steam whistle.

17th July. The "William Cory," finished paying out her cable at about 11.15 a.m., and as the sea was running high after a fresh breeze last night, it was impossible to make the splice, and transfer the expedition to the "Scanderia;" the end of the cable was buoyed, and the fleet put into Mira Bay, Cape Breton Island; here the damaged gear on board the "Chiltern" was repaired, and made good with that from the "William Cory," which was no longer required, and the expedition was shifted to the "Scanderia.

18th July. The squadron left Mira Bay about 2.50 a.m., but the cable-buoy was not found till 1 p.m., and, owing to the high sea running, it was 2.30 before the end of the cable was on board, and at 4.30 p.m., the splice being completed, paying-out was commenced from the "Scanderia." The mark-buoy, which was dropped some two miles from the cable-buoy, was picked up by the "William Cory;" the latter vessel accompanied us till we were off Halifax, where she put in to coal, and then returned to England.

20th July. Yesterday was very fine and all went well, but this morning about 7.9 a.m., the alarm was given; three flakes had fouled, and before the ship's way could be stopped, the entanglement had jammed in the paying-out machinery, and the strain thus suddenly thrown on the cable, caused it to part about $\frac{1}{4}$ mile from the ship. About this time the "Chiltern" was out of sight, having gone ahead to take soundings, and she was not seen again for two days; consequently, the "Scanderia" had no assistance, but had first to drop a mark buoy, then grapple for the cable, which was recovered after about six hours, then buoy the cable, then pick up the mark-buoy, and finally the end of the cable, so that by the time the splice was made and paying-out recommenced, it was 4.52 p.m.

22nd July. About 11 a.m. the cable was all paid out, and the "Chiltern" being still out of sight, we were obliged to buoy it, and a mark-buoy was dropped about a mile off. About 1 p.m. the "Chiltern" came in sight; our delay in losing the cable had led her to believe that we had passed her No time was lost in picking up the cable, which in these smaller vessels is done at the bow; the splice was made, and paying-out commenced about 6 p.m., the expedition having been transferred from the "Scanderia."

23rd July. Cape Cod was sighted at 9.30 a.m., and we were off it about 1 p.m., and as we were then about 30 miles from the landing place, the main cable was cut, (the whole of it not being required), and spliced on to the intermediate or E cable in the after tank.

The character of the country about Cape Cod is very low, and sandy near the sea, but rising into an undulating high ground in the interior. Duxbury beach is a fine stretch of sand, some three or four miles from the little village of Duxbury, near Plymouth, where the Pilgrim Fathers landed from the May Flower. A perfect swarm of boats came out to greet us as we approached the shore, and anchored about 7 p.m., at about 3 furlongs distance from it. The cable house was erected on the other side of a sand hill skirting the coast, and on the side of a knoll.

Preparations were now made for landing the shore end, and carrying it to the cable house. The cable was secured by stoppers, and then a coil made on deck of a sufficient length to reach to the cable house: a raft was then made on two boats, the junction of the cable coiled on deck with that in the tank was cut, and the deck coil, recoiled on the raft; the stoppers were then taken off, and the bight thrown overboard. A coir rope was stretched from the ship to the shore, the raft was towed by two or three boats rowing, and also hauling in the coir line: slowly paying out the cable by hand as it went, the raft reached the shore, and the end was duly landed and carried to the cable house.

Thus, the third Atlantic Telegraph Cable was successfully completed, and, although every description of accident had occurred, the circumstances had, on the whole, been propitious, and the skill of the Engineers equal to surmounting them all. Nearly every phase of cable laying had been encountered; in the 1st section, three faults had occurred, which were successfully recovered and cut out; picking up from the stern had, to a certain extent, been successful in a gale of wind; the cable had parted inboard, had been buoyed, and after two days, recovered in a depth of 1,800 fathoms; the course had been most accurately kept in spite even of foggy weather; the cable had escaped from the buoy, been grappled for, and recovered; an outside wire breaking, had stripped the outer covering for some way, and been effectually repaired; the paying out machinery of one of the vessels had been damaged by a collision, and repaired; a foul of three "flakes" had caused an entanglement, which, jamming in the machinery, strained the cable till it broke a quarter of a mile away from the ship, and the cable had been grappled for, and recovered: no less than six times was a buoyed cable picked up without difficulty. It may be gathered from the above, that with an efficient staff, good vessels, and a sound cable, the difficulties of cable-laying are reduced to a minimum.

I attach, together with two diagrams, an account of the tests which it was proposed to make during the laying of the cable, and which were carried out, as far as possible, in accordance with the programme.

Owing to the late period at which I proposed to contribute a paper on this subject, the space available is so limited that I am obliged to omit many details which would, I believe, be found interesting.

R. H. V.

APPENDIX.

ELECTRICAL TESTS.

Instructions for Ship and Shore.

1. The tests to be applied on shore may be put for convenience under five heads. The instruments on shore are to be connected, as shown in the diagram (No. 1), and not to be altered under any pretence throughout the voyage, unless instructions are received from the ship to do so.

2. The end of the cable must be brought direct to the testing room, and the conductor firmly secured to the switch S.

3. No. 1 arrangement consists of a very high resistance, R, permanently attached to the conductor, and one end of a galvanometer G, the other terminal of the galvanometer being connected to earth. This resistance being a variable one, it should be so adjusted as to allow a deflection of about 200 divisions on the scale of G from the tension of the ship battery. This deflection never, on any account, to be allowed to exceed 300. The purpose of this arrangement is to enable ships to signal to shore by either reversals or reduced or increased tension. It will also be an insulation and continuity test for shore, as well as a control tension test for ship.

4. No. 2 arrangement consists of a condenser, C, connected to an ordinary key, K, in such a way that it can be charged from the line at will, and discharged through the Galvanometer G′. This is to serve for a continuity test for ship, to ascertain the potential of the line at the shore end, and as a call signal when shore wishes to speak to ship.

5. No. 3 is an arrangement for enabling shore to speak to, or receive from, ship through a condenser, C′, which is connected to the line when required by means of the switch S″, so that either negative or positive currents from battery B may be sent into the condenser. This will produce on ship's insulation galvanometer deflections either to the left or right, which will represent dots or dashes in the Morse code.

6. No. 4 is an electrometer for ascertaining the potential of the line.

7. No. 5 is an ordinary bridge arrangement for testing the copper resistance of the line. It must be kept ready for use, but must not by any means be connected to the line until ship gives orders for the test to be made. It can then be attached to switch S by the wire leading to the resistance R, and it will thus not interfere in the slightest degree with the other connections.

8. The cable on board the "Great Eastern" will be joined into one entire length, and when joined to the shore end, ship will charge and commence the insulation test with 100 cells. This tension will be maintained throughout the

voyage, unless it should be thought prudent to alter it, of which due notice will be given to the shore.

9. The resistance, R, on shore must be so adjusted as to obtain the desired deflection on galvanometer G, and must not again be altered, unless the deflection exceed 300 divisions, or unless a serious fault occur, when it will have to be reduced until a sufficient deflection is obtained to enable ship to signal to shore. The deflections must be taken at stated intervals, directly after the zero of the instrument has been adjusted, and carefully tabulated for future reference.

10. The continuity test (No. 2 arrangement in diagram No. 1) will be applied every five minutes, commencing at the sixth minute after each hour, (unless shore is speaking to ship, when it can be discontinued during the time of speaking), and the discharge reading carefully tabulated. One charge of 10″ duration will be sufficient for this test. It is important, in order to make this reading very accurate, that it should be as high as possible, and therefore the readings should always be taken on the same side of the scale, with the zero point at the extreme end of the other side, by which means a reading of 600 divisions can be obtained. Shunts will have to be employed to regulate these readings. Shore must multiply these readings by the value of the shunt (which he will have previously determined), and telegraph to the ship the true value of his reading.

11. Ship will reverse the current every 15 minutes. In addition to this, ship will send four reversals of two minutes each, commencing at the 30th minute of each hour. After each of these reversals, the tension of the line must be taken on electrometer E, condenser C, and galvanometer G. As it is important that the potential should be taken on E and C simultaneously, S″ and S‴ will be generally connected together by means of a plug. Each of the four readings of each instrument must be sent to the ship by No. 3 arrangement in the diagram. The ordinary Morse "number" code to be used. The readings are to be taken at 31′ 30″, 33′ 30″, 35′ 30″, and at 37′ 30″. The reading of the electrometer test to be sent first, then the discharge reading from the condenser, and lastly the reading on G.

12. Ship's ordinary way of communicating to shore will be by K′ (diagram No. 2), and B′, the plug P‴ being first removed. At the end of each word, ship pauses long enough to get an approximate or accurate insulation reading.

13. To open communication with shore, ship will give three 20″ reversals, which will be continued with pauses between, until shore gives the "understand."

14. Shore's call signal will be one continuity test each minute until attention is secured. G G will be the signal for shore to commence speaking, but a reversal from ship will mean that shore is not to proceed speaking until the G G signal is given. G G would not be doubtful in case of a fault.

15. As ship will be on the alert for the hourly tension test from shore, shore need not send the call signal, but may at once proceed to transmit results, having first sent S S S.

16. If it be found necessary to add to, or alter any of these instructions, ship will do so by giving due notice to shore; but in no case is shore to depart from these instructions, unless ship gives permission to do so.

17. Should ship reverse the current while shore is speaking, or at any other time than that stated in the instructions, shore will understand it as a signal not to interfere in any way with the line until ship gives four 10″ reversals, when the ordinary signals or speaking may be proceeded with.

18. Ship will work to Greenwich time by chronometer, and shore must take that time as being correct, and work to it.

19. Should a misunderstanding arise while adjusting speaking instruments after the line or lines are laid, the paying-out speaking arrangements must be again adopted.

20. Records of the tests made, and results obtained, are to be carefully kept, both on ship and shore.

21. Once a day, ship will send distance run; miles paid out; and insulation resistance per mile in megohms.

Special Instructions for Ship.

1. The connections are to be made as in the diagram No. 2.

2. For ordinary insulation test, plug P must be inserted, and P′ and P″ removed.

3. Minute readings must be taken on G and recorded. Slide resistance SR and SR′ must not be used or interfered with except by the electrician on duty at the time. When required to ascertain the resistance of the G P by the slide arrangement, the plug P must be removed, and P′ and P″ inserted. When altering connections, care must be taken to shunt off the galvanometer G, so as not to allow too strong a current to pass though it. The resistance of SR and SR′ must be varied by the slides until the image on the scale of G stands at zero. If n be the number read on the slides; R, the resistance in line with the cable; and I the insulation resistance of the cable: then $I = R\left(\frac{10{,}000}{n} - 1\right)$. The same formula gives copper resistance if the remote end is put to earth.

R. H. V.

TABLE No. 1.—Shewing Lengths, Weights, and Distribution of the several kinds of Cable on board the different Ships.

Name of Ship.	Position of tank.	Lengths of Cables in Knots.						Total.	Grand Total.	Weights of Cables in Tons.						Total.	Grand Total.
		Section No. 1.			Section No. 2.					Section No. 1.			Section No. 2.				
		A	B	C	D	E	F			A	B	C	D	E	F		
"Great Eastern,"	Fore	719·815	......	......	......	....	......	719·815	......	1,189	......	....	....	....	....	1,189	......
registered tonnage	Main	1003·756	106·961	2·419	....	......	......	1113·136	......	1,658	668	49	......	......	....	2,375	......
about 13,343.	After	919·702	......	......	....	......	......	919·702	......	1,519	....	....	.....	......	....	1,519	......
		......	......	......	....	......	......	....	2752·653	....	......	.....	......	......	....	......	5,083
Chiltern,"	Fore	......	......	5·581	120·494	......	......	126·075	......	....	......	114	347	.....	......	461	......
registered tonnage	After	......	......	......	......	21·217	11·090	32·307	.....	......	......	......	....	133	186	319	.....
about 880.		......	......	......	......	......	......	......	158·382	....	......	.....	......	....	......	......	780
"William Cory,"	Fore	......	....	10·000	....	......	......	10·000	......	......	....	205	......	......	......	205	......
registered tonnage	Main	......	20·000	......	107·168	......	......	127·168	......	......	125	....	308	......	....	433	......
about 1,100.	After	......	......	......	22·132	33·021	10·895	66·048	......	......	....	....	64	207	182	453	......
		......	......	......	......	......	....	......	203·216	....	....	......	....	......	......	......	1,091
"Scanderia,"	No. 1 Fore	......	......	......	35·550	.... .	....	35·550	......	....	....	......	102	......	....	102	......
registered tonnage	No. 2 Fore	......	......	....	202·141	......	....	202·141	......	......	....	....	581	......	......	581	......
about 1,400.	No. 3 Fore	......	......	......	121·309	......	....	121·309	.. ...	....	....	....	349	......	....	349	......
	No. 4 After	......	......	......	91·000	......	....	91·000	......	......	....	......	262	......	......	262	......
		......	......	......	......	......	....	......	450·000	....	....	....	......	......	......	......	1,294
Total......		2643·273	126·961	18·000	699·794	54·238	21·985		3564·251	4,366	793	368	2,013	340	368		8,248

TABLE No. 2.—PAYING OUT LOG OF THE FRENCH ATLANTIC CABLE.

Paying out Ship the "Great Eastern." Description of Cable. Section 1. Brest to St. Pierre.

Date. 1869.	Ship's time. Hour.	Greenwich time Hour. p. m.	Depth of water in fathoms.	Latitude N.	Longitude W.	Tank	Maximum strain since last observation.	Distance run in the 24 hours.	Distance from shore at Brest.	Cable paid out in 24 hours.	Total Cable paid out.	Slack paid out in 24 hours.	Total slack paid out.	Description of Cable.
		h. m. s.		° ' "	° ' "		cwt.	knots	knots	†knots	knots	knots	knots	
								*5·0						
21st June	Noon.	12.23	67	48.18. 0	5.40.0	Main	10·25	45·0	50·0	52·16	52·16	2·16	2·16	C and B
22nd ,,	,,	12.36	85	48.30. 0	8.54.0	,,	9·95	130·0	180·0	134·90	187·06	4·90	7·06	B and A
23rd ,,	,,	12.48	900	48.30. 0	12. 0.0	Fore	10·75	123·0	303·0	128·69	315·75	5·69	12·75	A
24th ,,	,,	12.56	2,400	48.30. 0	14. 7.0	,,	80· 0	83·0	386·0	95·53	411·28	12·53	25·28	,,
25th ,,	,,	1. 8	2,510	48.54. 0	17. 0.0	,,	15·75	120·0	506·0	136·36	547·64	16·36	41·64	,,
26th ,,	,,	1.16	2,270	48.37. 0	18.57.0	,,	64·00	77·0	583·0	92·94	640·58	15·94	57·58	,,
27th ,,	,,	1.28	2,200	48.32. 0	22. 1.0	,,	18·00	123·0	706·0	138·00	778·58	15·00	72·58	,,
28th ,,	,,	1.41	2,000	48.22. 0	25.11.0	,,	17·00	126·0	832·0	141·00	919·58	15·00	87·58	,,
29th ,,	,,	1.52	1,925	48. 6. 0	27.50.0	After	17·00	107·0	939·0	123·00	1042·58	16·00	103·58	,,
30th ,,	,,	2. 0	1,925	47.56. 0	30. 5.0	,,	110·00	90·0	1029·0	101·39	1143·97	11·39	114·97	,,
1st July	,,	2. 0	1,925	47.57. 0	30. 4.0	Position of Cable end, which was buoyed.								
2nd ,,	,,	2. 1	1,850	47.57. 0	30.10.0	After	43·00	4·5	1033·5	4·61	1148·58	0·11	115·08	,,
3rd ,,	,,	2.12.40	1,945	47.26. 0	33.10.0	,,	15·00	125·0	1158·5	135·60	1284·18	10·60	125·68	,,
4th ,,	,,	2.24.16	2,400	46.54.22	36. 4.0	,,	15·75	124·0	1282·5	138·40	1422·58	14·40	140·08	,,
5th ,,	,,	2.35	2,430	46. 3. 0	38.47.0	,,	18·00	124·0	1406·5	141·00	1563·58	17·00	157·08	,,
6th ,,	,,	2.49.48	2,600	45.30. 0	41.42.0	,,	16·50	126·5	1533·0	142·90	1706·48	16·40	173·48	,,
7th ,,	,,	2.56.20	2,760	44.35.44	44. 5.0	,,	16·00	115·0	1648·0	134·10	1840·58	19·10	192·58	,,
8th ,,	,,	3. 6.12	2,760	43.50. 0	46.33.0	Main	17·00	115·0	1763·0	137·50	1978·08	22·50	215·08	,,
9th ,,	,,	3.17.16	not known	42.51. 0	49.13.0	,,	16·00	131·0	1894·0	142·50	2120·58	11.50	226·58	,,
10th ,,	,,	3.24.32	over 1,000	D.R. 43.23. 0	D.R. 52. 8.0	,,	10·00	153·0	2047·0	159·60	2280·18	6·60	233·18	,,
11th ,,	,,	3.39. 0	130	D.R. 44.53. 0	D.R. 54.45.0	,,	13·00	146·0	2193·0	154·40	2434·58	8·40	241·58	,,
12th ,,	,,	3.44. 0	90	46.21. 0	56. 0.0	,,	7·50	105·0	2298·0	110·42	2545·00	5·42	247·00	,,
13th ,,	,,	Ten miles of Cable C and 20 miles of Cable B. previously laid by the "William Cory."						29·0	2327·0	30·00	2575·00	1·0	248·00	B & C in "W. Cory"
			Greatest depth in fathoms 2,760.				Maximum strain on cable 110 cwt., and cable broke.		Total distance run in knots, 2327·0.		Total cable paid out in knots, 2575·0.		Total slack in knots, 248	

Remarks.

* This is the distance of the buoy at the end of the piece of the shore end laid by the "Chiltern" from the shore. The "Great Eastern" started paying out from this point at 2 30 a m , on the 21st of June.

† This amount includes the shore end laid by the "Chiltern."

The "Great Eastern" finished paying out Cable C at 3 a.m., on the 21st of June.

The "Great Eastern" finished paying out Cable B at 12.30 a.m., on the 22nd of June.

The "Great Eastern" finished paying out Cable A in upper part of main tank at 1.30 a.m., on the 23rd of June.

24th June—1st fault occurred at 3.27 a.m. ; cable picked up and fault recovered, and proceeded with paying out at 10.19 a.m.

26th June—2nd fault occurred at 9.17 a.m. ; cable picked up and fault recovered, and proceeded with paying out at 12.14 p.m.

29th June—Paying out of fore tank finished, and change made to after tank at 12.10 a.m.

30th June—3rd fault occurred at 7.7 a.m. ; cable picked up, and, in doing so, broke inboard ; was buoyed and left, a gale of wind blowing.

1st July—Sea too heavy to recover cable.

2nd July—3rd fault recovered, and proceeded with paying out at 12.30 p.m.

8th July—Paying out of after tank finished, and change made to main tank at 12.46 a.m.

10th July—No observations obtained on account of fog ; position by dead reckoning.

11th July—Ditto ditto ditto

12th July—Position of buoy of shore end laid by the "William Cory," was supposed to have been reached at 12.40 a.m , and there being a thick fog, the "Great Eastern" buoyed the end of her cable.

13th July—The junction between the shore end laid by the "William Cory," and the cable laid by the "Great Eastern," was made at about midnight.

The insulation resistance of the 1st section with zinc to line after 3 minutes electrification was 4,895 megohms per knot.

TABLE No. 3.—PAYING OUT LOG OF THE FRENCH ATLANTIC CABLE.

Paying out ships "William Cory," "Scanderia," and "Chiltern."

Description of Cable. Section 2. St. Pierre to Duxbury, Massachusetts, United States.

Date. 1869.	Hour, ship's time.	Hour, Greenwich time.	Depth of water.	Latitude N.	Longitude W.	Paying out ship.	Distance run since last observation.	Distance from the shore at St. Pierre.	Length of cable paid out since last observation.	Total length of cable paid out.	Slack paid out between observations.	Total slack paid out.	Description of cable.	REMARKS.
	h. m.	h. m. s.	faths.	° ′ ″	° ′ ″	Name.	Knots	Knots	Knots	Knots	Knots	Knots	Letter.	
15th July.	p. m. 7. 0	p.m. 10.30.0	..	....	....	"William Cory"	..	..	..	..	..	..	F, E, and D.	15th July—The "William Cory" commenced paying out from St. Pierre at 10.30 p.m.
16th ,,	noon	p.m. 3.50.22	200	46.24.0	57.59.0	,,	82	82	85	85	3	3		17th July—The "William Cory" finished paying out in foggy and rough weather, and buoyed the cable. The three vessels then ran into Mira Bay, near Scutari Point, and the Staff and instruments were moved to the "Scanderia."
17th ,,	a.m. 7.16	a.m. 11.15.0	92	45.37.0	59.46.0	,,	85	167	88	173	3	6	D.	
18th ,,	p.m. 1.0	p.m. 5.0.0	92	45.37.0	59.46.0	"Scanderia"	..	..	..	..	..	..	D.	
19th ,,	noon	p.m. 4.10.0	68	44.22.0	62.29.0	,,	141	308	147	320	6	12	D.	18th July—The "Scanderia" picked up the cable, spliced on, and commenced paying out at 5 p.m.
20th ,,	noon	p.m. 4.17.30	105	43.39.0	64.22.0	,,	98	406	101	421	3	15	D.	
21st ,,	noon	p.m. 4.26.0	70	42.55.0	66.31.0	,,	115	521	120	541	5	20	D.	20th July—At 7.9 a.m. the cable broke $\frac{1}{4}$ mile to sea, from three foul flakes jamming in the machinery; cable was grappled for and recovered, and paying out recommenced at 4.45 p.m.
22nd ,,	a.m. 6.27	a.m. 10.59.0	113	42.33.0	68.10.0	,,	80	601	82	623	2	22	D, E, and F.	
23rd ,,	p.m. 2.30	p.m. 7.12.0	..	42. 6.0	70.33.0	"Chiltern"	122	723	127	750	5	27		

Remarks continued.—22nd July—The "Scanderia" finished paying out her cable at 10.59 a.m., and the "Chiltern" not being in sight, the cable was buoyed. At 1.30 p.m. the "Chiltern" came in sight, and picked up the cable, spliced on, and commenced paying out at 6 p.m.

23rd July—The "Chiltern" anchored off Duxbury beach on the 23rd July, at 7.12 p.m., and the shore end was landed.

The insulation resistance of the 2nd section with zinc to line, after three minutes electrification was 4,571 megohms per knot.

Lithographed at the Royal Artillery Institution.

PAPER XII.

THE ABYSSINIAN RAILWAY.*

BY LIEUTENANT WILLANS, R.E.

When the Advance Brigade of the expedition arrived in Annesley Bay, in the latter part of October, 1867, they brought with them enough rails and sleepers to lay a mile of tramway, and a dozen light trucks to work it. It was originally intended to place the grand depôts some distance inland, and it was considered that a light line between them and the piers would be necessary. Rails were at once laid from about 100 yards above high water mark down the shelving sandy beach, as far as it was practicable to continue the line. A great saving in labour was made by landing stores at all stages of the tide direct from the Arab boats into the waggons, which were run out into the water alongside the former. Small branch lines at other points were constructed for conveying sand to raise a portion of the foreshore. Rails were laid upon the stone pier as it progressed, which were of utility for landing purposes, and assisted greatly in its construction.

In the middle of November, as soon as it was known that the Sooroo Pass would be the main route to the Abyssinian Highlands, Lieutenant Colonel Wilkins (the Commanding Royal Engineer) directed that a survey for a light railway should be made from the landing place to Koomayleh at the entrance to the pass. The orders regarding the line were to save cuttings and embankments as much as possible, and, to effect this, to diminish the radii of the curves and increase the gradients. Although the distance between Zoulla and Koomayleh by road was only $12\frac{3}{4}$ miles, twenty miles of rails and sleepers were sent for, as it was considered practicable—and if the expedition had been prolonged it would have been advantageous—to have continued the railway for the first six miles up the Sooroo Pass. A small fitting shop was also indented for and all the requisites and rolling stock for repairing and working the line when completed. In making the survey it was found very difficult to determine the proper waterway required for the numerous water-courses, then dry, which would have to be crossed. For the first two miles the country bore evidence of being at times flooded, and it was decided not to raise an embankment, but merely to give sufficient waterway for the ordinary channels, and to allow the whole line to be

* This paper gives a more detailed account of the construction of this Railway than that which appeared in Paper XI, in the last volume. For a plan and section of the Railway see that paper.—*Ed.*

nundated in the time of an unusual flood. It would have been imprudent not to have provided some outlets, as there was no certainty that the line would not be required during the rainy season. An alluvial plain extended from the coast to the foot of a low ridge of extinct volcanoes, about six miles inland. Over this portion, part of which was covered with low thorny jungle, little more was necessary than levelling the inequalities of the ground to make it ready for the sleepers. After the sixth mile a broken country was reached, and the line entered a large stony ravine, through which it wound for the next mile and-a-half, by a succession of sharp curves and steep gradients, the object being to save any heavy work which, at this portion of the railway, would have been doubly difficult from the necessity of providing the working parties with water from a distance of four miles, for the latter was not procurable at a nearer point until the end of February, and then only in a limited quantity.

From this low ridge, a short descending gradient brought the railway on to the Koomayleh plain. Hence the natural inclination of the country towards the Sooroo Pass was about 1 in 40, so, although pretty uniform in slope, it was necessary to have recourse to curves and a winding tortuous line to obtain the necessary limiting gradient of 1 in 60. This entailed crossing the natural drainage of the country, and consequently the construction of many small culverts and bridges. Fortunately, rock was not met with on any portion of the railway, although for the last few miles the ground was very stony, and strewn with large boulders, evidently washed down from the hills. The total length of the line between the landing place and Koomayleh was a little over eleven miles and a quarter, or about a mile and a quarter less than the road made by the Quartermaster General's Department.

The survey having been completed in the middle of December, the laying of the line was at once commenced. A company of native sappers worked for a short time in levelling the ground and forming the approaches to the Hadas bridge. The gangs of plate-layers not having yet arrived from Bombay, intelligent Chinese carpenters were employed to spike down and fish-plate the rails; and a small party of Shohoes*, under a native non-commissioned officer, brought up rails and sleepers.

At the commencement of the expedition the reconnoitring party brought with them from Aden a number of 25-ft. and 12-ft. iron girders for barrack floors, in the anticipation that they would prove useful. On the railway, four bridges, containing a total of six spans of 25 feet, and several small 12-ft. culverts were made of them, as the girders intended for the purpose did not arrive until the end of January. The safe load on each pair of girders being only 9 cwt. per lineal foot, they had to be supported in the centre by two uprights resting on a horizontal sill.

The Hadas bridge (see Pl. I) was made in this manner, the girders resting on trestles buried 5 feet below the bed of the river. In the middle of June I examined it carefully, after this temporary structure had stood, for $5\frac{1}{2}$ months, the continual passage of trains over it. There had been no settlement nor displacement,

* Natives of the country below the mountain range.

although the river had risen to within 10 inches of the bottom line of the girders; nor were the uprights, supporting the latter, worn or frayed by the hammering of the engine and waggons.

The sketches of this and bridge No. 7 (Plate II), are not intended to serve as models, but merely as examples of constructions which answered, without failure, the purpose for which they were intended. As no timber was sent especially for the railway, it was impossible to secure the sizes and quantities required for the bridges. We were compelled to use wood of the dimensions which could be be spared to us by other departments.

The railway cannot be said to have been properly commenced until the middle of January, when gangs of plate-layers and coolies, plant and stores, arrived from Bombay. The Hadas bridge and branch line being completed, the work was pushed on in the direction of Koomayleh, but the progress was very slow, on account of the want of spikes for fastening down the rails, and the limited supply of material which could daily be landed at the over-crowded pier.

Throughout the expedition, but more particularly during the first three months from its commencement, it was very difficult to find out what stores a ship was loaded with when she arrived in Annesley Bay. The Commissariat Department had the charge of shipping everything; and often a portion of a ship's cargo had to be changed, at the last moment, in Bombay, for something more emergently required in Abyssinia. The railway seemed more than usually unlucky, for rails were sent without spikes, rendering them useless; when the latter were procured, it was found that the augers (for boring holes in the sleepers) had been left behind to come in another ship. I may mention that the laying of the line was greatly expedited by the artizans of the Punjaub Pioneer Regiment (23rd), who made excellent augers, and repaired those daily broken on the works. Their workshop was on the ground in the burning sun, and a few simple tools, carried on a mule, were all they required to turn out augers better adapted for boring the hard wood of the sleepers, than those of English make.

Two engines and a sufficient number of trucks to form two trains were landed in the middle of January, and immediately the resources of the railway were taxed to the utmost in bringing up the commissariat and military stores from the piers to the store sheds. So great indeed were the demands on the two piers during the first three months of the year, that it was with the greatest difficulty the railway plant and stores were landed. So many trains were in requisition for other purposes, that it was almost impossible to keep the plate-laying parties at the end of the line supplied with material. In January, gangs of the Army Works Corps, an organised body of coolies, commenced to arrive from Bombay. Owing, however, to the great demand for labour there, and the objection that the natives of India have to cross the sea, the men composing it were physically much below the ordinary standard of native labourers, and the artizans, as a rule, were very indifferent workmen. They were especially intended for the railway, and were supposed to be about 1,200 strong; but I do not believe there were ever more than half this number employed upon it. Some gangs, composed of Chinese, picked up in Bombay, worked exceedingly well, gave no trouble, and were very useful in carrying heavy weights. Under the efficient direction of officers detailed for the purpose, the Army Works Corps did a great deal of valuable work, and were used for many duties which could not have been performed by Sepoys.

The head-quarter wing of the 23rd Punjaub Pioneer Regiment (about 400 strong), under Major (now Lieutenant-colonel), Chamberlain was detached for work on the railway in the middle of January. They continued about 2 months employed on its construction and proved most useful, working with great alacrity under the most trying circumstances. These men, admirably organised, equipped, and clothed, and accustomed to make hill roads in India during peace time, were especially adapted for this work. Captain (now Major) Darrah, R.E., was in charge of the railway during the whole time of its construction. He had as assistants two engineer subalterns (Lieutenant Pennefather, late Madras, and Lieutenant Willans), and Lieutenant Graham, 108th Regiment; Lieutenant Phillpotts, R.N., was also attached to the railway for the purpose of landing plant and material, and making the necessary arrangements for discharging the vessels in the harbour, containing railway stores. Lieutenant Baird, R.E., arrived in the end of February, and took over at once the onerous duties of traffic-manager. Lieutenant Pennefather, R.E., had charge of the account department; for the large staff of civilians, for working the line, entailed a series of complicated accounts, the responsibility of which rested with Captain Darrah. The commissariat arrangements and tenting devolved upon Lieutenant Graham. The special duties which were allotted to each officer, did not prevent his being employed with the working parties, when he had available leisure, but the principal portion of the outdoor work, and the construction of the line with its bridges, was done by Captain Darrah, assisted up to the middle of March by Lieutenant Willans. There was a great want of non-commissioned officers, especially those having a knowledge of Hindoostanee; indeed, only one Sergeant of the Royal Engineers (Madras Sappers and Miners) was available as an overseer on the railway works.* Some men of the 4th (King's Own) Regiment were employed as platelayers, carpenters, and clerks, and afterwards some of the 45th Regiment as carpenters and blacksmiths. A few of them remained on the work until the end of the expedition, although as a rule they joined their regiment when they marched from Zoulla.

During the month of January, about four miles of railway over the sandy plain, and three sidings at Zoulla, were made. The latter, though taking but few men to construct, gave a great deal of trouble, owing to the want of skilled labour necessary to lay them properly, and the interruption to the traffic they caused, when the line was broken up to insert them. From the first day that a locomotive got up steam, the additional difficulty of supplying it with water was imposed upon us.

The tank engines, with moderate work, consumed about 1,000 gallons a-day; and at the first the experiment was tried of mixing a small amount of salt water

* Two Sergeants of the Bombay Sappers were employed, in addition, from the commencement of April.

with the condensed, to economize, as far as possible, the latter. It was found, however, not to answer, for although some locomotives are constructed to use salt water, the priming, in one case, was so great with water in the slightest degree brackish, as to render the engine almost useless, and to cause a much larger quantity of condensed water being required than when it was solely fed from the latter source. A small condenser on the pier was given up exclusively for railway purposes. It did not yield, however, enough water, and the deficiency had to be supplied by the slow and laborious process of pumping from water-boats brought alongside the pier. Engines when detained on the line had often to leave their trains and run down to the pier to take in water, and in some cases even to draw their fires, not having enough water to bring them down there, causing very great delay, inconvenience, and loss.

The discovery of water at points along the line was almost, if not actually, essential to the success of the railway. Major Chamberlain recognizing the great necessity for obtaining it, detached several parties of skilled well-sinkers from the 23rd Punjaub Pioneers to dig wells in likely places in the alluvial soil. After several trials, a hot spring was met with 55 feet below the surface of the ground, and about $3\frac{1}{2}$ miles from Zoulla. The temperature of the water when raised was 120 deg. F., but by exposing it in open barrels for a day it became as cool as the water from the shipping. Although it contained a considerable amount of saline matter, it was not undrinkable, and worked moderately well for the engines. Soon two other wells were sunk, and the yield, amounting to about 12,000 gallons per diem, enabled us to establish tanks there for watering the engines, and to give up entirely the troublesome and precarious supply at the pier. It also allowed us to move out working parties ahead of the plate-layers, which had before been almost impracticable, as water had to be brought by railway from Zoulla for their use, and the Engineer officers were supposed to make arrangements for doing so. I can hardly overstate the previous delays and difficulties we encountered owing to the uncertainty and shortness of the water supply. One and a half gallons per diem were supposed to be allotted to each man, not an over abundant supply where work was carried on all day under a burning sun and often through parching dust storms. But until we got our own wells there was no certainty whether the apportioned amount would be given or not at the watering places. Often after working from daylight until noon, the natives could not cook their food, owing to the water-ration not having been served out, and the afternoon's work had to be postponed until a small supply was obtained. That it was unavoidable, no one can doubt, and my only reason for stating it is to give some idea of the difficulties, other than engineering, in our way.

In the commencement of February, the railway had nearly reached to the foot of the low hills, about six miles from the coast. Captain Darrah therefore applied for the military working parties to be increased, in order that the plate-laying might not be delayed by the earthwork. A well was also commenced at the site of the railway bridge in the stony ravine, in hopes that water might be obtained, and the camps moved on there, for marching the men nearly three miles from their present camp to their work, entailed great loss of time. As the responsibility of providing water for the working parties devolved upon Captain Darrah, it would have been very hazardous and imprudent, with the experience gained by our previous difficulties at Zoulla, to have sent a large number of men to a place where there was no water, and where it would have had to be brought upon mules from a long distance, to supply them.

About the middle of February, a wing of the 2nd Grenadier Regiment (Bombay Native Infantry) was despatched for work on the railway. The plate-laying, however, advanced slowly, for the rails had nearly all to be straightened, and many of them to be cut, being very much worn, crooked, and of odd lengths. When the government of Bombay determined that the railway plant, stores, and rolling stock should be sent entirely from India, it was found that light rails of the same pattern were not obtainable for the number of miles required. The railways at Madras, Kurrachee, and Bombay, were indented upon, and the result was that we were supplied with rails of no less than five different patterns.

For the first two miles a single flanged fish-plated rail, weighing about 45lbs. a yard was used, which answered very satisfactorily, made an easy road, and was everything that was required. Then for the next four miles we were compelled to lay down those sent from Kurrachee, single-flanged rails, weighing about 50 lbs. to the yard, and having joint-chairs instead of fish-plates. They had been in use for many years on the harbour works at Kurrachee; taken up and laid down several times; bent to fit sharp curves, and cut to suit the original line; so that when they arrived in Zoulla, a great portion of them were useless. So bad were they, that if the expedition had lasted another year, we should have been compelled to substitute other rails for them, and on more than one occasion the engine has gone off the line, owing to a rail having broken between two sleepers. The use of joint-chairs instead of fish-plates, the former being of wrought iron and very bad, made a very rough line, and the want of proper ballast rendered it worse. A small quantity of single-flanged rails, weighing 40 lbs. to the yard, were sent from Bombay, and had been fitted there in the government workshops with fish-plates and bolts. Unfortunately, the holes in the plates and rails were not at uniform distances apart, and the bolts fitted the holes so tightly as to allow of no play. This rendered the straightening and adjustment of the line almost impossible, and although they were well suited for the work, we were obliged to reject them.

A double-headed fish-plated rail, with chairs, weighing 65 lbs. a yard, was purposely left until the heavy gradients and sharp curves were reached. A rail with chairs takes considerably more time to lay than a single-flanged one with spikes; it is not, therefore, so well adapted for rapid work as the more temporary rail. Its weight was also against its use, as with chairs it cannot have weighed less than 95 lbs. a yard; but there was no comparison between the finished lines of the two descriptions. The smooth travelling on the part of the railway laid with the double-headed rail, and the ease with which it was kept in repair, almost repaid for the increased trouble and delay in laying it.

A quantity of 30 lbs. and 35 lbs. rails were also sent with cast-iron joint chairs, but they were too light to lay on the main line, and were used only on sidings; they here showed how badly they were adapted for fast traffic, by bending between the sleepers.

The rolling stock was, however, a much greater source of trouble than the rails. Six locomotives were shipped from Bombay, but owing to the great difficulty in landing them, and the time and skilled labour required to put them together, only four were used on the railway.

No. 1. A tank engine, although just turned out of the railway workshops at Bombay, after running for a fortnight, had to be supplied with new driving wheels. It had six wheels, two pairs of which were coupled, and with great difficulty ran round the curves, owing to there being no play in the axle boxes.

No. 2. Another small tank engine (6 wheeled) was very well adapted for the line, although old. The boiler tubes were worn out, and had to be replaced in Abyssinia.

Nos. 3 and 4 were also tank engines with only 4 wheels each; this gives great facility for running round curves, although dangerous for fast traffic. These locomotives were of a cheap description and old, having been in use for many years at Kurrachee. The working parts of the machinery were outside the wheels, an arrangement very badly suited for a sandy plain where dust storms were of constant occurrence, as the sand penetrated into the exposed parts, and soon wore away the bearings. All these engines were very light, weighing with coal and water from 16 to 20 tons each; none of them were powerful, and the best one could only draw 15 small loaded trucks up an incline of 1 in 60.

Sixty waggons were sent for working the line. They were the ordinary trollies, without springs. They had originally belonged to a reclamation company in Bombay, and having been used for running only two or three miles at a time along a railway, were not furnished with grease boxes, and were not adapted for a longer journey. The axle bearings being of cast-iron, and open to the driving sand, were soon worn through; indeed, I have known a truck thus incapacitated by a fortnight's running on the line. Gun metal bearings were sent for to Bombay and arrived in May, but few trucks were fitted with them. The want of springs and spring buffers were great causes of wear and tear to the rolling stock. The line being rough, and every truck being loaded to its utmost capacity, the jarring and oscillation increased the traction, more especially where there was no give or take from the springs, and everything was dead weight on the engine. Coupling chains were broken and coupling bars pulled out from the waggons at starting. The boxes containing the spare coupling chains had been left behind at Bombay, or were beneath several hundred tons of railway iron on board ship. From all these causes combined we were always very short of trucks, and at least 40 per cent., were continually under repair, or condemned as unfit for further service. In May, some open waggons with springs and spring buffers were sent from Bombay; their axles were too far apart to run easily round the curves, but several were altered and fitted with covers and seats to form passenger carriages.

On the 19th February, about half the line being completed, and a siding made at the Quartermaster General's road, this portion of the line was opened for traffic. From this date almost all the commissariat stores were brought up by rail from Zoulla, the baggage animals removed to Koomayleh, and the enormous expense of providing them with condensed water at the former place, greatly reduced in consequence. The railway was now taxed to its utmost to bring up these supplies, four to seven trains being required daily for the purpose, and at the same time to keep the plate-laying parties in material.

Two small iron girder bridges were built close to the Quartermaster General's road, No. 5 of two spans of 20 feet, and No. 6 one span of 25 feet. The trestles for both were prepared in Zoulla, and when brought to the site, it took three days to complete the bridges. The earthwork of the railway commenced here, for hitherto it had been only levelling the ground, and forming approaches to the bridges; but as the working parties were strong, there was no unnecessary delay to the plate-laying, on account of its being unfinished. Fortunately the Punjaub Pioneers again found water at the site of bridge No. 7, 70 feet below the bed of the dry water course, and sunk a well there, which was a model of neat and good work. The camps were moved close to this spot, but the supply of water was not enough for everyone, and 1,200 gallons a day had to be brought up by railway from the Pioneer well.

Commencing at bridge No. 7, the line wound through the ravine with an ascending gradient of 1 in 91 and with numerous curves up to the heaviest cutting and sharpest curve on the line which was about 3,500 feet from the bridge. The depth of the former was about 9 ft., and the radius of the latter 870 ft. To meet the increased labour so urgently required at this time, the other wing of the 2nd Grenadier Regiment Bombay Native Infantry, was sent to join the railway camp; but at the very end of February the Punjaub Pioneers were ordered to the front and their place supplied by a weak wing of the 45th Regiment. To say that we were great losers by the exchange, is no slur on the latter regiment, for they were numerically about one-third less than the Pioneers, had had no previous training in using the pick and shovel, and were incapable of the severe work in the burning sun, which came almost naturally to the Indian troops. The Grenadier Native Infantry Regiment, stimulated by the unusual sight to them of European soldiers being called upon to furnish working parties, increased their exertions, and until the close of the expedition, in the most intense heat, laboured with such alacrity as to call for special commendation in the report of the Commanding Royal Engineer.

The Skew Bridge (No. 7), see Pl. II, was commenced in the first week in March, and finished in ten days. At the same time four small 12-feet girder culverts were constructed, and on the 15th of March the rails had been laid up to the Koomayleh plain. In the latter part of January, Lieut. (now Captain) Merewether, R.E., was directed by the Commanding Royal Engineer to commence the earthwork of the line from Koomayleh. At first there was some difficulty in obtaining working parties, but having a company of the Madras Sappers at his disposal, being furnished with some military labour, and neither the cuttings nor the embankments being heavy on this portion of the line, the work was reported completed up to the end of the Koomayleh plain, in the middle of March. Very unfortunately, however, owing to Captain Merewether having been on the sick list, and unable to superintend the work in person, it was found that the line had not been accurately enough marked out, that on the curves the radii were not the same at different points on the same curve, and consequently a large portion of the line had to be rejected. The company of Madras Sappers and Miners excavated a well on the Koomayleh plain, where water was obtained 90 feet below the surface, in sufficient quantity to supply the railway. The camp was therefore moved and pitched close to this well. The wing of the 45th Regiment left for the front about the 28th March, and consequently the whole work devolved upon the 2nd Grenadiers and the Army Works Corps. Shortly afterwards the head-quarters wing of the Grenadiers was withdrawn, and replaced by a wing of the 18th Bombay Native Infantry.

In the latter part of March, a new siding was finished about 3 miles from Koomayleh, and 9 from Zoulla, and the new portion of the line reported to the Commanding Royal Engineer, as ready to be opened for traffic. The 50 lbs. single flanged rails (Kurrachee) were, however, so very bad, that he thought it advisable to substitute for them the new fish-plated rail (65 lbs.) with chairs. Fortunately almost all the extension consisted of the latter rail, and although there was some delay in replacing the former, where it had been laid, this extra portion was open to traffic on the 28th March. The heat had now become so intense that it was impossible to get the same amount of physical labour from the workpeople as heretofore. The railway progressed slowly, the energies of the officers being directed to the working of the line, as well as to its construction. The watering, coaling, shunting, and repairing abstracted men who otherwise would have been pushing on the construction. In the end of April, the fall of Magdala being known, the Commanding Royal Engineer thought it advisable to terminate the line when it had reached about one mile from Koomayleh, and to prepare for the great traffic which it would have to bear on the return of the troops. A loop-line and station sheds were accordingly made at the terminus.

The total quantity of line laid was 12 miles 106 yards, although the length of the main line was under 11 miles, the difference being made up by sidings and a branch line to one of the piers. From the middle of May to the close of the expedition in the middle of June, the railway was taxed to its utmost working capabilities in conveying troops, baggage, and stores. The arrangements for working the line had been much improved. Telegraph stations were placed at Zoulla, Pioneer wells, and the Koomayleh terminus. Watering tanks were erected at the Pioneer wells, which was the main watering place on the line; a stand pipe and tank were fixed at the siding in Koomayleh plain; and a fire engine stationed at the bridge in Stony Ravine, to supply the engines with water. At the Pioneer wells sheds had been built for repairing engines and waggons; sidings, for the rolling stock to remain in at night, constructed; and all the civilian employés camped there close to their work.

A commodious station was made at Zoulla, which proved very convenient, although most of the trains ran direct down to the piers. The working hours on the railway commenced daily at 4.30 a.m., and often were not over till past ten in the evening. Three trains only could be made up, as many of the waggons were hors-de-combat, and it was only by the most strenuous exertions that the locomotives could be kept in working order. The nights were devoted to their repair, but they got worse and worse daily. At the end it was found that two of them were not worth the labour and expense of re-embarkation, and they were accordingly abandoned.

As regards the question whether this railway might not have been better and more quickly made by a civil contractor than by officers of the corps with military and organized labour, I think the evidence is in favour of the latter. An English firm could not have employed European navvies in the burning sun on the shores of the Red Sea, and the labour must have been brought from either Egypt or India. It would have taken more time for a contractor to have organized and despatched gangs of Egyptians to Zoulla than for the Bombay government to have sent the necessary labour from India; for it should be remembered that it was not determined by the government of Bombay to have a railway until the end of November, 1867.

When the guarantee of the state, and the promise of high pay, failed to bring a good class of Coolie from India, a contractor would have had little prospect of securing any but the most indifferent hands, as labour was in great demand for the other departments of the expedition. All the officers on the railway were accustomed to employ natives on the public works in India, were acquainted with their language, and understood their management, qualifications which can be rarely met with out of the government service, and which can scarcely be overrated. Where neither food nor water was to be purchased, where no local labour was obtainable, where even shelter for workmen had to be imported, and where all the stores had to be landed at an overcrowded pier, it is hardly probable that a contractor could have made his own arrangements for everything, without the help of the military departments. It required all the influence of the Royal Engineer officers to procure such necessary assistance as barges for landing plant and stores, accommodation at the pier for discharging them, trains to bring up the material to the plate-laying parties, besides rationing the men, and providing them with water. The above can surely be done at the place of debarkation of an army better by officers than civilians.

We did not complain of the want of skilled labour on the Abyssinian railway, we could have pushed on much faster if the plate-laying parties had been supplied with a sufficient amount of good material, for the latter had to be largely rejected on account of its inferiority. Plate-laying is easily learned, and men accustomed to work together will soon understand the orders of a foreman. No great speed is required on a military railway, and, consequently, the line may be laid much more roughly than on an ordinary line, where it is requisite to run quick trains.

I venture to add the following remarks suggested by our experience in

Abyssinia. A narrow gauge line is most preferable for a military railway, as the waggons are lighter, run round the sharp curves with greater facility, and when they run off the line are more easily got back again, than those made for a broad guage. In construction, a short heavy gradient on a straight line, is preferable to a sharp curve as an alternative. Trains can rush at the former and overcome the resistance (which only acts one way) by their momentum. On a curve there is the liability of running off the line, and the resistance, which is very considerable on a rough one, acts both ways. Our sharpest curve on the Abyssinian railway had a radius of 870 feet, and was on an incline of 1 in 91. With a narrower gauge than the Indian (5 feet 6 inches) we might have adopted even a smaller radius. The heaviest gradient was 1 in 60, often combined with sharp curves.

A single flanged rail weighing about 40 lbs. per yard is most suitable for a military railway.* It should be fish-plated, and in lengths of 24 feet. If wooden sleepers are used, the rail is most quickly fastened to them for a temporary line by 4 inch spikes nailed into the sleepers, which are first bored with an auger. Considerable trouble is found, however, when this method is adopted, in keeping the line in gauge round sharp curves, and also at points. Chairs decidedly should be used for the latter if possible. Where there are only light tank engines, 9 sleepers to each rail will suffice, those at each side of the fish-plates, centrically, 2 feet apart, and the remainder about 2 feet 9 inches. It will be found convenient, and plate-layers say it makes a much easier line, to have the fish-plates on each line of rail exactly opposite each other. This necessitates cutting a rail on long curves, where the inner line is shorter than the outer one.

Iron pot-sleepers would be well adapted for a military railway.† The Commanding Royal Engineer in Abyssinia sent to Bombay for them, but they could not be obtained for a light rail. Iron pot-sleepers would be easily carried and loaded on railway trucks (the wooden ones were continually dropping off the waggons). The tie rod connecting the former could, without difficulty, be fixed in its place by an ordinary soldier or Sepoy, and the line can never be out of gauge when once laid. The pot-sleeper, being in two parts, is carried with much greater ease than the unwieldy wooden one, which is very awkward for men unaccustomed to lift heavy weights.

The small wrought-iron girders made up in Bombay for Abyssinia, were well adapted for bridges. They were in two lengths, 14 and 22 feet, answering for spans of 12 and 20 feet. They were calculated for a working load of 1 ton per running foot, rather in excess of our requirements. The weight of the larger one was about a ton, and it was conveyed and put up without difficulty. Gir-

* Major Darrah differs with me on this point. He considers that in all cases a rail with chairs and fish-plates should be used.

† Major Darrah thinks that iron pot-sleepers would be most probably broken in large numbers, before they reached the plate-laying parties. A very small per-centage of the cast-iron chairs were damaged in transit from the ships to the head of the line in Abyssinia, so I conclude that the loss would not be large with the pot-sleepers.

ders of 30 cwt. would not be inconveniently large, if it were desirable to increase the spans of the bridges. Wooden trestles make good temporary piers, and 3-in. sheet piling, driven by heavy mallets, retains small embankments well at the abutments. The bridges on the Abyssinian railway were not good examples of construction, as there was no timber sent especially for them; this should not be neglected in future, and it was with great difficulty that wood of any description was obtained.

We found it advisable to divide the plate-layers into four parties, according to the following plan:—

1st Party.—	2 N.C. officers .... 8 Men (Natives)	Laying sleepers at proper intervals, and fish-plating rails.
2nd Party.—	1 Foreman (Civilian) .... 1 Native Ganger .... 8 Men (augers) .... } Natives 8 ditto (hammers) .... } Natives 8 ditto (crowbars) .... } Natives	Spiking rails to sleepers.
3rd Party.—	1 Foreman (Civilian) .... 1 N.C. officer plate-layer........ ... 1 Native ganger with party varying from 20 to 50.	Levelling, raising, and adjusting the line to enable the ballast trains to pass over it.
4th Party.—	1 Foreman plate-layer .... 1 N.C. officer plate-layer .... 2 Gangers with two gangs (native) from 40 to 100	Ballasting and finishing the line.

It is impossible to give a correct estimate of the number of men required to carry rails and sleepers to keep the above parties supplied with material, as the lengths of the leads varied very much. On an average, where the ballast trains came up to the end of the line, as it was laid, about 120 men (natives) were employed in carrying rails and sleepers, and in unloading trains.

The rate of progress in Abyssinia with the single flanged rail, without chairs, where there was no delay on account of the want of rails, &c., was nearly 400 yards a-day (10 working hours); when the double flanged rail with chairs was used it was much less, being about 250 yards.

Tank engines are no doubt the best adapted for a temporary line; they are more powerful for their weight, and, consequently, can be made lighter than those with tenders, and require no turn-tables, as they run either end foremost with equal facility. They are, however, very destructive to the line for their weight, and require trouble and experience in working them.

The trucks should have their axles as close almost as the wheels on each side will permit, and should be small and light. Those we used weighed about two tons, but they required more power to drag than those properly made with springs, and three tons in weight.

All waggons should have springs, and also spring buffers. Economy alone can preclude these being furnished; the rougher the line, the more needful and advantageous are waggons of this description.

Sides to waggons are useful, but the catches for letting one side down should not be liable to be jerked up by the motion of the train. I have seen several waggons thrown off the line by their contents falling on the rails, owing to defective catches which became loosened.

Covered waggons would be convenient for some purposes, but would not answer for trusses of forage, &c., and in a hot climate could not be used for troops, unless constructed with several large doors. We found in Abyssinia that the ordinary small waggons were not suited for carrying rails, the length of the latter (24 feet) obliging them to be placed on two waggons, and often causing one of the trucks to run off the line at the first curve. Waggons should be made on purpose for rails and sleepers, especially where there are no appliances for loading high trucks. The platform should not be higher than 4 feet, so that the rails and sleepers can be easily lifted on to them. For a line with sharp curves, it would be advantageous to use bogies.

The civil establishment for working the Abyssinian line, when it was completed and in full work, was as follows :—

1 Storekeeper.
4 Engine-drivers.
5 Firemen.
3 Station Masters.
6 Guards (3 natives).
5 Clerks (1 native).
3 Railway telegraph signal men.
12 Pointsmen and signalmen (natives).

The repairing shops engaged the following :—

1 Locomotive foreman.
6 Fitters (2 natives).
3 Boiler-makers.

with a number of native mechanics (about 50).

We may conclude that we had to execute in our workshops the maximum amount of repairs, in proportion to the traffic and length of the line, that can well be incurred on any railway.

A very complete fitting shop was sent from Bombay, including steam lathes, stationary engines, quarters for mechanics, &c. It was never put up, and proved more in the way than otherwise ; for any careful packing arrangements made in Bombay were altogether neutralized by the vessel which brought them going ashore in the Red Sea, and by her cargo being transferred to another ship. We were, therefore, often obliged to land heavy machinery to procure useful stores, buried beneath it in the hold of the vessel.

The civil establishment, picked up in Bombay at a short notice, and without increased rate of pay being offered to them, could scarcely be expected to give satisfaction, although in some instances we met with valuable services. Some of the employés were dismissed, and their places supplied by promoting those who seemed deserving men. We lost through casualties and dismissal about 25 per cent. of the European civilians, and they were always a source of trouble and anxiety to us, and I think it would be advisable to substitute for them, as far as possible, men from the ranks.

Intelligent non-commissioned officers would make good station masters, as their most important duty is to obey orders. Guards could be furnished in the same manner. Pointsmen and signalmen could easily, if required, be supplied from the ranks. Engine drivers and foremen plate-layers are about the only men whose places could not be filled from the army or navy. Firemen and fitters can be supplied from the latter; and for some time on the Abyssinian railway, the duties of locomotive foreman were efficiently performed by one of the engineer officers kindly lent for the purpose from H.M.S. "Octavia."

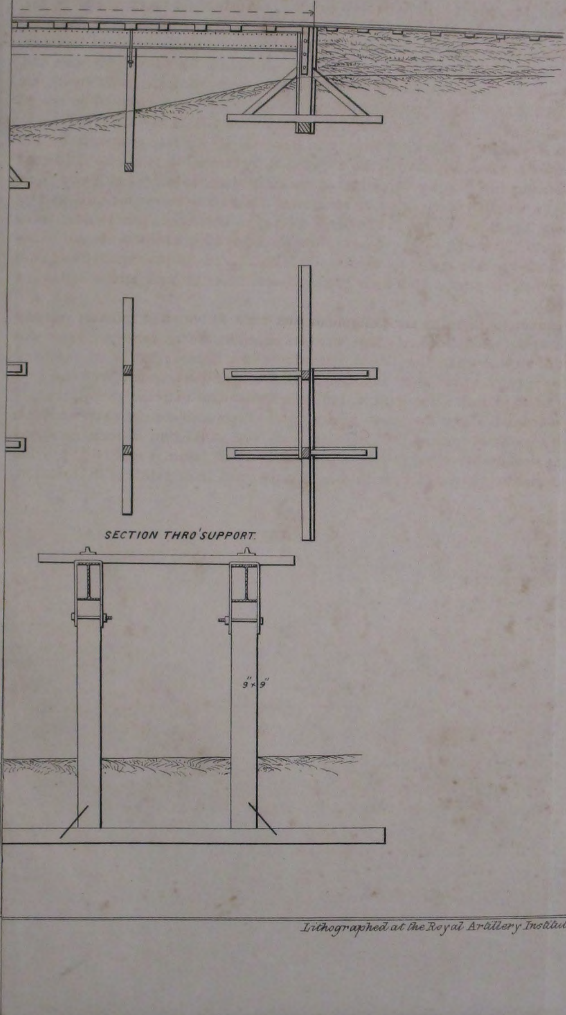
The Abyssinian railway was a great success, if we may gauge it by the amount of assistance it gave to the expedition, by the saving in money it effected by allowing the baggage animals, at an early date, to be taken away from Zoulla (where they were drinking condensed water at an enormous cost), and by the help it gave to the Land Transport Corps, in enabling them to send these animals to the front; by the celerity and dispatch with which by its aid stores were landed and brought up to the store sheds; and by the rapidity and ease with which the troops and their baggage were brought back and re-embarked at once.

It cannot be taken as an example of the time in which a military railway ought to be constructed, if there were no impediments in its way. From this point of view it was often judged by civilians as a failure; but as an auxiliary to the expedition, and as an additional means of transport, no one, who had anything to do in connection with it, can have doubted its extreme utility.

Constructed under the most unfavourable circumstances, in extreme heat, which sometimes reached 180° F. in the sun, with indifferent materials and bad rolling stock, it nevertheless proves how necessary in future it will be to provide all our military expeditions with a light railway at their points of debarkation.

T. J. W.

PL. I.



Lithographed at the Royal Artillery Institution

PAPER XIII.

CASEMATE AND SHIELD EXPERIMENTS.

By LIEUT.-COL. INGLIS, R.E.

In 1865, two masonry casemates, with embrasures in iron shields, formed the subject of a lengthened series of trials at Shoeburyness. In 1868 a still more extensive set of experiments was undertaken, embracing the trial of two casemates wholly fronted with iron, as well as other works. There have also been separate trials of two gun shields, which have not yet been noticed in these volumes. The present paper gives an account of all these experiments, and it also brings up the usual summary of current trials to the present time.

They are arranged, as far as possible, in the order in which they occurred. The plates will help to render intelligible the description of the more important of these works, and they will also, to some extent, assist in the account of the trials, inasmuch as they show the position of all the shot marks. The tables give the particulars of the practice, and the effects of each round in detail.

1. Masonry Casemates with Iron Shields, Pls. I and II.

The object of this trial was twofold. First.—To ascertain the resisting powers of a masonry casemated work of modern type. Second.—To test the suitability and convenience of such a work for all Artillery purposes.

Plates I and II show the structure experimented upon.

It consisted of two contiguous granite faced brick casemates. The vaulting over one casemate represented the intermediate floor of a two-tier fort, that over the other a bomb-proof roof carrying a terre-plein. The floors of both were made up solid from the ground.

For the sake of brevity the right casemate will be here called No. 1, the left No. 2, as marked on the plates.

The granite front of the work was in seven courses, varying from 1 ft. 10 in. to 3 ft. in height (average 2 ft. 4½ in.) The thickness of the front wall, or rather of the piers, was 14 ft.; the depth of the face stones varied from 6 ft. to 8 ft. The surface of the granite front measured 43 ft. to 46 ft., by 16 ft. 8 in. in height. The entire height of the front was 20 ft. 5 in. to 21 ft. 5 in., the difference being made up of brickwork.

There were	11	blocks of	granite	under	4	tons each.
,,	30	,,	,,	between 4 and	8	,,
,,	9	,,	,,	,, 8 ,,	10	,,
,,	2	,,	,,	,, 10 ,,	12	,,
,,	3	,,	,,	slightly over	12	,,
Total	55					

The blocks of the four lower courses of No. 1 casemate were backed by granite. The upper courses, including the arch stones, either by sandstone, or brick-work, or concrete. The granite of the six lower courses of No. 2 was backed by brick-work, that of the upper course by concrete. Everything in the way of cramps, dowels, or joggles, to secure the granite work was purposely dispensed with. The main part of the granite was from the Par Quarries, in Cornwall, and the Delank, in Devonshire. Six large blocks, used in the third and fourth courses of the centre pier, were from the Isle of Mull, on the Argyleshire Coast. It may here, at once, be said that little or no difference was found to exist as to the durability under fire of these several natures of granite.

The walls and vaulting of both casemates were of brick-work in Portland cement. The arching of No. 1 was in four half brick rings, making a thickness of 1 ft. 7 in., with concrete filling, to a level 13 in. over the crown. That of No. 2 was in six rings, or 2 ft. 4 in. thick, covered with concrete, to a level 3 ft. above the crown.

The front of each casemate was closed by an iron shield. The opening filled by the shield in No. 1 casemate was 12 ft. wide, with a segmental head. It was 6 ft. 7 in. high at the sides, and 8 ft. 2 in. in the centre. That in No. 2 was 6 ft. wide and 6 ft. high.

No. 1 shield, designed by the late Mr. J. Chalmers, was composed as follows: —The face-plates, four in number, were 4 in. thick. These were backed in one half of the shield by 8 in. of iron, made up of 1 in. plates, standing vertically, with their edges to the front. In the other half these backing plates, or bars, also 8 in. deep and on edge, were formed so as to be tongued and grooved, as shewn in the plates. This backing was supported in rear by an intermediate or second armour, 2 in. thick, resting against $6\frac{1}{2}$ in. of teak, in which were five angle-iron stringers. Behind this was a skin of 1 in. plate. The armour was held on by twenty three 3 in. bolts, nutted at the back of the inner skin. The intermediate armour was held on by a separate set of 2 in. bolts. Altogether this compound mass was $21\frac{1}{2}$ in. thick.

The opening cut for the port was 2 ft. 4 in. wide and 3 ft. high, and was slightly splayed on the inside. The structure thus far described was supported in rear by two struts, similar to those in former shields, connected at their feet with a base plate of 1 in. iron, 3 ft. 6 in. broad, running the whole width of the opening, and at their top with a massive built up girder, 1 ft. $6\frac{1}{2}$ in. deep, occupying the position of the chord of the segment-shaped head of the shield. The base plate was sunk flush into the granite floor, and was held down by ten

$2\frac{1}{2}$ in. lewis bolts, let into the granite. The entire weight of this shield was about 28 tons.

No. 2 shield consisted of a solid $13\frac{1}{2}$ in. rolled iron plate, 7 ft. high, and of the exact width of the opening it had to fill, namely 6 ft. It was secured at the top and bottom by being let in, to a depth of 6 in., between a head and sill, each of which was composed of the ordinary double-headed railway bars. These railway bars were laid flat, two being in front of the shield and five behind it, and were held together by cramps, ten in number, also composed of railway iron, turned at their ends so as to grasp the rails, and likewise to take hold of the masonry. The head and sill were built into the work as it advanced, and the shield was got into its place before the covering arch was turned. The port was 2 ft. 4 in. wide and 3 ft. 6 in. high. The corners of the opening were rounded, and the inner edges were splayed. The weight of the shield itself, as finished, was 8 tons. Before the port was cut out it weighed 10 tons 4 cwt. It was, of course, necessary to roll a much larger plate in order to obtain the square dimensions of this shield. The weight of railway iron in the fastenings was 4 tons 2 cwt.

The rear of No. 1 casemate was closed by timber framing, with doors and glass sashes hung in different ways, such as French casements, ordinary sliding sashes, and sashes on centre pivots, to try what effect the firing would have upon such constructions. The rear of No. 2 was left quite open.

The usual 12 ft. side-openings having been formed in the walls of the casemates to admit of greater traverse of the guns, those in the two outer side walls were closed by rough wood framing and boarding, to place the interior of the work more on a footing with that of a series of casemates in an actual work.

In No. 1 a 23 ton 13·3 in. gun was mounted on a wrought iron carriage ($2\frac{1}{2}$ tons), and a wrought iron traversing platform ($3\frac{1}{2}$ tons), with hollow-soled trucks, on raised racers. The front racers were let into granite; the rear into Bramley-fall blocks. The rack for the traversing gear was secured to 3-inch Yorkshire flags. There was a pivot in front, to which the platform was attached by means of a wrought-iron flap of special construction. As this pivot could not be placed in the true centre of movement, it was let through the iron floor-plate into the granite, just behind the shield. The pivot being thus eccentric, the flap worked upon it by means of a curved slot. The form and dimensions of the casemate itself would have allowed this gun to traverse laterally through an arc of 62°, but the port was so shaped that it could not actually traverse more than 36°. Also, the port did not admit of the gun being laid with any elevation, but this was owing more to the level at which it was cut with reference to the floor of the casemate, than to its form. It could be depressed from 2° to 8°.

In No. 2 casemate, a 12 ton 9·22 in. gun was mounted on a wrought-iron (1 ton 1 cwt.) carriage and wrought-iron traversing platform (2 ton 3 cwt.) on raised racers. This gun had no pivot. It traversed through an arc of 68° 30′; could be elevated 8°, and depressed $4\frac{1}{2}$°.

The 23-ton gun was afterwards mounted over No. 2 casemate, on raised racers in Bramley-fall stone, with a pivot as before.

The 12 ton gun was mounted without a pivot over No. 1, the front racers for it being let into Bramley-fall stone, and the rear ones, of special construction, were secured to a 2½-in. oak floor, laid on oak joists 3¾ in. by 3 in., on deal battens 3 in. by 1½ in., bedded in concrete; there were also oak filling-pieces between the joists under the racers.

The 23 ton gun was subsequently transferred to this latter position with a pivot added, the service raised racers being secured to the oak floor.

Before the work was fairly completed, and before the mounting of the guns, just described, had taken place, it was determined to make a preliminary experiment with a few shot from the 9·22-in. 12-ton gun against the centre pier of the work.

This was carried out on the 18th May, 1865, when three shots were fired with the following results:—

The first round was with a solid steel shot, with a hemispherical head, weighing 220 lbs. 8 oz. It was fired with a reduced charge of 30¼ lbs., to give a remaining velocity equivalent to that due to a range of 1,000 yards with battering charge. It struck the 5th course on the stone forming the springer of the arch over No. 1 shield, and just on the edge of the curved surface forming the rounding to the opening for the shield. Its striking velocity was 1,320 ft. per second, and the work in the shot was equal to 2,676 foot-tons. It penetrated the granite to a depth of 9 in., and cracked the block a good deal. The stones in the two courses above it were loosened, and the cement joints over the rest of the face of the pier were slightly opened. The brick-work inside the casemate was also a little shaken. The shot broke up.

The next round was also with a steel hemispherical-headed shot, weighing 220 lbs., fired with a charge of 39 lbs., to represent a range of 600 yards. Its remaining velocity was 1,395 ft., representing a force of 2,969 foot-tons. It struck fair on a Mull granite block in the 4th course, in an almost central position on the pier, and at a distance of 5 ft. from the former shot. It penetrated the block to a depth of 18 in., and broke off its face over an area of 20 superficial feet. A piece of the adjoining Mull block was cracked off, and displaced sideways, and a block in the course above was cracked in two places. A crack in the brick-arching of the roof of the casemate, observed after the last shot, was lengthened about 2 ft. Another crack, low down in the brick-work of the pier, was opened; and also another, running vertically and obliquely through 7 courses of brick-work towards the groin of the arch. The shot rebounded 5 yards, and was cracked in the head and set up.

The third shot was of cast iron, with a conical head, weighing 217 lbs. 12 oz., and was fired with the same charge as the first, and had nearly the same terminal velocity. It hit full in the centre of a block in the 3rd course, about equally distant from both shields, and 2 ft. from the centre of the last shot. It was thus within the limit of injury caused by that shot. The granite was knocked out to a depth of 2 ft. 1 in. An adjoining block in the same course was cracked in two and moved 2 in. out of place. Another block was displaced 3 in., and a third 1¼ in. The oblique vertical crack in the brick-work of the pier, inside the casemate, was considerably increased, and the brick-work through 7 courses was driven back 1½ in. There was a fresh crack in the pier through 10 courses, and the crack near the groin of the brick-arching was extended to the crown. Fine cracks could also be perceived along the crowns of the main arches of both casemates, almost from front to rear, and in the transverse arches from side to side of the structure.

By these three shots, giving an aggregate of about 8,300 foot-tons, about 1 ton 18 cwt. of granite was knocked away, 5 blocks were seriously injured, and two other blocks broken in two. The cement joints of the front work, from centre to centre of shield, showed cracks. The cracks in the brick-arching, inside the casemate, were not of a very serious nature.

The next stage of the experiments was that which stood first in the original programme, and comprised the operations of mounting, working, and firing the heavy guns.

To facilitate the mounting of the guns in the casemates, a set of five 2-in. eye-bolts had been inserted in the brick arches over each gun, in the positions shewn in the sections, but after the practice it was thought that three would be found sufficient for all purposes, namely, one about 5 feet from the inner face of the shield so as to be over the muzzle of the gun when run back; another (or in case of the 22-ton gun a couple of them) to be 12 ft. from the shield, over the trunnions; and the third about 17 ft. from it, to be over the breech. The eye-bolts used on this occasion, although made of 2-in. round iron, and tested after being made by a dead pull of 20 tons, were hardly equal to the oblique strain brought upon them in some parts of the operations with the 22-ton gun; in fact, one of them broke, but their construction may be easily improved, and all risk avoided for the future.

There was no serious difficulty in mounting even the 22-ton gun. To be sure, it fell once in the process, but this was by an accident that need not occur again. The internal height of the casemate was, perhaps, barely sufficient for the old fashioned tackle used, but with improvements in the appliances, 12 ft. will be found ample height for mounting the heaviest gun.

The 12-ton gun was mounted with facility, and the space allotted to it found sufficient for all purposes.

There were certain loose rings in the floors of the casemates, as well as six eye-bolts in the piers, to admit of tackle being used for traversing in aid of the gear attached to the platforms themselves.

Two blank and four shotted rounds were fired from the 22-ton gun in No. 1 casemate, and there was no injury from the discharge to the work itself nor inconvenience felt by the gun detachment; even the glass in the sashes (set open of course) in the rear of this casemate was not broken. After the second shotted round something went wrong with the compressor, and the gun recoiled violently to the end of the platform. The shock broke the front flap connecting with the pivot, and the platform jumped clean off the racers. The damage thus done to the platform, trucks, and flap took some time to repair. This flap was was very much in the way of the gunners serving the gun.

Four blank and ten shotted rounds were fired from the 12-ton gun in No. 2 casemate, and everything stood well. There was, of course, some vibration throughout the work, and the blast of these heavy discharges made itself felt at the adjacent port, but it was simply a rush of air; there was not, as far as could be observed, any flame with it.

As regards appliances to aid the working of these two heavy guns, it was the general opinion that nothing beyond the existing means was necessary for the 12-ton gun, but that improved facilities were required for moving and lifting the shot of the 22-ton gun. To illustrate one method of meeting this want, a light foundry crane was made on the spot, and set up in the front part of No. 1 casemate. This carried an overhead traveller which, while it gave the means of taking up the shot in a convenient spot at about the back of the masonry pier, allowed the delivery of it at the muzzle of the gun in whatever position it might be left after recoil. One such crane on each side of the gun would much facilitate the operation of loading. Ready means may also be provided in such a casemate for moving shot and ammunition.

It being thought that nothing more would be gained by continuing the fire from the casemates themselves, the guns were removed to the overhead positions. This was an interesting Artillery operation, and it was very skilfully performed, although through the failure of some of the tackle, the 22-ton gun fell through several feet when being raised.

The 22-ton gun fired altogether 30 rounds with 70 lb. charges and 518 lb. shot, at 5° depression, from the position over the bomb-proof arch, and there was no effect whatever observable upon the vaulting under it. The cracks, opened in the arches by the fire of the 18th May, were not increased in the slightest degree. One round was fired without the flap connecting with the pivot, and the want of it was not felt.

The 12-ton gun fired 35 rounds at 5° depression, with shot of 221 lbs., and charges of 44 lbs., from the position over the 1 ft. 7 in. arch, and it had no perceptible effect upon the arches.

The 22-ton gun afterwards took its place, and fired 10 rounds, and even this had no effect whatever upon the previous cracks. This was satisfactory, as the 1 ft. 7 in. arch was not, of course, intended to carry so heavy a gun.

The two butts which received the shot in this practice were composed of stiff marsh clay. They were first made 30 ft. thick (measuring across the top), and 10 ft. high. This being found insufficient for the 13-in. shot, one butt was afterwards increased in thickness by 15 ft., and raised about 4 ft. The penetrations, at 100 yards range, were as follows:—The mean of 23 shot from the 13·3-in. gun was 36½ ft., and the greatest penetration was 50 ft. The mean of 43 shot from the 9·22-in. gun was 32 ft., the greatest penetration being 40 ft. The shot were found in all sorts of positions, some even lying with their heads pointing in the direction from which they had come. But, with regard to these results, it must be mentioned that, as the trials were to test the casemate structures, no great attention was paid to the effect upon the earthen butts, so that some of the higher penetrations may possibly have been due to the shot having followed in the track of previous rounds.

The practice against the structure has next to be described. The guns, projectiles, and charges, were as follows :—

Gun.				Charge.		Full Battering Charge.	Weight of Shot.	Striking Velocity.		Vis Viva on Impact.	
Calibre.	Tons	cwt.	lbs.	600 yds	1000 yds			600 yds.	1000 yds.	600 yds	1000 yds
				lbs.	lbs.	lbs.	lbs.	ft. per sec.	ft. per sec.	ft. tons	ft. tons
10-inch	12	2	57	41·3	36	45	280	1273	1209	3146	2838
9·22 „	12	2	56	39·5	30·25	44	220	1395	1322	2969	2666
8 „	6	19	50	26	22	30	150	1369	1292	1949	1736
7 „	6	19	72	18	—	22	115	1370	—	1497	—

All the steel shot and the 7-in. cast iron shot had hemispherical heads. The heads of all the other shot were elliptical.

The battery was placed at 200 yards from the casemates, but the charges were so reduced as to give striking velocities equivalent to 600 and 1,000 yards ranges with full battering charges.

The firing commenced 16th November, 1865.

First, each shield was struck by a solid steel shot from each gun (7-in. at 600 yards, the rest at 1,000 yards), aimed in succession above, below, and on each side of the port. (Rounds 1,051 to 1,060). These shot, with the addition of an accidental glancing blow off the masonry on to the lower corner of No. 1, and a grazing blow on the edge of the port of the other, gave an aggregate of about 9,600 foot-tons on No. 1, and 9,300 foot-tons on No. 2 shield. The general effect was that No. 1 shield was slightly moved back, and six through-bolts and some rivets gave way; but, beyond one or two cracks and stars in the skin, there was but little to show in rear. The masonry pier, which was accidentally hit, was cracked through to the rear. No. 2 shield was cracked through in one place, with cracks of less consequence in two other spots. A part of the sill stone was knocked off, and the adjacent brick-work very slightly injured. Two of the rail cramps of the lower fastenings broke. The piece of the shot that glanced and went through the port, struck a brick pier inside the casemate, making a hole 2 ft. by 2½ ft. and 1 ft. deep. It also caused cracks in the pier and arch, but these effects were not serious.

After this, three 10-in. and one 9·22-in. steel shot (600 yards) struck No. 1 (rounds 1,061 to 1,064) with an aggregate force of 12,407 foot-tons, doing a great deal of damage, especially to the fastenings. Amongst other things, the large top girder in rear was broken, and the pivot was thrown out of position.

Next day, two 10-in. and one 9·22-in. steel shot struck No. 2 shield (rounds 1065 to 1067) with an aggregate force of 9,261 foot tons, one of which was on the upper edge of the port. After this, a large piece of the left side of the shield seemed nearly detached, and the cracks in rear were much opened. One of the rails of the lower fastenings gave way, but there was still ample hold for the shield. The granite sill and arch stones were a good deal shaken. The shield was certainly now seriously damaged, but still it was in its place; and, subsequently, it stood the blow of a heavy cast-iron shot without giving way.

No. 2 shield had now sustained in all 8 blows, giving a total of upwards of 18,500 foot-tons, to which something must be added on account of a blow afterwards delivered by the 9·22 in. gun with a cast iron shot at 1,000 yards. Taking the area of the shield exposed, less the port, at 28 superficial feet, it received a battering equivalent to more than 700 foot-tons per superficial foot; and the surface of the shield divided by the number of shot, gives 1 shot to $3\frac{1}{2}$ ft.

No. 1 shield next received (round 1,068) a 10 in. steel shell (600 yards), the head of which stuck in the plate, doing little damage, and a 9·22 in. cast iron shot (1,000 yards) hit it by accident (round 1,070). Later in the experiment, it also received two 9·22 in. steel shot (600 yards), making together 5,938 foot-tons, both of which did it a good deal of damage. (Rounds 1,127 and 1,130.) After all this, the shield was of course much cracked and dilapidated, but still, with the exception of the loss of about 3 square feet of the exterior plate, and a piece cut out of the sill of the port, it was substantially entire. The mode of holding it in its place was sufficient for the purpose, but not altogether satisfactory. The early displacement of the pivot by injury conveyed through the shield deserves particular notice. The 12 blows which this shield had sustained from 11 shot and 1 shell represent a total of upwards of 31,000 foot-tons; and if some addition be made on account of the 9·22 in. cast iron shot that hit it by mistake, this total may be fairly raised to 33,000 foot-tons. Taking the area of the shield, less the port, at 83 ft. superficial, it received a battering equivalent to about 400 foot-tons per foot, or 1 shot to every $6\frac{1}{2}$ square feet.

The fire was next directed at the arch over No. 1 shield. It commenced w!th a 10 in. cast iron shot (1,000 yards), which struck on the joint of the key stone of the lower ring of the arch. (Round 1,071.) It displaced 5 cubic feet of granite, injured severely 4 of the arch stones, and slightly lifted 2 of the stones of the upper arch. In rear, the key stone was found to be cracked through, the brick arching was also cracked, and the joints of the stone and brick-work were loosened.

The next was a 10-in. steel shot (600 yards) on the large stone forming the right springer of the arch. (Round 1,072.) The stone struck and the adjacent one, forming a voussoir of the arch, were much injured. The greater part of the stone above it, and a large piece of a block above that, were brought down. The blocks in the three courses below the block struck were cracked through, and the arching in rear was a good deal injured; 22 cubic feet of granite were knocked out. Next came a salvo (rounds 1,073 to 1,076) from all the guns against this arch. Three went off pretty well together. The 8-in. gun hung fire. The 7-in. was at 600 yards, the others at 1,000 yards. All the shot were of cast-iron. As nearly as could be ascertained, they struck towards the right side of arch. The stones of half the upper ring were quite gone, exposing the concrete-filling over it, and a large part of the lower ring was also knocked away. Some of the brick-work over the granite fell, and inside the casemate former injuries were increased, but still the casemate was tenable. After this there was another salvo (rounds 1,077 to 1,080) directed at this arch, and the destruction was very great, a hole being broken through the arch into the casemate. It was generally allowed on the spot that a gun could not have been fought any longer in this casemate.

As this arch received only one shot more (round 1,178), and that accidentally in the latter part of the experiment, it may be well here to sum up the blows it received. This accidental hit was from a 9·22-in. steel shot (600 yards), and hit on what was left of one of the arch-stones of the lower ring, knocking it completely out, and, therefore, entirely destroying the arch. There had been, then, on this arch, altogether, 11 blows (one steel 9·22-in. shot is counted as a miss), two of the heaviest hits being with steel shot. These amounted altogether to 26,427 foot-tons; and, taking the superficial area battered as 120 feet, (17 ft. by 7 ft.), there was one shot to about every 11 feet, or 220 foot-tons per square foot. This ended the second day's battering.

The next day, 21st November, 1865, in order to try the effect of splinters from the granite outside No. 2 shield, a few (five) 40-pdr. segment shells (rounds 1081 to 1085) were directed at this part, and great effect was produced on the wooden targets set up inside the casemate. Nor were the splinters confined to this casemate only, for a great number found their way into the adjoining chamber, and did execution there also.

After this, a steady fire was kept up, for the rest of the day, from three guns directed as follows:—The 7-in. gun (600 yards) at the right pier of the right, or No. 1, casemate; the 8-in. gun (600 yards) at the left pier of left, or No. 2, casemate; and the 9-in. gun (1,000 yards) against the arch over No. 2 shield. All the shot were of common cast iron.

First, as regards the right pier. This part of the work had been previously somewhat weakened by the 10-in. steel shot (round 1,054) which accidentally grazed it low down on the first day. It was now struck by ten 7-in. shot (rounds 1,086, 1,088, 1,091, 1,094, 1,097, 1,100, 1,103, 1,106, 1,109, 1,112), and one 8-in. shell (round 1,116), giving an aggregate of upwards of 18,000 foot-tons. The whole of this took place on an area of about 35 square feet, thus giving one shot to 3 square feet, and about 514 foot-tons per foot of surface. The effect was to demolish the granite face, and to leave but little of the internal structure of the pier. After the 8th round, the masonry in parts was cut back to a depth of 5 ft. 6 in. from the original face; and after the 10th round, this was increased to 7 ft.

Next as to the left pier. The 8-in. gun was directed on this, and struck it ten times (rounds 1,087, 1,089, 1,092, 1,095, 1,098, 1,101, 1,104, 1,107, 1,110, 1,113), all as from 600 yards. This gave an aggregate of 19,490 foot-tons on an area of about 35 ft., or one shot to every 3½ square feet, and about 557 foot-tons to every foot of surface. The fourth of these shot injured very severely the granite block in the fourth course, in fact, daylight showed through; and the 5th round broke completely through into the casemate, making a hole upwards of 5 ft. in area. The subsequent shot enlarged this hole, dislodged more granite, cracked the brick-work in rear, and carried away more of the face-work, bringing down large masses of the superincumbent work.

Then, as to the flat arch over No. 2 shield. This received ten blows (1,000 yards) from the 9·22-in. gun (rounds 1,090, 1,093, 1,096, 1,099, 1,102, 1,105, 1,108, 1,111, 1,114, 1,117), giving an aggregate of about 26,660 foot-tons, on an area of 50 ft., or one shot to every 5 ft., and 533 foot-tons to every foot of surface. When each of the three stones forming the arch had received one blow it was very much crippled, and four shot more cut the centre of it back to an irregular depth of about 5 ft. At this time, also, the brick arching in rear began to give way. One shot (the 3rd) hitting the keystone, broke itself into two pieces, one of which glanced on to the shield, and the other went into the casemate, carrying away a railway bar of the lower fastening of the shield, and breaking the front racer. It produced, of course, a great many splinters inside the work. Another (the 6th) smashed the lower part of the key-stone, and cut away the two upper rail fastenings in the front of the shield. The last three shot brought down large masses of the upper work, exposing the concrete filling of the bomb-proof, but did not shew any great effect inside the work. The shield alone prevented the remainder of the granite arch from falling. This ended the third day's battering.

The 10-in. gun (600 yards) was now (22nd November, 1865) directed against the centre pier, and continued steadily at it for the greater part of the day. The effect of the three 9·22-in. shot fired at this pier on the 18th May has already been recorded.

It was now, on this occasion, struck first by nine single shots (rounds 1,118 to 1,126) the result of which may be given as follows:—The first shot, of course, shook out all the rubble work with which the injuries of the 18th May had been temporarily filled up. It also injured several large blocks severely, and exposed to view the end of a cramp forming part of the upper fastenings of No. 2 shield. The masonry in rear was driven back 2½ ins., and a slight crack was formed in the brick-work.

The next shot was also a destructive one, both in bringing down the granite face, and in general injury to the pier. A granite backing block was broken in two by a blow conveyed through a massive face stone.

The next shot struck rather high, and injured the upper granite work very much. Some large overhanging masses of granite and brick-work fell down from above. The pier showed an increase of cracks on the inside.

The three following shot continued the injuries, and threw down so much material in front that it became necessary to clear some away. Some fresh cracks and injuries appeared in the interior, especially about the centre pier, but, otherwise, the effect inside was less than might have been expected.

The remaining three shot of the nine could not be aimed lower than the fourth course on account of the *debris* in front, and, therefore, had most effect on the upper part of the pier. The granite face, about the centre of the pier on the fourth course, was now cut out to an irregular depth of about 5 ft., and the brick backing of the pier was driven back some inches.

The next shot (round 1,127) was on No. 1 shield, and this, together with the three following (rounds 1,128 to 1,130) has already been disposed of, in the mention either of the shield itself or of the arch over it.

After one more 10-in. shot (round 1,131) on the pier, which brought down large pieces of granite and brick-work, already loosened, a steel shell (round 1,132) from the 9 22-in. gun, with a bursting charge of 11 lbs. struck on the fourth course, and blew a hole about 2 ft. 6 in. high, and 1 ft. 6 in. wide, quite through the pier into the casemate. It knocked in some of the brick-work of the pier, and brought down a good deal of the arches springing from it, but there was enough still left in the heart of the pier to sustain the vaulting in fair condition.

After this came a salvo of cast-iron shot (rounds 1,133 to 1,136) from all four guns, directed at the upper part of this pier. One shot, it was thought, passed through a former opening without doing further injury. The rest caused a great fall of material in front, amongst which was the bed-stone of the pivot that had been used for the 22-ton gun over No. 2. In rear, some more brick-work was knocked out of the pier, and more of the arching fell, quite blocking up the front part of the casemate.

Then came the final salvo (rounds 1,137 to 1,140) which, on account of the *debris* in front, could only take effect high up. This brought down great masses of brick-work, concrete, and granite. The brick arching in the fore part of the right casemate was cut back to a depth of 12 ft. or 15 ft. from the original front. The material fell in quantities, driving the gun, which had been mounted there, quite to the back of the casemate. There was also an opening forced through from the front into the left casemate, rather high up, bringing down more of the pier and brick arching.

This centre pier had thus received on this occasion eighteen cast-iron shot (reckoning one to have missed), of which twelve were from the 10-in. gun, one from the 9·22-in., two from the 8-in., and two from the 7-in., as well as a 9·22-in. steel shell; all as from 600 yards. These gave together about 50,582 foot-tons. Adding to this the blows received on the 18th May, as already described, the pier had stood, altogether, about 59,000 foot-tons. Taking the surface of this pier at 180 superficial feet, it received in 22 blows an equivalent to about 330 foot-tons per square foot, and there was one shot to about 8 superficial feet.

Summing up the whole practice, then, it appears that 86 projectiles, having an agregate *vis viva* of upwards of 200,000 foot-tons, actually struck the work. These, distributed over the entire surface of iron and granite, would give one projectile to $8\frac{1}{2}$ square feet of front, or 270 foot-tons per superficial foot. Taking the iron only, against which were used steel projectiles, there were 22 blows, giving an aggregate of 52,000 foot-tons on 111 superficial feet, which is equivalent to 468 foot-tons per square foot, or one projectile to 5 feet of surface. On No. 1 shield, there were 13 blows, giving altogether about 400 foot-tons per foot, or one projectile to 6 square feet. On No. 2 shield, 9 projectiles gave about 700 foot-tons per foot, or one projectile to 3 square feet.

Taking the granite surface alone, against which cast-iron projectiles were used, 64 projectiles gave about 240 foot-tons per foot, or one projectile to 9⅓ feet. The right pier received 11 blows, giving 514 foot-tons per foot, or one projectile to 3 feet. The centre pier, 22 blows, giving 333 foot-tons per foot, or one projectile to 8½ feet. The left pier, 10 blows, giving 557 foot-tons per foot, or one projectile to 3½ feet. The right arch received 11 blows, giving 220 foot-tons per foot, or one projectile to 11 feet; and the left arch, 10 blows, giving 533 foot-tons per foot, or one projectile to 5 feet of surface.

It is almost needless to say that with this amount of battering the work was fairly breached; in fact, the granite front was completely destroyed.

The following extracts from the report of the committee that conducted the experiments, will sufficiently indicate the conclusions they drew from the trials.

With regard to the shields, they said: "Both the iron shields have resisted "well, and the fastenings of both may be said to be still effective, inasmuch as "they have held them in their places to the last; those of the east shield are, "indeed, hardly impaired. Those of the west shield have been weakened by "the breaking off of three out of ten iron cramps, but the remainder continue "to hold the plate; both shields continue to afford a fair amount of protection "to the gun behind them, nor can anything be said to have got through them, "although they are cracked through, bent, and started, from the effects of the "fire."

As to the effect on the granite, they spoke of the demolition being such "as "would have caused the abandonment of the two casemates before the firing "ceased, in fact, they were beginning to be untenable after the 33rd hit on the "granite, and quite so after the 54th hit. With them, the casemates in the "tier above, and, probably, also any barbette guns in the same vertical section "must have been also abandoned;" and "it was also observed that the dust, "grit, and fine splinters of granite sent into the work were sufficient to amount "to annoyance, if not to an actual obstruction of the working of the guns."

The committee also remarked as follows:—"This experiment has proved that "whilst the attack of a properly constructed iron-built battery would be hope-"less, except with steel or hardened shot, at a range not much exceeding 600 "yards, the destruction of a granite fort may readily be effected with cast-iron "shot at 1,000 yards. It is proper to add, that, considered as a granite fort "with iron shields, the one now reported upon appears not to have been as "strong as such a structure might be made with those improvements which the "result of the present costly experiment will doubtless suggest to the Depart-"ment of Works, if any more such works are to be designed. But the com-"mittee have, for the foregoing reasons, no hesitation in recording their opinion, "that granite should, if possible, not be used in exposed parts of the structure "of forts liable to be regularly engaged by heavily armed iron-clads. That "when unavoidably used, it should not be combined in the piers with brick-"work or any other inferior material in the manner in which it was combined "in this structure, and that it would be far preferable to provide forts in such "situation with external defences entirely of iron."

On the other hand, the Deputy Director of Works, in a Memorandum, dated October, 1866, on the results of these experiments, after comparing the latest construction of English casemates with like works in America and other countries, and shewing that the granite works with iron shields constructed in England, are far superior in strength to the casemated forts of any other nation, speaks of the effect produced on these experimental works as being not so great as was anticipated. He says—"The granite outside was, of course, much "smashed" but "in the interior of the casemates there was, for a long time, no "effect produced which would have prevented the guns being worked. The "result, indeed, shewed a much greater stability under a close and deliberate "fire of modern ordnance than had been expected."

The Deputy Director of Works also points out that, while the experiments had suggested a few improvements in the detail of construction, they shewed the structural parts of the work to possess some good qualities in an unexpected degree, and proved further that the casemates were admirably adapted for the working of heavy guns

In speaking of the opinion, held by some, that these experiments shewed that granite should not be used in those parts of a casemated work which would be exposed to fire, he submits "that this view is fallacious," and says that a just conclusion cannot be formed on this matter without ascertaining what portion of the fire which destroyed the fronts of the two experimental casemates would have taken effect upon a corresponding part of a fort in a naval attack.

He points out that the conditions under which these experimental casemates were tried, were very different from those that would exist in a naval attack upon a fort. The measure of accuracy of fire was 200 yards, notwithstanding that the nominal ranges were 600 or 1,000 yards. The fire was from a land battery, leisurely conducted, every shot, and sometimes four together, being aimed with the most perfect accuracy, and without the disturbing influences of a return fire. There was also the absence of smoke, which during action interferes with the precision of a ship's fire; and considering the liability of the ship being disposed of by a few, perhaps, one or two, well directed shots from the numerous guns mounted in the fort itself, and other works in support, he urges that it is improbable that vessels could remain in action long enough to do any effectual damage to a work such as that represented by these experimental casemates.

He further analyzes the effects of the combined attack, by the French and English fleets, on Sebastopol, when the result of 1,244 guns, firing 30,000 to 50,000 rounds, was only the dismounting of 28 guns, and the disabling of 11 carriages (all in open batteries), and when Fort Constantine, a casemated battery of masonry of a rather inferior character, was exposed to the most severe fire, but in no case penetrated, and not a gun in the casemates was dismounted. He takes also the case of Fort Sumter, which was built entirely of brickwork, only 5 feet thick about the embrasures, and at no part more than 11 feet thick, and in an engagement of $2\frac{1}{2}$ hours, with eight "Monitors" and one iron-plated ship, carrying 15-in. and 11-in. ordnance, it appeared that out of about 83 shots, at an average range of 1,200 yards, only 58 struck the fort at all, there being only one instance of three shots striking near together.

Applying this experience to the experiments now in question, he concludes that the proportionate area of the part of the experimental casemates fired at, being about $\frac{1}{12}$th of that of the portion of Fort Sumter fired at, and the proportion of shot which hit that fort, being, at most, three-fourths of the number fired at it, the number of shot that would probably have hit two casemates such as those tried at Shoeburyness, during a naval attack similar to that upon Sumter, against a fort of 24 casemates, would have been $\frac{3}{4}$ of $\frac{87}{12} = 5{\cdot}5$ shots nearly, instead of 87; that is to say it would require 16 times the accuracy and concentration of fire that was attained by the iron-clad fleet against Fort Sumter, to produce the result which occurred in the experiments at Shoeburyness.

He adds "it must be remembered, moreover, that the assailing fleet would "not only be opposed by the fire from the casemated works, but that powerful "open batteries, and guns in turrets, sub-marine mines, floating obstructions, "and moveable floating batteries would also be employed in aid of the defence."

While not disputing that works wholly plated with iron of sufficient thickness, will afford superior powers of resistance to granite works provided with iron shields at the embrasures, the Deputy Director of Works maintains that, in many, if not in most cases, the latter construction is strong enough for its purpose. He concludes by saying that "the works constructed in England on "this principle (granite casemates strengthened by means of shields at the "embrasures) are far superior in strength to the casemated forts of any other "nation, and except in cases where a work is entirely isolated, and from its "position specially liable to a concentrated fire, or where the nature of the "foundations may render an iron structure advisable, there are no sufficient "reasons for incurring great additional expense by the *general* adoption of "wholly iron-plated works."

Reviewing these experiments at the present time (1869-70) by the light of the experience acquired since they took place, and taking into account the progress of events in the interval, it must be admitted that these general conclusions have been, in a great measure, justified.

The introduction of pointed projectiles has largely added to the destructive effect of the fire of heavy guns. Also the arming of ships of war with guns of 18, 25 and 30 tons, in turrets, which in 1865-6 was regarded as a probability only, is now actually taking place, and we cannot be blind to the prospect of still heavier ordnance being effectively worked in floating structures.

Yet for all this, well armed masonry forts, strengthened with iron shields at the embrasures, will, with the improvements suggested by these trials, be generally sufficient for the purposes of inner-harbour defence for a great length of time, while the iron-fronted forts, which, mainly as the fruit of these very experiments, have been wisely adopted for the more prominent and important positions of outer defence of our principal naval arsenals and dockyards, will, for centuries, stand secure against any attack.

II. OPEN BATTERY SHIELD, KNOWN AS THE "GIBRALTAR SHIELD." PL. III.,

The trial of this shield formed the subject of an investigation, the proceedings of which were published in a B'ue Book, entitled, "Report of a Special Committee on the Gibraltar Shields," with a separate appendix. This report was afterwards discussed in a paper by the Deputy Director of Works, styled "Observations by Colonel Jervois, C.B., R.E., on the report of the Special Committee, &c.," which was also published. The present notice will, therefore, be strictly confined to a technical description of the shield itself, and to an account of the practice during its trial.

Its construction, shewn in Plate III, may be described as follows:—

The front armour consisted of two $5\frac{1}{2}$ in. plates, running horizontally, each 12 ft. long and 4 ft. 1 in. wide, making together the face of the shield 12 ft. by 8 ft. 2 in. Out of these was cut a port 4 ft. by 2 ft. 5 in., with the corners rounded to a radius of 8 in.

Next to this came a 5 in. thickness of armour, consisting of three plates, standing vertically. The centre of these, called the "Port plate," was 5 ft. 6 in. wide, and had a port cut in it, 4 ft. 1 in by 2 ft. 9 in., with the corners rounded as before. The other two plates were 3 ft. 3 in. wide, and all were 8 ft. 2 in. in length or height.

Behind this came a $1\frac{1}{2}$ in. skin, composed of four plates; one on either side of the port, 4 ft. $5\frac{1}{2}$ in. wide and 8 ft. 2 in. high, one above the port 3 ft. 1 in. by 1 ft. $6\frac{1}{2}$ in., and one below the port, 3 ft. 1 in. by 2 ft. 7 in. The port in this thickness was 4 ft. $0\frac{1}{2}$ in. by 3 ft. 1 in.

In rear of this skin, and riveted to it were seven rolled iron ⊢⊣ girders, running horizontally; they were 12 in. by 6 in. by 1 in., and weighed 70 lb. per foot run. Three of them were in close order above the port. The other four were below the port and were in pairs.

Twenty-nine 3 in. bolts with conical heads and shanks, reduced on Major Palliser's principle, secured the front armour plates; fifteen of these passed through to the rear of the ⊢⊣ girders, the remainder to the back of the skin. There were besides nineteen 2 in. bolts, with conical heads to secure the second thickness of armour, and these were nutted at the back of the skin. India rubber washers $\frac{3}{4}$ in. thick were fitted under all the nuts.

The shield was supported by struts made of 1 in. plate, and angle irons 8 in. by 6 in. by 1 in., and 6 in. by 5 in. by 1 in. The struts were further stiffened by 1-in. strips, and they had 8 in. by 6 in. angle irons set on their inner face, to take the ends of the ⊢⊣ girders, already described. All the rivets of the struts were 1 in. diameter, laid out at a 6-in. pitch.

The struts were held down to transverse sill-pieces, 8 ft. 9 in. long, and 11 in. by 5 in. in section, by means of $1\frac{1}{2}$-in. screw bolts; there were 12 of these bolts to each strut. The sill-pieces were notched out at the front ends, so that the front armour rested against a shoulder, 3 in. deep. The rear ends of these sills were notched and bolted to a floor beam, 18 ft. 6 in. long, running parallel to the front of the shield, and forming horns, as it were, which, in an actual work, would be built into the masonry to secure the shield from movement.

A mantlet made of 3 in. rope, in 2 thicknesses, was hung at the back of the shield.

With regard to the quality of iron used in these shields, it may be stated that all the sample pieces of armour-plates proved at Shoeburyness received the highest figure of merit, A-1.

Specimens of the armour-plates, taken in the direction of their length, and proved in test machines, broke with an average tensile strain of 18·9 tons per square inch of original section, their elasticity being overcome by 10·3 tons, and the ultimate elongation per unit of length being ·155. Another average gave an ultimate strain of 19·8 tons, 9·2 tons as the yielding strain, and ·23 as the ultimate elongation per unit of length, in specimens taken longitudinally in the armour plates; while in specimens taken transversely, the averages were 15·25 tons ultimate strain, and 9·35 tons yielding strain. Specimens taken through the thickness of the armour gave an average ultimate tensile strain of 7·7 tons, the yielding point being at about 6 tons. Specimens of the same armour plates tested by compression gave an average permanent compression of ·288 in. with a weight of 50 tons per square inch, the specimens being ·533 in. in diameter, and 1 in. in length.

Specimens of the $1\frac{1}{2}$-in. skin, taken longitudinally in the plates, gave, under tensile strains, the following averages, namely: breaking strain, 20·8 tons; yielding point, 11·3 tons; final elongation per unit of length, ·18. Transverse specimens of the skin gave a breaking strain of 14·75 tons, and a yielding strain of 10·5 tons.

The iron for the 3-in. bolts, which was principally of Staffordshire crown iron, broke, on the average, with a tensile strain of 23·5 tons, the yielding point being at 11·5 tons, and the final elongation per unit of length, ·278. Another specimen broke with 22·3 tons per inch of original section, with a reduction of sectional area at the point of fracture of 37·8 per cent., and elongation, ·294 per unit of length. The rivet iron broke with 25 tons, yielded with 14 tons, and elongated ·3 per unit of length.

The weight of the shield was as follows:—

	Tons	cwts.	qrs.	lbs.
$5\frac{1}{2}$-in. front plates	8	8	0	14
5-in. intermediate plates	7	10	3	14
$1\frac{1}{2}$-in. skin	2	3	3	4
⊢⊣ Girders	2	8	2	17
Struts	2	0	1	24
Sill and floor beans	2	9	3	22
Bolts, nuts, washers, &c.	1	10	1	22
Total	26	12	1	5

The shield was set up for trial in a temporary manner only, by weighting the floor beams with some cast-iron blocks, and driving piles in rear to prevent its driving backwards.

The guns employed in the trial were as follows, and they were placed in battery at 70 yards from the shield:—

The 9-in. rifled muzzle-loading gun of 12 tons, with a charge of 37 lbs, to represent a full battering charge at 400 yards range; and also full battering charge of 43 lbs.

The 10-in. rifled muzzle-loading gun of 18 tons, with a charge of 54 lbs., to represent full battering charge at 400 yards.

The 15-inch Rodman smooth-bore gun, of $19\frac{1}{4}$ tons, with a charge of 50lb. of English powder, which is equivalent to 60 lbs. of American powder.

A preliminary trial took place on the 25th October, 1867, when two rounds (Nos. 1469-1470), were fired from the 9-inch gun with 37lbs. charges. An account of these rounds will be found in Table I.

In consequence of the failure of so many bolts on this occasion, it was thought desirable to institute a test that would represent, in some measure, the sudden action to which bolts are subjected under the impact of heavy shot, instead of relying as heretofore on the test of a gradually increasing strain as applied in ordinary test machines. For this purpose, the action of a falling weight was preferred, and trials were set on foot to test by this means armour bolts, made of different qualities of iron and steel, with heads formed in different ways. These experiments were conducted in the manner described by Lieut. English, R.E., in paper X of this volume.

It may be mentioned that the results obtained by this test have been found to be so reliable a guide in judging as to the fitness of iron for armour bolts, and the apparatus itself has been so successful, that it is now employed to a great extent in testing the armour bolt iron for all contracts.

Speaking generally, it may be said that the 3-in. bolts of Staffordshire iron tried in this way broke near the head with a crystalline fracture at the first blow of the monkey, without any elongation; while the best of the bolts of other iron of special make, broke fibrous in the shank at the third blow of the monkey, and elongated 45 per cent. Some Bessemer and crucible steel bolts stood three blows, and one of them elongated fairly, but the results were uncertain.

The effect of these trials, therefore, was to show that the Staffordshire iron, which had given satisfactory results in the test machine, would not develop a fair amount of work under impact, and for the further trial of the shield new bolts were made of a soft fibrous iron manufactured at the Cyclops Works; also, to adopt more fully Major Palliser's principle, the heads of the new bolts were made by "drawing down" the entire bolt from a bar of the larger diameter of the head, instead of forming it by "upsetting" the end of a bar of the full diameter of the thread. It must be mentioned, however, that the experiments just described did not, by any means, prove the disadvantage of the "upsetting." A specimen of an upset head, which was cut in sections and subjected to a chemical process to bring out the texture of the iron, showed the fibre to retain its longitudinal direction in perfect order, except, perhaps, at the very top of the head, thus disproving the argument that the fibre in an upset head, if not altogether destroyed, must, at any rate, be deranged throughout. Also, in the new bolts the reduction of the shank to the lesser diameter of the thread was continued throughout its entire length, instead of confining it to a small portion, as at first thought sufficient.

In addition to the above alteration of the bolts, it was found desirable to enlarge the 3-in. bolt holes in the 5 in. armour and $1\frac{1}{2}$-in. skin plates of the shield to 4 in. diameter, and to round the inner edges of the holes in the front armour. The space thus left around the bolts was filled with ash-wood tubes. The enlargement of the holes was intended to obviate, as far as possible, the injurious effect that is produced when an armour bolt at the instant of its being put under sudden tension is subjected also to a cross strain or "nip." The edges were rounded to reduce the shearing action between the several layers of plate. Emery also was put round the conical heads of all the 3-in. bolts to prevent their drawing through the armour, this having been found very effective in the experiments with falling weights.

With the above exceptions, and the substitution of washers of a patent cork material, and 1-in. elm for the india-rubber washers before used, the shield, at the time of the second trial, was in the same state as at the conclusion of the preliminary experiment.

The further trials took place on the 19th December, 1867, and the 16th and 22nd January, 1868, a special committee, composed mainly of the Members of the Committee on Iron Plates, which had been disbanded in 1864, taking the place of the Ordnance Select Committee, which conducted the preliminary experiment.

A report of these trials will be found in Tables I and II, and Plate III will further assist in identifying the shot marks.

TABLE I.—GIBRALTAR SHIELD.

Report of Practice on the 25th of October, 1867.

Photographic No. of Round.	Gun.	CHARGE. Weight and Brand of Powder.	PROJECTILE. Nature, Length, Weight, and Diameter.	Striking Velocity.	$\frac{Wv^2}{2g}$ in Foot Tons on Impact.	Foot Tons per Inch of Shot's Circumference.	Observed Effects.
1469	9-inch M.L. rifled gun of 12 tons, 70 yards.	lbs. 37 Rifle L. G.	Palliser shot. Head 1 D. 18 ins. 248 lbs. 8·92 ins.	feet. 1276	2799·9	99·92	Struck 3 ft. 6 in. from right, 1 ft. 9 in. from bottom; shot penetrated 10·92 in., base 7 in. out, most of body dropped off in front. In the bottom plate three bolts above hole, two on level, and one below, gone; broken close to head. In upper plate three bolts broken above hole. The inner, or 1½ in. plate, forced away from 5 in. plate ¼ in. *In rear*, the shot struck fair between two of the horizontal girders, the bottom one of which it broke through. The upper girder cracked in web and outer flange, and horizontally 7 ft. 9 in, three inches from inner side; the third also cracked through web and outer flange. Inside skin buckled and cracked; five small plate-bolts broken, and seven rivets sheared. The mantlet saved the nuts from being driven to the rear. The bottom plate buckled 1¼ ins. in its whole length. Nos. of bolts broken—28, 30, 33, 36, 37, 40, 42, 44, and 47.
1470	...	...	...	1275·0	2795·5	99·76	Struck upper plate 3 ft. from left, 9⅜ in. from bottom. Shot penetrated 11½ in., and partly broke up. Plate buckled 1·2 in. below shot. Bolts broken on left side, Nos. 27, 29, 31, 34, 38, 39, and 41. *In rear*, the inner skin-plate cracked through, and skin bulged about 6 in.; the embrazure plate about 1 in. (the shot having struck on the right edge of the former.) The left inner plate cracked through to right edge in wake of shot; opening of crack about 2¼ in. on rear face; the crack extending for about 5¼ in. horizontally along plate, then downwards for about 7 in., ending about 11 in. from right edge. The embrasure plate apparently not cracked at all. The top front plate pushed sideways in embrasure, now overlapping the bottom one about one inch. The horizontal crack in web of girder opened out considerably on left of embrasure, the lower armour plate separated from inner 1¼ in., and the upper one 1 in. On left side the upper inner armour plate buckled forward 1 in. at top, and ½ in. at bottom. The outer armour-plate ⅝ in. at top from inner, and outwards ½ in. at bottom.

TABLE II.–GIBRALTAR SHIELD.

Report of Practice on the 19th of December, 1867; 16th and 22nd of January, 1868.

Photographic No. of Round.	Gun.	CHARGE. Weight and Brand of Powder.	PROJECTILE. Nature, Length, Weight, and Diameter.	Striking Velocity.	$\frac{Wv^2}{2g}$ in Foot Tons on Impact.	Foot Tons per Inch of Shot's Circumference	Observed Effects.
		lbs.		feet			
1477 Dec. 19 1867	9-inch M. L. rifled gun of 12 tons. 70 yards.	37 R. L. G.	Palliser shot Head 1 D. 18·0 ins. 248·5 lbs. 8·92 ins.	1283	2836·5	101·22	Struck top plate 20 inches from proper right of shield. Plate driven in 1 inch, and buckled 7 inches along its bottom edge, 7 inches on right edge, and 1·4 in. on edge of indent. On right side the 5-inch plate 1 inch from skin at top, and 0·2 inch at bottom. The bottom of top front plate 0·7 inch from 5-inch plate. Shot remained in plate, and penetrated 10 inches; base broke off. The shield moved bodily to the right about 1·5 inch, and turned on its centre, right back, and left forward. In rear, the skin bulged and cracked vertically from No. 30 bolt-hole up to top girder; probably extending some distance behind it. The width of the crack about 1½ inch. The 5-inch plate also cracked, and bulged up to girder; one large and one small bolt broken off at skin plate; the nut of the large bolt made a deep indent in the mantlet; the bulge of skin plate about 2·75 inches.
1478	9-inch M. L. rifled gun of 12 tons, 70 yards.	37 R. L. G.	Palliser shot, Head 1 D. 251 lbs.	1276	2833·7	101·12	Struck lower plate 3 ft. 6 ins. from left, and 1 ft. 11 ins. from bottom. The plate horizontally buckled along bottom, 1·5 inch under shot, and 1·7 inch under left edge of port, 0·7 inch over 40 inches under shot hole, and 0·65 inches over shot hole. Vertical buckle 0·8 inch on left, and 1·2 inch on right of shot hole. Shot penetrated about 10 inches; base broken off. (This shot a better chilled one than the last.) The left side of shield driven back 2·5 inches, and the bottom plate started 0·6 inch at top, and 0·7 in. at bottom, away from 5-in. plate. This shot was knocked out by No. 1479; depth of indent found to be 10·5 inches. In rear, the 4 bottom girders broken through web, and rear flange close to and in the line of the two armour-plate bolts, Nos. 44 and 48, on right, and below indent. The upper girder of these four also broken through web and flange, in line with right edge of port; and in flange only, in line with centre of port. The skin plate bulged and cracked vertically, for a distance of 3 feet 6 inches from the bottom, and 34 inches from left of shield. (The crack extended 6 inches above the lower girders.) Two small armour bolts and 8 rivets broken.

Photographic No. of Round.	Gun.	CHARGE. Weight and Brand of Powder.	PROJECTILE. Nature, Length, Weight, and Diameter.	Striking Velocity.	$\frac{Wv^2}{2g}$ in Foot Tons on Impact.	Foot Tons per Inch of Shot's Circumference	Observed Effects.
		lbs.		feet			
1479	15-inch Rodman gun of 19¾ tons. 70 yards.	50 R. L. G.	Spherical cast-iron (American) 451 lbs. 14·89 ins.	1157	4186·3	89·49	Grazed 58 feet short, and struck target on bottom plate, 1 foot 11 inches from left, and 17·5 inches from bottom. Crack in face of indent about 1 inch deep, and 11 inches long in lower half. Shield driven back 5 inches at left, and 4 inches to the left. The vertical buckle of plate 6 ins. On left side, the front lower plate buckled away from 5-inch plate, 1·3 inch at top, and 0·6 inch at bottom; 5-inch plate buckled away from skin, 0·7 inch at top. 8 rivets broken in strut, and the angle iron of bend at bottom cracked. The shield shifted right, about 3 inches forward, and 5 inches to the left. In rear, the skin plate cracked and bulged, and another crack 6 inches to left of former, and 11 inches from left of shield, 1 foot 8 inches long. The 3 upper bottom girders broken away at inner flange, up to Nos. 44 and 48 bolts; two pieces of which, measuring 2 feet 11 inches by 11 inches, and 1 foot 10 inches by 9 inches, weighing 1 cwt. and ¾ cwt. respectively, driven 4 feet and 11 feet to the rear, the nut and part of No. 45 bolt carried 58 feet to the rear. (These pieces must have passed under the mantlet.) The lower girder broken through its web longitudinally, and across web and outer flange, close to No. 48 bolt. The crack in skin plate made by No. 1478 extended into that made by No. 1470; 8 rivets broken, and two small armour plate bolts. The whole shield driven back, and slewed about 5 inches. The 4 bolts fastening inner bottom flange of strut to sill, sheared off. Lower angle piece of strut had 5 rivets broken; angle piece bulged and cracked in angle. Shot rebounded from target, and fell 10 feet in front of it, partly broken. Diameter of shot after firing 13·1 inches, striking surface to base, and the maximum diameter 14·9 inches.
1480	9-inch M.L. rifled gun of 12 tons. 70 yards.	43 R. L. G.	Palliser shell. Head 1·5 D. 20 ins. 250·4 lbs. 8·92 ins. Bursting charge 2·375 lbs.	1329	3066·8	109·44	Struck top of lower plate 3 feet 6 inches from right, on edge of plate. THROUGH, and burst in doing so. A crack joins bottom of hole with No. 1469, and a piece of front plate carried through the shield. The bolt on left of No. 1469 drawn in 0·3 inch. The bolt on edge of shell hole driven in and lying in hole. A bolt in bottom row of upper plate above

Photographic No. of Round.	Gun.	CHARGE. Weight and Brand of Powder.	PROJECTILE. Nature, Length, Weight, and Diameter.	Striking velocity.	$\frac{Wv^2}{2g}$ in Foot Tons on Impact.	Foot Tons per Inch of Shot's Circumference	Observed Effects.
		lbs.		feet.			
1480 contd.							hole broken at neck (head of bolt fell in front of shield); and a bolt in second row of bottom plate, 6 inches from edge of hole, also broken at head. The shield was driven back about 9 inches below port. In rear, the piece of the 5½-inch plate broken away was driven 12 feet to the rear. The 5-inch port plate, on right side of port, broken across horizontally, through bolt hole, 11 inches from top of girder, and forced back. A triangular piece of its rear mould, 10 inches by 2½ inches thick, carried 15 feet to the rear. The bolt on proper left of shell hole found twisted, and bent in bolt hole. The 5-inch plate also cracked nearly through, from level of port to No. 43 bolt. The right edge of shell hole touched and slightly indented right hand 5-in. plate, which also buckled about 1 inch in 12 inches. The skin plate broken across horizontally, through bolt hole, and, vertically, following the junction line of the 5-inch plates up to 3 feet 6 inches from top of lower girder, (and forced back); the bottom of the crack joined that formed by No. 1469. The lower piece of the skin plate 14 inches by 15 inches next girder, broken off, and carried 2 feet to the rear. The head and large portion of the shell found 20 feet in rear; three large and two small bolts, and one rivet, broken; half the mantlet carried 16 yards to the rear, over earthwork, and a 6-ft. by 6-ft. wood target, which was resting against the shield, blown to pieces.
1481	9-inch M.L. rifled gun of 12 tons. 70 yards.	43 R. L. G.	Palliser shell. Head 1·5 D. 20 ins. 247·6 lbs. Bursting charge 2·562 lbs.	1342	3092·0	110·34	Struck top plate 21 inches from left, and 18 inches from top of shield. Head of shell buried in plate, remainder blown away. Shell burst on face of plate. The plate broken through from top of indent to top of shield, through No. 29 bolt hole, and a crack 6 inches long extended from left of indent towards edge of shield; cracks developed around No. 1470, one from bottom of hole to bottom of plate, and one on upper right of indent 4 inches long. The outer bolt (left top) broken off at head, and the plate appeared cracked inside the bolt hole. On top of shield, the break in the front plate 1 inch wide, and 27 inches from left. The 5-inch plate cracked 2 inches deep in its rear face, and 2 feet 3 inches from left. The upper girder

Photographic No. of Round.	Gun.	CHARGE. Weight and Brand of Powder.	PROJECTILE. Nature, Length, Weight, and Diameter.	Striking Velocity.	$\frac{Wv^2}{2g}$ in Foot Tons on Impact.	Foot Tons per Inch of Shot's Circumference	Observed Effects.
1481 Contd.		lbs.		feet			cracked for 6 inches along its front flange, directly in the line of the shot. The skin plate buckled to the front 1½ inch, the 5-inch plate 2½ inches, and the front plate 2¾ inches; the latter overlapping the 5-inch plate by 1½ inch on left edge. In rear, the skin plate bulged and cracked for a length of 5 inches, 11 inches from left, close under top girder. The lowest top girder cracked across web diagonally, commencing at inner flange, at 3 feet 3 inches from left, to 4 feet 6 inches, and bulged about ½ inch. The bolt on left top corner driven back 2 inches, and rivets of upper angle iron broken.
1482 Jan. 16, 1868	9-inch M.L. rifled gun of 12 tons. 70 yards.	37 R. L. G.	Palliser shell. Head 1·5 D. 21 ins. 248·5 lbs. 8·92 ins. Bursting charge 2·5 lbs.	1297	2899	103·44	Struck lower plate 2 feet 9 inches from left, 9 inches from top, and burst, the pieces flying back. No. 41 bolt sheared 5 inches from front, and showed in shell hole. Bolt No. 39 sheared at 6·5 inches from front, but remained in shield. Crack from top to bottom of plate through Nos. 1478 and 1479 indents. In No. 1478 there was a crack about 3 inches broad through shield. In rear, the crack in skin plate made by No. 1470 opened out to 6·5 inches in widest part, and extended from top to bottom of shield. A crack in skin, 21 ins. below that by No. 1470, and up from the bolt on left (No. 44) of porthole, 6 inches long. The top bottom girder now pushed back at old fracture 19 inches, and cracked diagonally across on left 12 inches. A block of iron, 1¼ ton, which was touching the bottom girder, driven back 2 feet 6 inches by the shock. The 5-in. plate cracked nearly through, and bulged in line with the shot-opening of crack, 1½ inch wide on rear face. The crack extended horizontally along the plate apparently up to bolt No. 44.
1483	9-inch M.L. rifled gun of 12 tons. 70 yards.	43	Palliser shot. Head 1·5 D. 18·9 ins. 248·0 lbs. 8·92 ins.	1348	3124·8	111·51	Struck upper plate 22 inches from right, 20 inches from top, partly overlapping No. 1477; the hole now 15 inches in diameter at widest part. Shot broke up, and part remained in hole; when removed, the indent was found to be 13·86 inches. Piece of plate about 2 feet square, and weighing 7 cwt. 3 qrs. 7 lbs., broken off top corner, and thrown 9 yards to proper right. Bolts Nos. 24 and 30, broken off at distances of 6·5 inches and 6 inches from head respectively; 5-inch plate 2½ ins. from skin at top corner.

Photographic No. of Round.	Gun.	CHARGE. Weight and Brand of Powder.	PROJECTILE. Nature, Length, Weight, and Diameter.	Striking Velocity.	$\frac{Wv^2}{2g}$ in Foot Tons on Impact.	Foot Tons per Inch of Shot's Circumference	Observed Effects.
		lbs.		feet			
1483 contd.							In rear, the damage joined that of No. 1477; a piece of skin plate about 14 inches by 15 inches torn off. The opening in 5-inch plate now about 7 inches wide; a portion of the bottom inner flange of bottom top girder, 14 inches long, broken off (4 rivets broken). The bottom top girder also bulged and broken in web, and cracked in the web, and inner flange in line with the edge of port. The plates about 1 inch away from the skin plate. The head of this shot and that of No. 1477 about 6 inches apart, and both visible in the opening of the 5-inch plate. Portions of No. 1477 shot were driven to the rear of the shield at this round.
1484† Jan. 22 1868	10-inch M.L. rifled gun of 18 tons. 70 yards.	54	Palliser shell. Head 1·5 D. 27·2 396 lbs. 9·92 ins. (large capacity). Bursting charge 10 lbs.	1211*	4027	129.22	Struck 19 inches below centre of port, penetrated 5½-in and 5-inch plates, and burst, fragments flying principally backwards. The shield driven back about 1 inch. Piece of 5½-inch plate nearly broken off (only holding by about 2 inches of front mould at right bottom corner). Plate cracked through from No. 1469 indent to No. 47 bolt; from No. 43 bolt to nearest point of fracture caused by No. 1480, and from present shell hole to No. 44 bolt. Remains of No. 1469 shot, which were sticking in target, thrown 5 yards to front. Head of No. 34 bolt broken off and thrown 5 yards to the front. This was the only large bolt broken by this round. The 5½-inch plate also cracked from top of indent to top of plate, and from rear to within 2 inches of front, the crack being 1 inch wide in rear. In rear, the 5-inch plate at 10 inches from left edge of port, split from top to bottom, and opened out 3½ inches at widest part. Behind shot hole there was an H crack in the inner skin 12 inches by 12 inches, and 2 inches wide. All the bottom girders cracked through web and flange, and two pieces of centre girder (each 24 inches long) carried one yard to rear. A piece of the bottom girder, about the same size, also broken off.

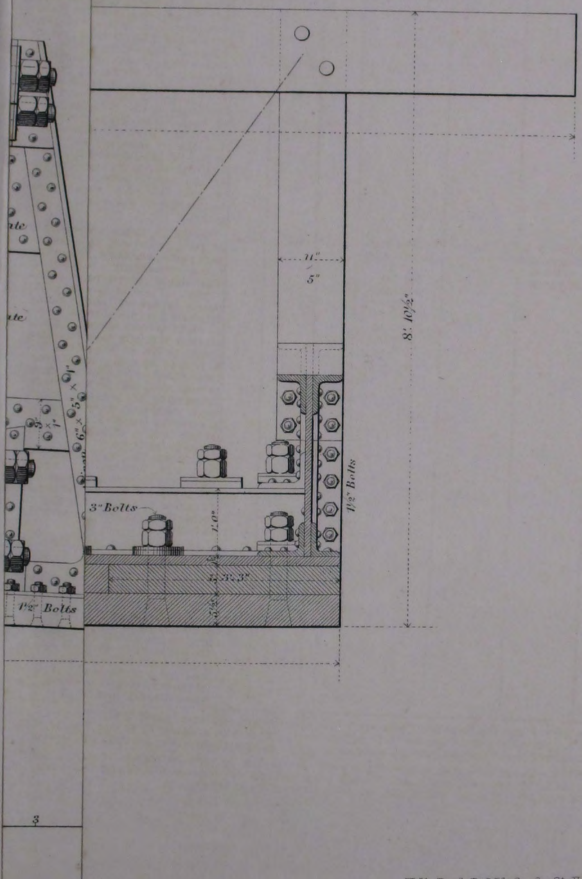
* Bore of gun wet from rain; gun was loaded about 20 minutes before being fired.

† A 10-inch Palliser shell, head 1·5 D, weight 398 lbs., fired with a charge of 54 lbs., Jan. 16, 1868, penetrated 23 feet of earthen parapet, and passing out in an upward direction, fell 300 yards beyond.

NOTE.—The girders on each side of the port were broken by previous rounds. Crack in 5-inch plate made by No. 1480, continued through plate. Small bolt between Nos. 34 and 38 broken off in line with front of skin. No. 48 bolt bent to an angle of about 150 degrees.

Pl: III.

GIB



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III.—Iron Fronted Casemate representing a portion of Plymouth Breakwater Fort. Plate IV and V.

The following description of this experimental structure is taken principally from a paper printed by order of the Director of Works, for the information of the committee to which the conduct of the experiments was entrusted.

The design of the actual Breakwater Fort was followed as closely as circumstances would permit, the chief point of difference being this, namely: that, to avoid useless expense, the experimental work was made with a straight face, while the outline of the fort itself is an oval, made up of curves described with radii of 50 and 90 feet.

In so small a portion of the curve, the effect of the oval form would have been lost, while there would have been more difficulty in placing the short experimental front on an equal footing with a similar portion of the continuous face of the fort itself. It is certain, also, that the difference, as regards resistance, would have been inappreciable.

Opportunity was taken of the occasion to introduce some improvements in the constructive details which had suggested themselves during the progress of the work on the fort; and in other instances, minor alterations were necessary to make up for the want of continuity in the experimental structure. Also, as the principle of construction adopted in the fort is favourable to the future addition of armour in layers, a portion equal to nearly one-third of the experimental front was covered with an extra armour-plate.

Plate IV illustrates the construction.

Proceeding with the description of the structure, it may be said to have been composed of two main parts:—

1. The front wall;
2. The structure carrying the roof.

One object of the construction was to make these two parts so far independent of each other, that until the front wall could be actually breached, the structure carrying the roof would be little affected by horizontal fire.

First, with regard to the *front wall.*

This occupied a frontage of 21 ft. 9 in., the interval allowed between the guns in Plymouth Breakwater Fort. It had a batter of 1 in 11 to a height of 11 ft, and from that it fell back in a curve to the outline of the roof. It contained a port suitable for either an 18-ton, or 12-ton gun, mounted on a muzzle-pivoting carriage. In either case the gun could train laterally through an arc of 70°. The 18-ton gun could have 10° elevation and 5° depression. The 12-ton could have 15° elevation and 7° depression.

The wall was made up of three thicknesses, except at that portion where there was the extra layer of 5 inches. In the first or front thickness the lower armour plate measured 21 ft. 9 in. by 4 ft. $9\frac{3}{4}$ in.; the next was the same length and 4 ft. $1\frac{1}{2}$ in. wide. Above this there were four plates, all 6 ft. 6 in. long, and 5 ft. $11\frac{1}{2}$ in., 6 ft. 6 in., 5 ft. 3 in., and 5 ft. 4 in. wide, respectively, standing vertically with their upper part curved back to form the slope of the roof.

The second thickness was composed of a vertical plate 11 ft. long and 5 ft. 3 in. wide, in which the port, 3 ft. 0¾ in. by 3 ft. 0¼ in., was cut, and on the right side of this there were seven vertical armour planks 16½ in. by 5 in. in section, and on the left side five of the same; all the same length as the port plate.

The inner or third thickness was composed of pieces running horizontally, as follows:—Commencing at the floor level there was an armour plank 12 in. by 5 in. in section, 21 ft. 9 in. long. Next above this, an armour plate of the same length, 4 ft. 2 in. wide, out of which the lower part of the port was cut. On the right of the port there was one 16½ in. by 5 in. plank, 10 ft. 9 in. long, and another on the left 8 ft. long. Above these came three planks, each the length of the entire front, out of the lower of which the top part of the port was cut.

The extra thickness on the front consisted of a 5 in. vertical plate, 16 ft. 11 in. long, with the upper part curved back to the slope of the roof. The width of the lower part of this plate was 6 ft. 3 in., and of the upper part only 6 ft.; this reduction in width was rendered necessary by the hydraulic press in which the plate was bent being too narrow to take the full width of 6 ft. 3 in..

The supports of the front wall consisted of five sets of uprights in rear, composed of 12 in. by 5 in. planks, 14 ft. long, placed in couples 6 in. apart, the pair next to the port on either side being strengthened by an additional plank of the same scantling. The 6 in. spaces between the uprights were filled in with oak timber. The feet of the uprights passed through a base plate 2 ft. 7 in. wide, 2½ in. thick, and 22 ft. 9 in. long, sunk in the masonry floor; and they were run with lead into the stonework. Between the back edge of the base-plate and the granite of the floor an inch of oak was introduced.

All the uprights passed through a ¾-in. plate 1 ft. 10 in. wide and 21 ft. 9 in. long, at a height of 10 ft. 8 in. above the floor level, and each set was bolted together by two 3-in. bolts, one above and one below the ¾-in. plate. The upper ends of these uprights were shaped to suit the curve of the upper bent armour plates before described.

Between the second and third thicknesses of armour, there was a layer of hides about ⅜ of an inch thick, and weighing, per foot superficial, about 1¼ lbs.; strips of the same material were inserted between the third thickness and the uprights.

Generally the armour bolts were 3 in. diameter, with a conical head formed by upsetting; the larger diameter of the head was 4 in.; the shank was reduced for its whole length to the lesser diameter of the screwed part, or 2·8 in., according to Major Palliser's plan, and a rounded thread was cut for a length of about 6 in. with 5½ threads to the inch.

At the ends of the front there were eight and nine (17 in all) 3½ in. armour bolts, the increased diameter being intended to provide, in some measure, against the extra strains due to the want of continuity in the structure. These bolts were formed with screwed heads having five threads to the inch, and the nut end had the same thread; the shank was reduced to the lesser diameter of the thread, or 3·3 in.

There were, besides, eight 2¼-in. bolts securing the second and third thicknesses of armour, and these were made on similar principles.

The bolt holes were generally made 1 in. larger in diameter than the bolts they received, except in the case of the planks in the third thickness, where the holes were only half an inch larger, and in a few instances where they occurred near the edges of armour plates in the third thickness. All the edges of the bolt holes were rounded off, and the space around the bolt was filled with ash tubing.

Where the armour bolts passed between the coupled uprights, clip washer plates, $1\frac{1}{2}$ in. thick, were fitted to the backs of the uprights; these had flanges to hold the edges of the uprights together, and they were bolted through the timber to a small plate on the front side of the uprights, to hold them in their places without the assistance of the armour bolts.

Each armour bolt was secured in the following manner on the inner side of the wall.

Next to the armour there was a circular washer of well seasoned elm, and on this a wrought-iron washer $1\frac{1}{2}$ in. deep, having a slight dish on the side next the elm, and a spherical segment-shaped cup on the reverse. Into this cup fitted a screw-nut 2 in. deep, with one face shaped to a portion of a sphere, and next to this the main nut 3 in. deep. The ash tubing in the armour was continued through the elm and into the cup-washer.

By this arrangement of cup and ball, a certain amount of movement in the parts of the front could take place without of necessity subjecting the bolts to cross strains. The nuts and washers belonging to the $3\frac{1}{2}$-in. and $2\frac{1}{4}$-in. bolts were on precisely the same principle, but the dimensions were slightly altered.

The bolts connecting the coupled uprights were 3 in. in diameter screwed at both ends, and their shanks were reduced to the lesser diameter of the screwed part. The upper bolts passed through distance tubes 1 in. thick between the uprights, and both were provided with elm washers, a plain iron washer, and a 3-in. nut at each end.

Those of the armour bolts which passed through from the front to the $1\frac{1}{2}$-in. stringer plate, to be hereafter described, were also provided with distance tubes, wood washers, and dished washers and nuts as the other armour bolts.

All the armour plates and planks used in the front, as well as the bolt iron, were made by rolling. Samples of the armour plates and planks were proved at Shoeburyness, and found to be very good; and the armour bolts, tested by falling weights, also gave very good results.

The foundation on which the front was erected was composed of the lower course of the granite casemates of 1865, worked to correspond with the upper courses of the granite work of Plymouth Breakwater Fort.

Next with regard to *the structure carrying the roof.*

This consisted mainly of two piers, two box girders, four single web girders with arch plates between, and a continuous $1\frac{1}{2}$-in. stringer plate attached to the front ends of these girders and arch plates.

The piers, which in plan differed somewhat from those in the actual work in order to adapt them to the site, were made of $\frac{1}{2}$-in. boiler plate and angle iron, the joints being covered by strips on both sides. They were filled with Portland cement concrete, and in one place, where the stone foundation under them was faulty, short lengths of armour bars were inserted vertically to make up for the defect. A portion also of the filling in of the left pier consisted of stonework, to meet in some degree the tendency of newly made concrete to compress under a heavy load.

The two box girders were made of $\frac{3}{8}$-in. webs and $3\frac{1}{2}$ in. by $3\frac{1}{2}$ in. by $\frac{3}{8}$ in. angle irons, with $\frac{5}{8}$-in. plates in the top and bottom flanges. The front girder was 18 in. deep, 25 ft. 9 in. long, the interval between the bearings being 14 ft. The rear girder was 2 ft. deep, 28 ft. long, the interval between the bearings being 17 ft. The top tables of both were sloped transversely to suit the inclination of the girders resting on them, and the front girder was filled with Portland cement concrete.

The transverse single web girders rested upon the box girders and piers, and were riveted to them. They were 1 ft. 9 in. deep, 20 ft. 8 in. long, the interval between the bearings being 17 ft. 6 in. They were spaced at intervals corresponding, as nearly as possible, with the spaces in the actual work, but in one instance it was necessary to have a half space.

To the top tables of these girders, near their front ends, were riveted knees or brackets, through which the long bolts, holding back the upright supports of the front wall, were nutted.

The arch plates between the girders were made of $\frac{3}{4}$-inch plate for a distance of 5 ft. 10 in. from the front, and the remainder was of $\frac{1}{2}$-in. plate. They were riveted to the girders, and in the case of the plate next to the large box girder of the adjoining casemate it was bolted to its lower flange through a block of wood laid for the purpose of adjusting the different levels of the two girders.

On the under side of the transverse girders tie bars, 4 in. by $\frac{5}{8}$ in., were riveted, to meet in some degree the want of continuity in the thrust of the arches; and also against the outer girder forged knees were secured with the same object.

The $1\frac{1}{2}$-in. plate attached to the front ends of the girders was strongly riveted to them as well as to the angle irons on the ends of the arch plates lately described. This plate was 21 ft. 9 in. long and 2 ft. deep.

The $\frac{3}{4}$-in. plate, through which the upright coupled supports passed, as before described, was attached to an angle iron on the upper edge of this $1\frac{1}{2}$-in. plate.

Between the uprights and $1\frac{1}{2}$-in. plate an inch of oak was inserted; and also in the interval over the port, the space between the front wall and the $1\frac{1}{2}$-in plate was filled with oak.

Wood was used in those parts only where it could be examined and replaced in case of decay.

As regards the filling-in of the front part of the roof, this consisted mainly of a concrete composed of cast-iron turnings, asphalte, bitumen, and pitch, of which the weight, per cubic foot, was about 200 lbs., the iron weighing about three-quarters of the whole.

Between the upper part of the second thickness of the front wall and the upright supports, as well as in the intervals between the supports themselves, some railway rails were embedded in the iron concrete to compensate in some degree for the want of solidity in the concrete, due to the short time allowed to it for setting; some railway rails were also inserted in the iron concrete between the transverse roof girders, near their front ends, to hold down the washers through which the upper tier of armour bolts were nutted; at this part also, as well as at the rear ends of the girders, cross strutting of railway rails was introduced between the girders to compensate for the freshness of the concrete.

From a point about 2 ft. from the front ends of the transverse girders, to the masonry in rear of the casemate, 14-in. brick arches, in Portland cement, were turned in three rings over the arch plates before described. As the old brick arch forming the rear of the casemate did not correspond with or form a continuation to the new arches, a timber beam strengthened with an iron flitch plate was thrown across to close the interval. Over the whole of the arching of the new roof Portland cement concrete was filled in to a depth varying from 2 ft. 9 in. in front to 4 ft. 6 in. in rear to render it bomb proof.

Lastly, a rope mantlet, measuring 16 ft. long by 7 ft. 9 in. high, composed of 6-inch hempen rope worked round a 3-in. round iron bar at top and bottom, with a port of the proper dimensions left in it, was suspended from eye-bolts passing through the roof arch plates in such a position that the ends of the mantlet were between the front wall and the piers. The object of this was to answer the purpose of catching splinters or other fragments that might be thrown off from the back of the wall under a heavy battering. In an actual work it would be of essential use in deadening the sound of heavy blows, and preventing injury to any person from contact with the front wall when struck.

Account of the Experiments.

The trials took place on the 16th, 17th, and 18th June, and 7th and 8th July, 1868.

The guns employed in the attack were as follows:

Nature.	Weight. Tons.	Powder charge. lbs.	Mean weight of projectile. lbs.
12-in. rifled, muzzle-loading	25	76 pellet	600
10-in. rifled, muzzle-loading	18	60 R.L.G.	400
15-in. Rodman, smooth-bore	19	100 American = $83\frac{1}{4}$ English	450

The battery was placed at 200 yards from the work.

The committee in charge of the experiment consisted of the President and Members of the Ordnance Select Committee, with an additional officer of the Royal Navy, two additional officers of the Royal Engineers, and the Chemist to War Department, as associate members.

After weighing all the conditions under which an actual attack of the Plymouth Breakwater Fort could take place, it was determined that these trials should be made with charges to give effects equivalent to those due to full battering charges at 500 and 1,000 yards; and a programme, based on that arrangement, was prepared. But, at the last moment, this decision was reversed, and, without regard to the distance at which ships would be able to engage the fort, or the feasibility of defending the shoal water in its vicinity by a system of marine obstructions, or the effect of the fire of other batteries in its support, it was decided that full battering charges should be used, the attack thus partaking of the character of one made against an unarmed, and, in all but the strength of its own wall, an unresisting work.

Accordingly, the following rounds were fired:—

No.		
6	..	12-in. Palliser shot
4	..	12-in. „ shell
3	..	10-in. „ shell
1	..	9-in. „ shot
5	..	15-in. Rodman shot
1	..	15-in. „ „ at the granite base.

Making a total of 20 rounds, of which three were fired in salvo.

In addition to this, two 12-in. and six 10-in. Palliser shell were fired with charges to represent ranges of 1,000 yards, and sometime afterwards three more rounds were fired at the work from the 15-in. Rodman gun, making up 31 rounds in all.

The accompanying tables give the detail of the practice, as well as an abridgment of the principal effects produced.

It was also decided on the eve of the trial that the rope mantlet should be removed, so that on the first day it was not in use at all, and subsequently it was only allowed to be hung temporarily from the roof at some distance from the front wall, where, of course, it was quite out of place, and lost much of its effectiveness.

Of the 31 rounds fired altogether at the structure, there were—

2	12-inch shot	at the 20-inch portion.
2	„ shell	
4	Rodman shot............	
4	12-inch shot	at the 15-inch portion.
4	„ shell	
9	10-inch shell	
5	Rodman shot	
1	9-inch shot	

But one of the Rodman shot aimed at the 15-inch portion, missed the iron target, and struck the granite base, only glancing up against the iron front.

In the first three days firing, there were 21 rounds, exclusive of the Rodman which missed. Of these 21 rounds—

2	12-inch shot	were at the 20-inch portion.
2	„ shell	
*2	Rodman shot............	
3	12-inch shot	were at the 15-inch portion.
4	„ shell	
6	10-inch shell	
2	Rodman shot............	

* One of the 12-inch shells struck partly on the 15-inch portion

The following is taken from the report of the committee on the condition of the structure at the close of the third day's firing :—

As regards the exterior, the extra 5-in. plate was broken through by four large cracks connecting various shot holes, and a piece of 5 or 6 square feet at its lower left hand corner was broken off. The right hand top curved plate, on the 15-in. portion, was broken in two, and one half of it swung round on to the top of the roof, turning on one of the bolts as a pivot; an extent and form of damage that probably was occasioned by the want of lateral support, a deficiency which would not occur in the fort itself. The adjacent top plate had also considerable pieces broken off its lower corners.

As regards *the effects in rear*, the report of the committee says, that the inner plank above the port was cracked vertically and started; a piece of the inner plate, about 3 ft. by 1 ft. 6 in., under the port had been detached in two pieces by the effects of two separate blows, and a portion of it driven to the rear. A fragment, measuring 14 in. by 16 in., of one of the inner planks in the next bay to the proper left had been detached. A small portion of an inner plank in the bay to the right of the port was detached, and near the bottom there was a large starred fracture. In the next bay to the right, there were two complete perforations through the front wall, the projectiles or the fragments carried in by them having sufficient force to indent the ½-in. iron skin of the pier, and in one case to crack it.

Twelve bolts in all were broken, and a few rivet heads knocked off. The vertical uprights were more or less bulged, and in one instance an upright was cracked across its whole depth and one half its width.

The committee consider it extremely improbable that such a weight of fire would ever be delivered upon an area of this limited extent under the conditions of an actual naval attack, and at this point the casemate was *perfectly defensible.*

When the practice was resumed on the 7th of July, six rounds were fired as follows:—

3	10-in. shell..................		at the 15-inch portion.
1	12-in. shot	in salvo.	
1	15-in. shot		
1	9-in. shot		

Of these, the three 10-in. shell struck either close to, or fair on, old wounds, and increased the damage previously done. In one case, the shell striking fair on an old mark, passed through, exploding in its passage, and carrying numerous fragments into the casemate. It is probable, however, that had the mantlet been in its place, many of these would have been stopped by it. One of these shells struck close to the top right hand corner of the port, and broke away the whole of the three 5-in. layers forming the top of the port; but it must be observed that this portion of the work had been struck previously by four 10-in. shells, all five being within an area represented by a triangle, with sides of 2 ft. and a base of 2 feet 7 in., measuring from centre to centre of the holes. A great many fragments (one a very large one) were carried into the casemate by this round, some being thrown a considerable distance to the rear, either over the mantlet, or through the port-opening in it. This shell burst inside the casemate and filled it with smoke. The mantlet was slightly ignited and a good deal cut by the splinters.

After this the salvo was fired. It was intended that the shot from the 12-in., 10-in., 9-in., and 15-in. guns should strike the target simultaneously, on a limited area of the 15-in. portion, already a good deal damaged by previous rounds. The guns were fired by means of the ebonite frictional machine, but the tube failed to ignite the charge of the 10-in. gun, and, therefore, only three shot struck the target; but these were planted, within less than 2 ft. of one another, on a part previously shaken by one 12-in. shot, one 12-in. shell, one 10-in. shell, and one 15-in. shot. It is not surprising that a large opening was formed in the wall. The casing of the pier which stood immediately in rear of this injury was indented to a depth of 9 in., the concrete filling being exposed over an area of about 2 ft. 6 in. by 2 ft. 4 in., and it was thought the pier had been slightly driven back at the top. A large number of fragments of shot and small pieces of plate were found inside the casemate, but nothing passed through the mantlet.

In addition to this direct fire at the front, the roof structure was tested by vertical fire from 13-in. land service mortars at 900 yards range. The charges varied from 3 lbs. 1 oz. to 3 lbs. 5 oz., and the elevations from 58° 45′ to 60° 45′, except in a few rounds which were fired at 70° with 5 lbs. 6 oz. of powder. Before commencing this practice the concrete roof was covered with earth and sand bags to a depth of 5 ft. The shells that were fired were filled with sand, but in two instances of these shells falling on the roof, they were dug out, and live shells, with bursting charges of $10\frac{1}{2}$ lbs., were inserted in their place, and fired by magnetic tubes.

The first of these (5th round), struck on the roof and penetrated 3 ft. 3 in. into the earth, or 4 ft. 4 in. measuring to the bottom of the shell. The crater formed was 4 ft. by 4 ft. The live shell formed a crater 13 ft. 6 in. by 14 ft. 6 in., and 3 feet deep. The earth thrown up fell back again chiefly into the crater. The explosion had no effect whatever on the roof structure, and scarcely bruised the concrete.

The other shell (16th round) fell on the roof, after one half the earth-covering had been removed, leaving it 2 ft. 6 in. deep. It penetrated 1 ft. 1 in., or 2 ft. 2 in. measuring to the bottom of the shell. The live shell inserted in its place formed a crater, 9 ft. by 10 ft. 6 in., down to the concrete; but there was no effect whatever observable on the structural parts of the roof, either from the falling shell, or the explosion of the live shell.

After this the whole of the earth covering and sand bags were removed from the roof, but it was not until the 276th round that another hit was obtained; the penetration then was only 8 inches. A live shell was fired, but it produced so little effect that the firing was discontinued at the 298th round.

As regards the *general effects* of the attack, the following is an outline of the conclusions drawn by the committee :—

1st.—That the 15-in. structure was penetrated when hit direct between the vertical struts by a 12-in. and a 10-in. shell (rounds 1513—14) fired with battering charges at 200 yards, and nearly penetrated between the struts by a 12-in. shell (round 1523) at 1,000 yards. They considered, therefore, that the structure was deficient in strength in those spaces.

2nd.—That the employment of planks necessitates numerous joints and should be avoided, and that the substitution of wide plates for the planks would have greatly added to the resistance of the structure.

3rd.—That greater equality of strength in the different parts of the structure would have been obtained by the introduction of more uprights in rear of the wall, and that more strength was required immediately round the port.

4th.—That the employment of the iron in three thicknesses compared very favourably, in point of resistance, with that of the single solid plates of equal thickness; and if the cost of the two systems were the same, the effect of repeated blows on the solid structure was so much more destructive than on the compound, that the solid could not be recommended.

5th.—That the Palliser through-bolts and the special washers answered admirably.

6th.—That the wood casing round the bolts and in other parts, proved advantageous, and probably contributed, in an important degree, to the success of the fastenings.

7th.—That the operation of curving the upper plates injured them, and should not be practised.

8th.—That the framework of the structure gave a very satisfactory degree of resistance, and that the roof was proof against the fire of the mortar shells used.

9th.—That a mantlet is a necessary accessory to works of this nature, and that had the one constructed for this experiment been fixed in its proper place during the attack, few, if any, of the fragments which were thrown into the casemate, except those passing through the port left in the mantlet, would have injured the garrison.

As regards these general conclusions of the committee, it must be observed that the main point kept in view in designing the iron work of Plymouth Breakwater Fort was that of giving facility for future additions of strength in the front wall.

For this purpose, the increase of the number of rear uprights was the first measure contemplated, as it was seen that not only could the general front thus be uniformly strengthened to a very great extent, but also considerable additional support could be given to the sides of the ports.

The facility with which this method of strengthening has been carried out in the actual fort, proves these views to have been correct.

With regard to the next most obvious way of increasing the strength of such a wall, that is, by putting additional armour on its face (which plan was tried on part of the experimental front), it is clear that by this means almost any conceivable amount of strength can be given; and it should be remembered that the extra plate thus put on for this trial did not fairly represent the case of this method being adopted in an actual work, because the individual plate used on this occasion was left without the support that the edges of a plate in a continuous layer would receive, which circumstance, no doubt, partly accounts for its tendency to crack under the blows of the heavy shot which struck it.

The trials of this front suggested to those engaged in its construction another very important way of improving its resistance, which must be next noticed.

It will have been observed in the description of the structure given above, that a layer of hides was inserted between the second and third thicknesses of the front wall, and also some of the same material was used in front of the rear uprights. Also, wherever it was possible to introduce small quantities of wood, to act as a cushion, it was employed.

Circumstances prevented the use of more of this sort of material on this occasion, but it was clear that what little was done was in the right direction. Accordingly, experiments were set on foot to ascertain the effect of separating the armour, in a "plate upon plate" structure, by layers of other material in somewhat thicker masses. The experiments will be found further on. The general result, as bearing upon the Plymouth Breakwater construction, will only be noticed now. This may be stated in a few words, as having proved that the insertion of a heavy concrete, composed of iron borings and bitumen, between armour plates, leads to highly favourable results, as regards both the local effects of penetration by projectiles, and the general injury done to the structure. So decided an improvement, in fact, was produced by it, that it could not long remain a question whether it should be applied to the Plymouth Fort; and one great advantage resulting from these trials has been that of introducing a 6-in. layer of iron-concrete between the front armour and middle thickness of the wall of this fort, as well as a thin layer of the same material between the middle and third thicknesses.

The next point to notice is that of the employment of planks of iron in the front wall itself.

No doubt, a wall composed entirely of broad plates will be superior to one composed of an *equal quantity* of narrow plates or planks, but this is not the question at issue. For a given sum of money a much greater quantity of iron can be used in the shape of planks than as broad plates. The proportion, in the case of moderately broad 5-in. plates and planks, is nearly as 5 : 3. Hence, for the money that will build a 15-in. wall of 5-in. plates, one 25 in. thick could be made of planks. But this does not exactly state the case, because it is not suggested that a wall intended to resist heavy shot shall be *faced* with planks. The real question is whether a wall of three thicknesses of 5-in. armour plates, supported in rear by uprights at close intervals, will be superior to one made up of 5-in. front armour plates and three layers of $5\frac{1}{2}$-in. planks as backing, with an equal number of uprights in rear; or, putting it another way, which would make the best protection, a wall composed of 11 inches of plates in two thicknesses, or one made up of 5-in. front plates, backed by two layers of 5-in. planks, that is, 15 inches in all, for they would both cost about the same money? Moreover, the question is not thoroughly stated until it has been explained that, from the mode of manufacture and the dimensions of these planks, there is more opportunity of bringing the iron in them to the best condition for resisting shot than in ordinary armour plates.

With regard to the advantages of the plate-upon-plate as compared with the solid plate system, it is only necessary here to draw attention to rounds 1,512 and 1,515, from the 12-in. and 10-in. guns, at the part below the port of this experimental work. These two rounds have been already noticed in Paper XV of last year's volume, pages 203 and 204, and their effects were then compared with the practice, from the same guns, at two solid 15-in. plates. The committee do not over-state the case in saying that the iron in three thicknesses has compared "very favourably" in point of resistance with the single solid plates.

As regards the fastenings, some valuable instruction came of this experiment. In the first place, the bolts reduced in the shank to the lesser diameter of the thread, on Major Palliser's principle, answered very well indeed; but it must be mentioned that the results of this trial did not bear out the idea that a conical-headed armour bolt should be made by drawing down the whole bolt (except the head) from a bar of the largest diameter of the cone, instead of using a bar of the proper diameter of the bolt, and "upsetting" the iron to form the head; for the whole of the conical heads of the armour bolts in the front were formed by "upsetting," and no disadvantage was observable in the results. It may be stated that the decision to upset the heads of the bolts for this trial was arrived at, after a careful consideration of the results obtained in some trials (with falling weights) of bolts formed both ways. The most noticeable point, however, about the fastenings was the introduction of the "cup-and-ball" system, proposed by Lieut. English, R.E., for the nuts and washers.

The great difficulty that the fastenings have to contend with, in compound structures, is that of their being subjected to cross or oblique strains, at the instant of their being placed under great tension in the direction of their length. A bolt that will draw out more than 50 per cent. of its length, and ultimately break fibrous under the fair blows of a falling weight, will, if subjected at the same time to cross pressure, or an oblique strain, break off short, and show a more or less crystalline fracture. The power of self-adjustment which the "cup-and-ball" principle allows, if it does not altogether free the bolt from the injurious effects of cross strains, must at any rate place it in a very much more favourable condition than it can be in, if fixed at both ends. In this experimental work, the nut ends only were made capable of self-adjustment, but in subsequent trials, the heads as well have been constructed on this principle, and the best results have been obtained thereby.

The Tables show the effects on the bolts in detail. Perhaps the most noticeable result was that where the 12-in. shot and 10-in. shell (rounds 1,512 and 1,515) struck within 2 feet of each other on the least supported portion of the target, containing together an energy of upwards of 10,000 foot-tons, and not one of the six bolts holding the armour together at this part was broken, although three or four of them were a good deal bent.

Out of the total number of 76 armour bolts in the target, 21 were broken in the course of the experiments.

Returning to the other general conclusions to be drawn from these experiments, there is the case of the somewhat unsatisfactory performance of the upper curved plates. Whether the tendency in them to crack arose from injuries received in the process of bending, or whether it was the natural result of their peculiar form and position in the work, it is hard to say. At all events they did not fully answer the purpose for which they were intended, and a simple way of dispensing with them and substituting another arrangement in their place has been arrived at.

Nothing could have been more satisfactory than the way in which the framework of the casemate, consisting of piers, roof girders, arch plates, &c., did their work in supporting the front wall, and in resisting the vertical fire.

As regards the mantlet, it is certainly unfortunate that it could not be allowed to occupy its proper position during the trials, for, however desirable it might have been that the effects of each round on the inner face of the iron work should be noticed in detail, the mantlet belonged so essentially to the defensive structure, that its absence altered to a great extent the character of the defence. To show how important a part such a mantlet would play, if fairly placed, it is only necessary to look at the report of round 1,515, where a great piece of armour was hurled against the rope-work, and, only cutting the rope slightly and bending the iron tube on which the bottom edge of the port opening had been worked, it rebounded upwards of 5 ft. from the mantlet. In fact, throughout the trials, it showed itself to be admirably suited for stopping splinters.

With regard to the three additional rounds fired some time afterwards at this target from the 15-in. Rodman gun, the practice took place on the 31st March, 1869.

The gun was at 200 yards.

The shot weighed from 451 lbs. to 457 lbs., and being fired with $83\frac{1}{4}$ lbs. charges, struck with a velocity varying from 1,360 to 1,384 ft. per second.

It was difficult to distinguish the effects of these rounds from those due to the earlier battering, and as they were fired more for the sake of testing the metal in the shot than to try the target, the results have not been tabulated here.

The indent of one of the shot was 4·6 inches; parts of the other two remained fixed in the plates, so that the indents could not be taken.

One of them (No. 1,646), striking on the 15-in. portion, did, besides other injuries, considerable damage in rear by breaking two of the uprights; the others, striking on the 20-in. portion, did more injury in front—cracking and knocking off portions of the extra face-plate, and otherwise extending the effects of previous rounds.

Although the strict object of this Paper would be fulfilled if the present notice were confined to a record of the trials at Shoeburyness, yet, as this experimental structure was the representative of an actual work in progress, the subject would seem to be left in an incomplete state without some account of the extent to which these trials have affected the work upon the fort itself.

The following observations give the main points of improvement adopted since the experiments, and Plate V shows how the Plymouth fort is being actually carried out:—

1st. The two lower tiers of front armour plates have been set out 6 in., in order that the interval may be filled with concrete, composed of cast-iron turnings and tar.

2nd. The upper bent front plates have been replaced by plain armour plates, a layer of 1 in. of concrete being inserted between them and the next thickness; an additional tier of planks has also been provided over the port in the third thickness.

3rd. The number of upright bars in rear of the front wall has been increased from 12 to 18 per gun, those next to the embrasure being of a larger section. The clip washer plates, fitted to the backs of the uprights, have been generally replaced by plain plate washers, bolted to timber which has been inserted between the uprights.

4th. An additional thickness of armour plate has been provided at the port, the extra plates used for this purpose being supported on their edges by the uprights of large section just mentioned.

5th.—An alteration has been made in the armour bolts, by which the principle of the "cup-and-ball" has been more fully developed. Each armour bolt is now a plain bolt with a thread at each end and a reduced shank, and is fitted with a spherical nut at each end. The front nut sets into a cup shaped hole in the armour plate, that in rear into a cup washer, as shewn in the drawing. The holes in the several thicknesses of the armour are made to admit of considerable movement of the parts without bending the bolt.

TABLE III.

STRUCTURE REPRESENTING PLYMOUTH BREAKWATER FORT.

Report of Practice on 16th, 17th, and 18th June, 1868.

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, Total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			20-INCH PORTION.
1501	12-in. rifled M. L. gun of 23 tons.	76 pellet.	Palliser shot, head 1·25 25·2 ins. 602 lbs. 11·92 ins.	1170	5714	152·6	Struck on the proper left of the extra 5-in. plate, centre of indent 3 ft. from bottom, 5 ft. from right edge. Indent 13·5 in. deep, diameter 17 in. by 13 in. The plate buckled forward about 6-in. beyond the bolt, and driven in 0·5 in. at the bottom; the plate was cracked vertically through indent, extending about 2 ft. 6 in. above it and downwards to bottom of plate (maximum opening of crack 3·5 in. at indent) cracked also horizontally to left edge; opening of crack at edge of plate 7 in. Some of the lead packing between the plates squeezed out. *In rear.*—Plate bulged and indented near upright, several fine cracks shewing. Upright bulged about 1 in.; small bolt under No. 1501 bent.
1502	„	„	Palliser shell, head 1·5 28·7 ins. 602 lbs. 11·92 ins. Burster 14·06 lbs.	1168	5695	152·1	Struck right edge of extra 5-in. plate above left top corner of port, 7 ft. 6 in. from bottom; made a scoop in the plate, and head of shell buried itself in the original face of the target; the head was knocked out by No. 1504, when the shell having passed through the extra plate, the depth of penetration was found to be 6·25 in. in proper front of target, point just indented centre layer. Shell burst on striking, numerous fragments entering the casemate through the port; a good deal of the lead packing between the plates squeezed out. The concussion broke off the left bottom corner of extra plate that had been cracked by the previous round. Scoop out of extra 5-in. plate 12 inches long, 5·5 inches wide. Diameter of indent in proper front 11 in. by 9 in., point of shot just indented centre port plate; the proper front plate broken through from top to left upper angle of port through indent; a bolt on left bottom of indent has had a slice cut off it 6 in. long, but otherwise uninjured. *In rear.* — Plank above port broken through vertically at left edge of port and driven back 2·75 in. Gape of crack 2·5 in. at top, 1·2 in. at bottom. Wood washers

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, Total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1502 contd.							of 28 and 33 bolts crushed, and 28 bolt apparently bent. Right plank of No. 4 upright bulged about 0·25 in., and clip washer bent back 0·75 in. from it; bottom clip also bent back 0·75 in. on right.
1505	12-in. rifled M. L. gun of 23 tons.	76 pellet.	Palliser shot, head 1·25 25·2 ins. 597·5 lbs. 11·92 ins.	1167	5642	150·7	Struck extra 5-in. plate, 6 ft. 1½ in. from bottom, 2 ft. 6 in. from left edge. Indent 13·4 in. The crack of last round extended up to the shot hole, the plate also cracked horizontally on left, from indent to edge; head of bolt below No. 1504 broken off 4·4 in. in. Total depth of indent 13·4 in. *In rear.* — A piece of No. 2 plank, 14 in. long, broken away and carried 30 yds. to the rear after passing through 2-in. wood target. A piece of the 2nd layer of planks (6 in. by 7 in. by 2·5 in. thick) broken away and plank starred. No. 3 plank bulged 3·5 in. No. 48 bolt (out of upright) broken 3 ft. 3 in. from rear, and carried 9 ft. 6 in. to rear, knocking down wooden targets. Small bolt on left of shot bent.
							15-INCH PORTION.
1506	,,	,,	,, 600 lbs.	1166	5656	151.0	Struck partly on the line of strut, 6 ft. 5½ in. from bottom of target to centre of shot, 5 ft. 8 in. from proper right of target, 6 in. of circumference of shot hole on upright strut; a bolt on right of port came out 7·5 inches, this was a stud bolt, and was only screwed into the 2nd plate 1·5 in. Front of shot penetrated up to the rear of the front stud equal 12·6 in. Buckle of plate 2·4 in. over all; exactly under shot hole, plate was driven back 0·9 in. Plate sprung forward next port hole, 0·5 in. and 0·3 in. on the opposite side. The adjacent bolts drawn in 0·4 in., 0·2 in., and 0·3 in. respectively. *In rear.*—Left plank of No. 2 upright bulged 2·75 in., wood backing smashed, and top and middle clip washers bent back on left. Shot struck on joint of Nos. 3 and 4 horizontal planks, both of which were bulged and No. 3 broken vertically through in line with No. 2 upright; No. 46 bolt broken and loose in socket, No. 39 bent, small bolt above No. 36 broken and 12 in. of it sent 6 ft. to the rear. The horizontal stringer plate was bulged about 1 in. Top clip washer bent back on left. When the head of the shot was removed, the vertical planks were found to be much bulged, and daylight was visible through the opening.

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, length, total weight, and diameter.	Striking Velocity.	Total energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1507	12-inch rifled M.L. gun of 23 tons.	76 Pellet.	Palliser shell head 1·5 28·7 in. 601 lbs. 11·92 ins. Burster 14·06 lbs.	1159	5598	149·5	Struck, partly on strut, exactly beneath No. 1506, 18 in. from bottom and 5 ft. 9 in. from right; penetration not quite up to stud. Buckle under shot mark 2. 2 in. head of bolt No. 46 came out to the front. Diameter of hole 12 in. Head of shell up to stud remained in, but was shaken out by No. 1508. Indent as measured after head was out, 14 in. *In rear.* — Bottom of plate bulged; No. 2 upright bulged about 3·5 in. and wood packing splintered. Small bolt on upright of No. 55 broken and driven 30 yds. to the rear; bolt No. 63 driven back about 2 in.; bottom clip washer much bent.
1508	,,	,,	Palliser shot, head 1·25 25·2 ins. 603 lbs. 11·92 ins.	1165	5675	151·5	Struck 2 ft. 11 in. from bottom, 6 ft. 1 in. from proper right (6·5 in. of body of shot remained out); the penetration was 19 in. There was 4·5 in. between this shot and No. 1507. Buckle to line of port-hole 3 in. A crack 6 ft. 3·5 in. from proper right ran down the plate 1·5 in. from the top. Whole plate driven back 1 in. clear of lead. *In rear.* — Plate very much bulged and point of shot showing in centre of star crack. Gape of crack 3 in. in widest part. No. 2 upright very much bulged, and left plank of it cracked horizontally across at 2 ft. 1 in. from the ground, the crack extending half through plank in rear. Bolt No. 55 and small bolt above, much distorted.
1512	,,	,,	,, 605 lbs.	1177	5812	155·2	Struck below proper right corner of port, 2 ft. 3 in from bottom of target and 11 ft. from right; the head of the shot up to front stud remained buried in plate. The horizontal buckle below shot 1·5 in. over 40 in., and the vertical buckle 2 in. in 4 ft. A bolt in left drawn through 0·6 in. and one above on the right 0·3 in. The whole plate appeared driven in, and cracked for a depth of 7 in. down from the right bottom corner of the port. *In rear.*—Long crack 2·75 in. wide and 10 in. deep. Bulge in centre of crack 7·5. Bolts Nos. 51 and 54, slightly bent, and No. 59 much bent, wood washers of all these bolts crushed, and the iron washers of No. 59 distorted, but the bolts were still holding well. Left plank of No. 3 upright bulged 0·75 in. and clip washer bent back about the same.

Photographic No. of Round.	Gun.	Charge and Powder.	Projectile. — Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1513	12-inch rifled M. L. gun of 23 tons.	76 Pellet.	Palliser shell head 1·5 28·7 ins. 602·4 lbs. 11·92 ins. Burster 14·44 lbs.	1158	5601	149·6	Struck the centre plate between struts 6 ft. 8 in. from botton and 3 ft. 3 in. from proper right. Shell passed THROUGH the target and burst in doing so; a quantity of fragments of the shell were found in the hole; the shell appeared to have struck just on the intersection of the junction of two horizontal with two vertical planks and fair between the first and second pair of struts, the target was 15 in. thick at the place of perforation. The explosion and shock knocked out the head of No. 1506, and produced radial cracks from its indent, 10 in., 11·5 in., and 8 in. long, daylight being visible through the target at the bottom of the indent. In the indent of No. 1511, it separated, by a wide crack, the disc of metal driven in by that shot, and cracked the plate radially; a crack was also found joining Nos. 1508 and 1507. *In rear.*—The point of the shell struck on the junction of Nos. 2 and 3 horizontal planks, passed through and burst; the head and a great part of the shell were picked up inside having been stopped by the pier. Nos. 2 and 3 planks broken through at the point of impact (which was between Nos. 1 and 2 struts); the broken end of No. 2 plank driven against the pier, which it indented considerably; No. 2 plank opened out 11 in. at crack made by No. 1506, through the indent of which daylight is visible. No splinters in working part of casemate in consequence of everything having been stopped by pier.
1520	,,	57·5 ,, Rifle L. G.	,, 600 lbs. Burster 14·0 lbs.	1084	4921	131·4	Struck high 1 ft. 6 in. from right edge of target and 3 ft. 7 in. from bottom of upper (curved) plate, and carried away a piece of plate (4 ft. 3 in. by 3 ft. 8 in. by 5 in. weighing about 30 cwt) 147 feet to the rear; a 2¼-in. armour plate bolt was still attached to plate when found; a large part of the shell was found in the hole. The plate struck driven back on right 1·3 in. and projects on left 1 in. from centre plate. The nut was broken off No. 1 tie bolt, and bolt itself bent and driven back about 6 inches; cross bolt of girder sheared, and left of strut deflected to right and a scoop taken out of left of it by the shell. The iron concrete seemed to stand very well. *In rear.*—No effect.

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet			20-INCH PORTION.
1521	12-inch rifled M. L. gun of 23 tons.	76 Pellet.	Palliser shell head 1·5 28·7 ins. 602·4 lbs. 11·92 ins. Burster 13·937 lbs.	1169	5685	151·8	Struck 1 ft. 9 in. from left of extra 5-in. plate, 9 ft. from the bottom. The shell penetrated the extra plate, and also the front layer of original structure at the junction of the upper and middle plates, the point of the shell just indenting the vertical layer of planks. The extra 5-in. plate was much broken ; a long vertical crack extending from 2 feet above indent runs down into No. 1505 and from No. 1505 to 1501 ; plate is also cracked from No. 1505 to 1504, where it joins an old crack ; the plate is also cracked from indent to left side, through bolt hole, and from left side for a length of 13 inches, 18 inches below last crack, the screw bolt close to indent was cracked at the end of the screw thread and twisted to the left. The shell burst on striking, all the fragments falling to the front of the target. *In rear.*—No. 4 plank (from bottom) broken vertically through bolt hole, 7½ inches from left strut. No. 23 bolt driven in on to horizontal stringer plate, which it has bulged 1·6 in. ; the "distance" tube over bolt split longitudinally nearly its whole length and its head set up and the collar broken. Wooden wedge piece behind top of left strut splintered, and the top clip washer on same strut bent back on the left. The wood-work of the strut is splintered ; 5 rivets broken off arch angle piece, which is cracked at top.
							15-INCH PORTION.
1523	,,	57·5 Rifle L. G.	,, Burster 14·0 lbs.	1081	4862	129·8	Struck on the lower right corner of 2nd curved plate, and broke away a large triangular piece of it, measuring roughly 4 ft. 9 in. by 2 ft., the line of fracture running through No. 1519. On removing the head after the experiment, an opening measuring roughly 8 in. by 4 in. was visible right through into casemate ; the two vertical beams in line with the shell hole were bent back 4 in. from front plate ; the head of the bolt on right of hole was sheared off by the explosion ; the rails that fill in behind the vertical planks much twisted and distorted. The 2nd bolt from right along top of middle plate broken off 8·5 in. in The shell penetrated the vertical beams, breaking up one of them

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
1523 contd.		lbs.		feet			(or centre layer), and also broke two in the horizontal planks, or inner layer. The head and part of the body of the shell remained in hole. The explosion of the shell blew the upper portion of the right hand curved plate completely round on to the top of the casemate, the $2\frac{1}{4}$ in. bolt at the left corner of it acting as a pivot, leaving vertical or 2nd layer exposed over an area of about 5 ft. by 2 ft. by 3 ft. deep. *In rear.*—Nos. 4 and 5 planks (from bottom) broken vertically across, 11 inches from No. 3 strut. Point of shell showing in hole. Triangular piece of No. 4 plank (15 in. by 10 in. by 18 in) dropped inside the work. No. 20 bolt much distorted and its iron washer broken. The stringer plate bulged and broken from the bolt hole to bottom, 3 rivets in bottom flange of No. 2 girder, 2 in arch angle plate, and 1 in piece broken off. At the conclusion of this day's practice, daylight was visible through an extensive gap in this hole.
1514	10-inch rifled M. L. of 18 tons.	60 R. L. G.	Palliser shell. Head 1·5 27·3 ins. 397·7 lbs. 9·92 ins. Burster 9·687 lbs.	1260	4378	140·5	Struck on upper part of lower plate, 3 ft. from proper right, and 4 ft. 3 in. from bottom. The shell passed through target and burst in doing so; the place struck had been weakened by No. 1511, and the damage done by this round joins also that done by No. 1511. (This round was purposely aimed at a damaged portion of the target in order to obtain the necessary data for the correct elevation, no previous practice having taken place with the gun at 200 yards.) *In rear.*—Shell passed through and burst, point of it indenting the pier 3 inches, breaking away the iron skin and exposing the concrete; there was another crack in the skin of pier 8 inches long, also exposing concrete. The greater part of the shell and large pieces of the target (including a piece of No. 3 plank 32 in. long) fell between target and pier. The pier was thrust back about 0·25 inch.
1515	"	"	" 399·7 lbs. Burster 9·625 lbs.	1261	4407	141·4	Struck below port in lower plate 3 ft. 4 in. from bottom of target and 11 in. from the side of the 20-inch thickness. The shell burst just after striking; the whole effect of the burst being outside, head of shell remained in hole. Depth of indent 16·5 inches; the crack in the corner of the port produced by round No. 1512 now joins its indent, and a fresh crack from the indent extends horizontally 7 in. long

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1515 contd.							towards the present round. The vertical buckle of the plate is 2·5 inches under the port. The bolt below the port, previously drawn in 0·6 inch, is drawn 0·3 inch further. *In rear.*—Piece of the rear plate 39 in. by 16 in. broken away, a portion of it 30 in. by 16 in. was thrown against the mantlet (cutting the rope slightly and bending the iron bar at bottom of port opening 6 inches out of straight) and rebounded 5 ft. The point of the shell shows through the second plate. No. 54 bolt very much bent and elongated; no bolts gone, nothing through mantlet; No. 1 plank slightly bulged between struts. On examining the shield at the termination of the 3rd day's practice, daylight was visible through No. 1512 shot hole.
1519	10-inch rifled M. L. of 18 tons.	48 R. L. G.	Palliser shell. Head 1·5. 27·3 ins. 398·9 lbs. Burster 9·875 lbs.	1162	3735	119·8	Struck 2nd curved plate, 2 ft. 5 in. from bottom, 13·5 in. from its right; diameter of the hole 11 in. by 10·5 in. The plate is broken through to its edge on the right of the hole and driven upwards 1·2 inch, and outwards 1 inch at the bottom. The shell penetrated into the iron concrete, taking an upward direction from meeting the railway bars which it forced aside and burst in entering, the distance it penetrated being 2 ft. 4 in. from top of hole and 2 ft. 10 in. from the bottom. The head of the shell remained buried in the concrete; the iron concrete in rear appears somewhat shaken. *In rear.*—No effect.
1524	"	"	" 398·7 lbs. Burster 9·687 lbs.	1176	3823	122·7	Struck just above the port, on the left bottom corner of 2nd curved plate which it broke off; the piece measured 1 ft. 3 in. vertically by 11 in. horizontally. The shell made a clean indent of 8 inches in diameter in the centre port plate; the total indent being 16 inches, and diameter in front plate 11 inches. The greater part of the fragments of the body of the shell fell in front of the target, the head and portion of body being found lying in the indent. This round developed star like cracks close to edge and above a bolt in 3rd curved plate. *In rear.*—The stringer plate bulged about 2 inches, and the wooden beam between it and shield crushed and splintered. No. 28 bolt bent and apparently elongated, the iron washer plate on it being quite loose. Wooden washers of all the bolts near point of impact of shell crushed.

Photographic No. of Round.	Gun	Charge and Powder.	PROJECTILE. — Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet			
1525	10-inch rifled M. L. gun of 18 tons.	60 R. L. G.	Palliser shell, head 1·5 27·3 inches 397·2 lbs. Burster 9·75 lbs.	1261	4380	140·5	Shell apparently grazed the granite base of the target, and struck the bottom plate in a "splash," 2 ft. 9 in. from right, and 10 in. from bottom. The granite block flaked and broken 9 in. deep. *In rear.*—No effect.
							15-INCH PORTION.
1526	,,	48 R. L. G.	,, 398·8 lbs. 9·92 inches Burster 9·75 lbs.	1169	3779	121·3	Struck 2nd curved plate 12 inches from No. 1524, and 6 inches from bottom of plate; the edge of the shell hit a bolt, which it drove in 15 inches; the effect was apparently about the same as No. 1524. The head of the shell (a good deal broken) remained buried in the target, so that the depth of the penetration could not be ascertained. *In rear.*—No. 4 plank broken vertically across, 3 inches from No. 3 strut, on right of port. No. 21 bolt driven against cross girder. 6 rivets broken in arch angle piece, the wood work crushed and splintered.
							20-INCH PORTION.
1503	15-inch smooth-bored Rodman gun of 19¾ tons.	83·25 R. L. G.	Spherical cast iron shot (American), 452·5 lbs. 14·89 inches.	Not obsvd.	—	—	Grazed 106 yard short of target. Struck target en ricochet on extra 5-in. plate, 1 ft. 3 in. from bottom, 4 ft. 1 in. from right edge. Indent 4·5 inches; diameter 13 inches. The bottom of the plate was driven in, slightly loosening the lead filling in. *In rear.*—The bottom plank is bulged about 2 inches between struts and bottom of plate above, about 1 inch. No. 67 bolt driven back 4 inches; granite at base of structure slightly fractured.
1504	,,	,,	,, 451 lbs.	1385	5999	128·2	Struck extra 5-inch plate 5 ft. from bottom, 1 ft. 7 in. from right edge. Indent 4·5 inches. Plate cracked through from right edge of indent to right edge of plate. Knocked out head of shot No. 1502. *In rear.*—Centre clip washer of No. 4 strut bent back slightly on both sides; the two planks on right of same strut bulged 1·25 inch in centre. The centre of strut is now 1 inch from plate in front of it. The left port plank is 1·5 inch from the plate in front of it (in port).
							15-INCH PORTION.
1511	,,	,,	,, 452·5 lbs.	1386	6027	128·8	Struck lower plate 4 feet from bottom, 4 ft. 5 in. from right, and partly on junction between the lower and middle plates; the

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1511 contd.							centre of indent is fair on one of the struts ; the indent on lower plate 16·5 in. by 16·25 in. wide, and on middle plate 11 in. long by 1·5 in. ; depth of indent 7 in. Indent and buckle 8·2 in. over 40 in. A crack was formed in face of plate running round the bottom of the indent, at a distance of 3 inches from it, for a length of 3 inches. The shot rebounded 13 feet. *In rear.*—No. 2 strut is now bulged 7·5 inches at 6 feet from bottom. The plate is 2 inches from strut at top, and projects 2·2 inches beyond No. 2 plank, which is 4·5 inches at bottom and 3·2 inches at top from strut. No. 3 plank is 3 inches from strut. Bolt No. 45 is pushed back about 1 inch, and the clip washer more bent. There has been no apparent motion of bolt No. 58, nor of the small bolts above and below it.
1522	15-inch smooth-bored Rodman gun of 19¼ tons.	83·25 R. L. G.	Spherical cast-iron shot, (American) 453 lbs. 14·89 ins.	1373	5921	126·6	Struck the right curved plate 3 ft. 11 in. from right, 19 inches from bottom. Centre of indent fair on a bolt hole, depth of indent 7 inches; broke the plate diagonally across, and vertically through a bolt hole. The upper portion of the plate is started forward about 7 inches at No. 1522, and 4·5 inches at left bottom. The second through 2¼-in. bolt broken at head, leaving the upper portion of the plate, measuring about 6 ft. by 3 ft. 2 in. hanging by the one 2¼-inch bolt. *In rear.*—No effect inside casemate. (The explosion of No. 1523 that blew away the piece of curved plate disclosed the fact that the 3rd vertical plank had been broken in two through the bolt hole, and driven in about 5 inches by this round.)
1527	"	"	" 453 lbs. "	1373	5921	126·6	Missed iron fort and struck the 5th block from right of granite foundation; the block was completely broken up to the face of the target. The dimensions of the block being 5 feet wide by 4 feet. The 4th block is also fissured horizontally. The shot, after striking the granite, glanced up against target and broke, the fragments falling some distance around. *In rear.*—No effect.

State of the front of the structure representing the Plymouth Breakwater Fort, at the conclusion of the first three days' practice.

Beginning from the left.—The bottom front plate of the original structure is buckled forward 1 in. at top and 0·5 in. at the bottom, the centre plate 0·5 in. at bottom, and 1·25 in. at the top. The left curved plate is cracked, apparently through, horizontally along a line 3 ft. from bottom, the crack running under the extra plate (not observed during the experiment.) The extra 5-in. plate is touching on its left edge at the bottom and up to No. 1501, above that it is away from the front about 2·5 in. to 3 in. up to the curve, from this to its top the space between averages 1·5 in., the lead being about 0·7 in. thick. At 21 in. from the top this plate is cracked through, horizontally, for a length of about 2 feet; the crack is about 2 in. from a bolt, and to which a short crack runs from the longer one. (Not observed during the experiment.) This plate is also broken up by fissures into a number of detached pieces, principally by No. 1521, though the fissures themselves radiate chiefly from No. 1505. Beginning on left, the principal one starts from the right of No. 1501, passes through No. 1505 (with a maximum opening of 1 in.) joins this last with No. 1521 (maximum opening of 2 in.); from No. 1521 it runs up 2 ft. 6 in., and to within 9 in. from left side of plate; from No. 1505 radiate four others, one on the left to edge, one on right to edge through top of No. 1504, one about 20 in. long towards right top, and one on left side from angle towards No. 1505, 9 in. long. The portion of plate actually broken away on left bottom measures 5 ft. 6 in. up by 2 ft. at No. 1501, 1 ft. 8 in. at No. 1503, and 10 in. at bottom—on its right edge the plate is away from face of target 1 in. at bottom, 2·5 in. at 2 ft. up, 2 ft. at 4 ft. up; from this point to 8 ft. 6 in. up, the plate is much broken and touches in places. Taking the lower plate between the extra 5 in. plate and end of target, under the port, it is buckled vertically 2·6 in. in centre. The bolt beneath the port is driven in about 0·8 in., and ovalled by No. 1515, the head of which remains in. On right lower corner of port, a crack runs down through the plate to No. 1512, the edge of which is 7 in. from a strut; at the bottom of the port the front plate is separated from centre plate 1·5 in.; below No. 1515 the bolt stands out from the plate about 0·5 in., from the latter having been driven in away from it; the bolt above No. 1512 is driven in about 0·3 in. At 11 ft. 6 in. from the proper left, the vertical buckle of the plate is 1·3 in. in line with No. 1512; at 13 ft. the vertical buckle is 0·5 in. No. 55 bolt stands out 0·2 in.; the plate has been penetrated by Nos. 1508 and 1507, the head of the shot still remaining in the former. Cracks join No. 1508 to 1507, and to 1511, and 1507 with the bolt below it, which is driven in 0·5 in. Above No. 1508 there is a small crack from edge of plate 1·5 in. long, and another upwards from No. 1508, 4·5 in. long. There appears to be a complete separation of the front lamina 1 in. thick, extending over the area occupied by Nos. 1514, 1511, and 1508, down to 1507; No. 1511 has driven a disc 0·13 in. in diameter 8 in. in, the bolt on its left top has been driven away; the plate, behind where the bolt was, is completely broken up; the bolt below No. 1511 is drawn in 1 in. No. 1514, which perforated the target, broke off a large flake 10 in. × 9 in. × 1 in. thick of front lamina between Nos. 1511 and 1514; the top of the plate above the latter is also broken away. Below No. 1514 is the head of No. 1525, still remaining in plate in a splash; horizontal buckle of plate 2 in. under No. 1525.

Centre front plate; commencing from proper right. Vertical buckle at 2 ft. from end 0·6 in.; No. 1513 perforated the target; at 4 ft. from end buckle is 2 in. in line with No. 1513, the plate is also driven in somewhat all round; above No. 1506 buckle is 1·2 in. and 1·8 in. below. The plate is cracked above and below the indent 12 inches, and horizontally on the right for 5 in. between the two indents, and on the upper half of the plate the through bolt is broken off 9 in., the corresponding bolt in bottom of plate is drawn in 0·2 in.; at 6 ft. from end the plate is 0·7 in. back from the bottom. No. 36 bolt, in centre of plate, is drawn in about 0·2 in.; near the port the plate projects ·9 in. from bottom, and in port 1·1 in.; the horizontal buckle of lower edge of plate between right edge of target and port is at 2 ft. from end 1 in., at 4 ft.-2 in., at 6 ft.-1·9 in., at 8 ft.-1 in., and at 10 ft.-0·3 in. The two plates are 1 in. apart at right, and touching at port.

Top row. The right top corner of plate is broken through nearly diagonally from half way up right edge down to left corner, the upper half being turned half round on its left top bolt as a pivot, and resting on the roof proper; the plate is also broken through below No. 1522, through a bolt hole; the vertical planks are much bent and broken especially in rear of No. 1522; the plate projects 2·5 in. on left, and is drawn in 2 in. on right. The second curved plate has had a triangular piece 4 ft. 6 in. × 2 ft. broken off its right bottom corner, and the left corner 2 ft. 9 in. × 1 ft. also broken off; this plate projects 2·4 in. at bottom, the whole plate is away from the next layer about the same, and 2·5 in. from No. 3 curved plate. No. 3 curved plate is cracked through star-wise above its lower right hand bolt.

On top of casemate. The concrete is cracked through horizontally about 9 ft. from rear edge, just at the junction of old with new part. The bolts in the top row of 2nd curved plate have started up a little; the iron concrete appears to have held well. The condition of the rails, planks, &c., behind curved plates cannot be ascertained, from the iron concrete having fallen in among them.

State of the rear of the structure representing the Plymouth Breakwater Fort at conclusion of first three days' practice.

Commencing on the left. No. 37 bolt broken off 15 in. from the rear. No. 2 plank is projecting 1·8 in. beyond the plate below it in rear, and 1 in. on the left.

No. 5 strut. Left plank slightly bulged and separated from No. 1 plank 1·8 in., from plate 1·5 in. at bottom, and 1 in. at top, from 2 and 3 planks slightly. Right plank bulged about 1·5 in. in centre, and not touching shield, except above tie bolt. Wood packing splintered below centre clip. Top clip washer bent back about 1 in. on the right. Iron washer of No. 30 bolt broken, and wooden washer smashed; arch angle piece bent back about 1 in. and cracked from bottom to rivet hole; 2 rivets gone. Middle clip washer bent back about 1 in. on left and 2 in. on right. No. 49 bolt loose, and wooden washer gone. Lower clip washer bent back about 1 in. on each side, and No. 67 bolt driven back about 3 in. For space between Nos. 5 and 4 struts, *vide* reports on rounds Nos. 1501, 1503, 1505, and 1521. The gape of the crack in No. 4 plank, caused by No. 1521, is 1 in., and the plank is bulged 1 in. between uprights.

No. 4 *strut.* Left plank slightly bulged and indented by No. 1505. Right plank slightly bulged. Wood packing splintered below top clip washer. All the clip washers are bent back at their sides. Wooden wedge piece above the top clip washer smashed. No. 48 bolt gone. For space between Nos. 3 and 4 struts, *vide* rounds Nos. 1502, 1512, 1515, 1524 and 1526. Daylight is now visible through No. 1512.

No. 3 *strut.* Left plank bulged about 1·5 in. Left centre plank slightly bulged. Right plank bulged about 1 in. Top clip washer much bent back on both sides, and wooden wedge above it smashed. Centre clip also much bent. Bottom clip slightly bent. The wooden washers of all the bolts crushed, but the bolts themselves are all right.

Space between 3 and 2 struts, *vide*, rounds, 1506, 1507, 1508, and 1523. Daylight now shows through 1523 and 1506.

No. 2 *strut.* The left plank is about 7 in. out of straight, and is much bulged and indented by Nos. 1506 and 1507. It is cracked horizontally at 2·2 in. from floor right across and half through. The wood packing is destroyed. The right plank is bulged about the same as left. No. 26 bolt is touching the pier, No. 46 bolt is 1 in. from pier, which has been indented by it to the depth of about 1 in. The centre clip washer has disappeared and the other clips are much bent. No, 63 bolt is touching the wooden slip between granite floor and iron foot plate. The wooden washers of all the bolts are destroyed.

Between Nos. 1 *and* 2 *struts.* The front layer of plates is exposed for a distance of about 5 ft. vertical and, 2 ft. horizontal. The space between Nos. 1 and 2 struts is almost choked up with the debris of the two rear layers of planks, broken away by rounds Nos. 1513 and 1514, rendering it impossible to take any accurate observations of the state of the shield beyond No. 2 strut.

No. 1 *strut.* Left plank much bulged in centre. Nos. 38 and 45 bolts nearly touching pier. The centre clip washer is loose, and about 4 inches from strut. The top clip is loose and about 4 inches from strut, and is much bent back on left. The layer of hides, has, where exposed to blows, become disintegrated, and, in many cases, fallen to pieces, leaving a vacant space.

TABLE IV.

STRUCTURE REPRESENTING PLYMOUTH BREAKWATER FORT.

Report of Practice on the 7th and 8th July, 1868.

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			15-INCH PORTION.
1562	10-inch rifled M. L. of 18 tons.	48 Rifle L. G.	Palliser shell. head 1·5 27·3 ins. 398·7 lbs. 9·92 ins. Burster 9·687 lbs.	1185	3882	124·6	Struck the 2nd curved plate just above No. 1526, 9 ft. 7 in. from right, 1 ft. 3 in. above the upper edge of centre plate, and increased the damage done by rounds Nos. 1524 and 1526. Shell burst in target. The plate is cracked from the right of the hole upwards for a length of 2 ft. 7 in. The shot struck on the junction of the port plate (centre layer) and 1st vertical plank on its right. Diameter of indent on this layer 8 inches. The point of the shell forced its way between the plank and plate, and indented a plank of the inner or horizontal layer, breaking it in halves through the indent; the point of the shell remained in the hole, but was afterwards knocked out, when the total penetration was found to be 1 ft. 6 in. *In rear.*—Piece of the lower flange of the roof girder (5·5 in. by 6 in.) and piece of the arch angle iron, 12 inches long, broken off. The stringer plate is bulged and has crumpled the arch plate slightly. No. 21 bolt is now touching girder.
1563		”	” 399·9 lbs. Burster 9·875 lbs.	1171	3802	122·0	Struck on No. 1526, making a slight scoop on top edge of centre plate, 10 inches long, 1·5 inch deep; shell passed into target and burst in doing so. The 2nd curved plate had been previously broken away at this place by No. 1526, so that this shell struck fair on the already damaged part of the vertical layer (target being only 10 inches thick at the place of impact). The explosion blew the bottom of the curved plate 9 inches out from the front of the target. The port plate (centre layer) appears broken from the indent of No. 1524 down to No. 1502, and upwards to the left, the crack running behind the 3rd curved plate, and a longer portion of the right side broken away 12 inches wide and 20 inches long. *On top.*—No. 5 bolt (the middle top one of the plate) is sheared off 5 inches in, being caused probably by the shifting of the plate to the right (it having moved 1·75 inch), the bolt being held between two uprights. *In rear.* — Shell penetrated, daylight being visible through target, numerous fragments of shell and small pieces of plate fell inside the mantlet. A piece of plate weighing about 4 lbs. driven 19 yards to the rear. The crack

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1563 Contd.							in No. 4 plank (caused by No. 1526) has opened out to 3 inches. The wooden beam in front of the stringer plate is destroyed, and No. 21 bolt and the vertical bolt near it more distorted than before.
1564	10-inch rifled M. L. of 10 tons.	48 Rifle L. G.	Pallisher shell, head 1·5 27·3 ins. 397·6 lbs. Burster 9·625 lbs.	1168	3761	120·7	Struck above right top corner of port, bottom of the hole 4 inches above it. This round broke away the whole of the three 5-in. layers forming the top of the port. In the front plate, the portion carried away extended from No. 1564 on the right to No. 1502 on the left, the line of fracture on the left being determined by the old fissures caused by No. 1502. In the centre layer the lines of fracture were from No. 1524 down to No. 1502 on the left, and from No. 1524 through No. 1563 down to No. 1564 on right, all but the last being old. It will be observed that rounds Nos, 1524, 1526, 1562, 1563, and 1564 all struck in an area represented by a triangle, of which the sides are 2 feet and the base 2 ft. 7 in., measuring from centre to centre of holes. The breaking away of this large mass of the two front thicknesses uncovered the 5th inner horizontal plank, which was found to have been broken through by both Nos. 1524 and 1563. *In rear.*—Shell passed through shield and burst inside, filling the casemate with smoke, and setting mantlet slightly on fire. A large jagged hole, about 3 feet square, was formed by the breaking away of the whole of the armour plates above the port, and a large piece of hide was hanging down in the gap. A large fragment of the shield, consisting of three thicknesses of plate held together by No. 28 bolt fell inside the mantlet. Size of fragment:—Outer plate 27 in. by 22 in. and 28 in. by 22 in.; centre plate 18 in. by 42 in; inner plate 16 in. by 48 in. A piece of the base of shell was found lying on sill of port, also a piece of plate. No. 3 horizontal plank (which had been previously broken away between Nos. 1 and 2 struts) shifted 12 inches to the right, between Nos. 2 and 3 struts. The rope mantlet was much cut by splinters, and one of the baulks supporting it cut in two. The floor of casemate, both in front and rear of mantlet, was covered with fragments of iron, some of which were thrown a considerable distance to the rear.

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE, — Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of Shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			SALVO.
1575, 1576, 1577	—	—	—	—	—	—	All struck the right side between port and end of target, making a clean breach through target.
1575	15-inch S. B. Rodman.	$83\frac{3}{4}$ lbs. R. L. G.	Solid shot, 453·2 lbs.	Not observed.	6000	128	On the lower plate, 3 ft. 8 in. from bottom, 4 ft. 3 in. from right.
1576	9-inch rifled M. L.	43 lbs. R. L. G.	Palliser shot, head 1·25 251 lbs.		2900	104	On the middle plate, 5 ft. 2 in. from bottom, 4 ft. 3 in. from right.
1577	12-inch rifled M. L.	76 lbs. Pellet.	" 600 lbs.		5680	152	On the same plate, 7 ft. 5 in. from bottom, 2 ft. 5 in. from right.

Looking at the target from the front, the effect of the salvo was to break off an irregular piece of the right end of the middle plate, measuring about 4 ft. $1\frac{1}{2}$ in. × 4 ft. 8 in., which fell in front divided into two by No. 1577, the line of fracture running through No. 1513. On top row of curved plates, the triangular piece in No. 1 between Nos. 1520 and 1522, and separated from the rest of the plate by fissures, was shaken out and also fell in front. In the lower front plate, the top edge from No. 45 to 46 bolt, and down to bottom of the indents Nos. 1575 and 1511, measuring about 4 ft. × 1 ft. 9 in. and 1 ft. 2 in. was now broken away and driven in, and that portion previously separated by No. 1511 turned nearly half round behind the rest of the plate by the combined force of Nos. 1575 and 1576. In the vertical layer, No. 4 plank was broken through at No. 46 bolt, and an irregular piece carried away from its right side 1 ft. 6 in. long by 12 in. deep (this plank had been previously injured by No. 1506). No. 3 vertical plank (previously injured by Nos. 1513 and 1514) was broken away from about 4 ft. up to 9 ft. from bottom, the 4 ft. length being bulged back 7 in. No. 2 plank was broken in half at junction of lower and middle front plates, the bottom of the upper portion projecting 5 in. to front. The plank was also broken through at No. 25 bolt, at the upper edge of No. 1577, and a large scoop taken out of its left side 15 in. × 11 in. In the third or horizontal layer, the 5th plate was broken away on its upper edge over a space of about 1 ft. by 3 ft. No. 2 horizontal plank was broken off for a length of 4 ft., 2 ft. 3 in. from right, and bulged back considerably on each side of the fracture. No. 3 horizontal plank was broken away between Nos. 1 and 2 struts No. 4 horizontal plank had a piece broken out of it between the struts (and only hanging by No. 18 bolt) 13 in. long by the depth of the plank. No. 5 horizontal plank had a similar piece 1 ft. 6 in. long broken out of it in line with No. 1 strut, the piece broken off resting on No. 18 bolt and the stringer plate. The horizontal stringer plate was fractured and driven back against the box girder by the piece of No. 5 plank.

The screw bolts Nos. 25, 31, and 35 were broken at the screw thread, and No. 58 bolt drawn in 1·5 in.

The concussion jarred out the head of No. 1525 shell. Indent found to be 4·5 in.

In rear.—The pier seemed to have moved slightly at the top. It was indented to a depth of 9 in., and the concrete (with pieces of chilled shot embedded) exposed over an area of about 28 in. by 30 in. The damage had chiefly been caused by the 12-in. shot. The top flange (angle iron) of side of pier next shield was cracked for a length of 8 in. and 0·3 in. wide, and was slightly driven up. The skin plate along the left edge had opened slightly at joint, and was broken through 9 in. below box girder. The casing in front of the box girder was driven in against it; area of bulge 12 in. by 10 in.

No. 2 *strut.* The left plank was broken through at former crack (27 in. from ground) and the upper portion projected 1·5 inch over the lower on left and 1 in. in rear. The whole of the centre part of the strut had shifted to the left.

The distances of the left plank from the pier before and after the salvo, were—

Height above Floor.	Before.	After.
6 inches.	16 inches.	17 inches.
39 "	9·5 "	10 "
63 "	7 "	8·5 "
76 "	7 "	8 "
88 "	7·5 "	9·5 "

The right plank was broken through at about 7 ft. from ground, the lower portion projecting 2·5 in. beyond upper. There was an interval of about 2 in. (in rear) between the two portions of plank, in which a large portion of shot was jammed, partly supported by the pier which it had deeply indented. This fragment of shot had also scooped out the lower portion of plank 2 in. by 4 in. Neither Nos. 1 nor 3 struts were much affected by the salvo; the heads of the bolts in No. 1 were nearly touching the pier before, and any further bulge in the strut was thereby prevented. The maximum bulge in its left plank was now 6 in., just above centre clip washer. A large number of fragments of shot and small pieces of plate were found inside the mantlet, chiefly on the left of port. A piece of plate 15 in. by 12 in. was shaken out from above port and fell just inside.

Nothing passed through mantlet (which was about 7 ft. from rear face of shield).

TABLE V.

STRUCTURE REPRESENTING PLYMOUTH BREAKWATER FORT.

Report of vertical fire from 13-inch land service Mortars, at 900 yards, on the 2nd of July, 1868.

Round.	Charge.			Elevation.		Penetration in earth.		Points struck by the shell.	Total penetration to bottom of shell.	
	lbs.	ozs.	drms.	deg.	min.	ft.	ins.		ft.	ins.
1	3	5	0	59	30	2	0	44 yds. over casemate, 14 ft. west.	3	1
2	3	3	0	,,		6	0	33 yds. short, 45 ft. west.	7	1
3		,,		58	45	—		Hit iron face of the adjacent casemate 15 ft. west 3 ft. from proper left, 4 ft. 8 in. from bottom; shell broke up; made no indent.		
4	3	3	1	,,		2	3	25 yds. short, 1 ft. 6 in. east.	3	4
5	3	3	8	59	15	3	3	Struck on the roof, 6 ft. from proper right, and 7 ft. from front. Crater 4 ft. by 4 ft., 24 ft. east of line.	4	4
6	3	3	9	59	27	1	5	20 yds. over, 63 ft. west.	2	6
7	3	3	8	58	45	2	6	19 yds. short, 29 yds. east.	3	7
8		,,		58	47	3	6	18 yds. short, 27 ft. east.	4	7
9	3	3	9	59	21	—		3 yds. short, 18 ft. east. Hit the brick-work in rear of cramp wall 4 ft. from eastern pier, breaking away the edge 3 ft. by 1 ft. 6 in.; shell rebounded 31 yds.		
10		,,		58	45	—		Hit face of the adjacent casemate 9 ft. up and 1 ft. east of centre line on 21 bolt; shell broke up.		
11		,,		,,		1	2	43 yds. over, 73 ft. east.	2	3
12		,,		59	0	4	3	41 ft. short, on line.	5	4
13		,,		59	15	3	6	44 ft. short, 44 ft. east.	4	7
14		,,		59	0	4	6	24 ft. short, 14 ft. east.	5	7
15	3	3	10	59	30	3	0	23 yds. over, 4 ft. east.	4	1
16	3	3	9	59	45	1	1	Struck on the roof 14 ft. from right, 10 ft. from front.	2	2

Two live shells, with a bursting charge of 10·5 lbs. of powder, were used as follows:—

No. 5 shell was dug out and a live shell inserted in its place, 11 feet 6 inches from right, 10 feet from front, and fired by magnetic tube. Crater 13 feet 6 inches east and west, 14 feet 6 inches south-west. Depth 3 feet. Edge of crater 6 feet from front and 6 feet from right. The splinters did not range any distance. The earth thrown up fell back again chiefly into the crater and on the roof. The burst had no effect on the interior of the casemate.

No. 16 shell was dug out and a live shell inserted in its place, and fired by magnetic tube. Crater 9 feet east to west by 10 feet 6 inches north to south down to concrete, laying it bare for an area of 3 feet 6 inches. Depth of crater 2 feet 6 inches. Several pieces of shell in hole; centre of crater 13 feet 9 inches to right, 11 feet to front. Pieces of shell had a spread of not more than 300 yards. Inside casemate no effect whatever.

Rounds 1 to 5.—The roof covered with earth and filled sand bags, 5 feet deep over concrete.

,, 6 to 16.—2 feet 6 inches of earth and sand bags removed.

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Round.	Gun.	Charge.	Projectile.	Weight.	Burster.	Head.	Part of Target.	Distance from Support.	Indent.	Diameter.	Buckle.	…ARKS.
	in.	lbs.		lbs.	lbs.				in.	in.	in.	
1501	12	76	Shot	600	..	1·25	Plate, plate, plank, plate.	On No. 5 strut.	13·5	12	1	
1502	12	76	Shell	586	14	1·5	Plate, plate, plate, plank.	11 in.	7 in. on 2nd plate	12	1	…te cracked from
1503	15	83¼	Shot	451	..	0·5	Plate, plate, plank.	14 in.	4·5	17	2	…cked to bottom ; …ed.

TABLE VI.

STRUCTURE REPRESENTING PLYMOUTH BREAKWATER FORT.

Report of vertical fire from 13-inch land service mortars, at 900 yards, between the 7th of July and the 2nd of September, 1868.

Rounds.	Shells filled with sand. Weight.	Charge.	Elevation.	REMARKS.
	lbs.	lbs. ozs. drs.	deg. min.	
34	207	3 3 9 to 3 3 14	58 18 to 60 30	Note.—Rounds Nos. 6, 7, 45, 75, 97, 133, 169, 187, 242, 256 struck the top of the adjacent casemate.
4	207	3 3 14 to 3 3 15	59 30 to 61 30	
20	207	3 3 6 to 3 3 15	59 10 to 60 45	
28	207	3 2 13 to 3 3 14	59 30 to 60 30	
22	207	3 2 9 to 3 3 10	59 36 to 60 18	
18	207	3 1 0 to 3 5 1	60	
20	207	3 1 0 to 3 4 0	60	
14	207	3 3 8 to 3 4 0	60	1 round (159) struck granite foundation. Shell broke up. Granite slightly splintered.
20	207	3 2 11 to 3 3 10	60	
30	207	3 2 2 to 3 3 0	60	1 round (195) grazed right edge of structure, slightly damaging iron on that side.
50	207	3 1 15 to 3 2 3	60	1 round (228) struck granite foundation.
20	207	3 2 0	60	1 round (267) struck roof, shell penetrated 8 inches, and rebounded. 1 round (275) struck casemate and sand bags.
18	207	5 6 0	75	
298				

A live shell was exploded afterwards in the spot struck by No. 267, and had no effect whatever on the interior of the casemate.

IV.—Casemate with Iron Front of Cellular Construction.—Pl. VI.

This work differed in one or two essential features from that last dealt with.

In the first place, it did not represent any particular Fort of our defences, but was designed with the view of deciding certain disputed questions as to the best disposal of armour in a plated wall.

It also had these distinctive features, that the main structural parts of the casemate itself formed generally the backing to the front wall, and that it was a masonry casemate of nearly the ordinary form and dimensions, with an iron instead of a stone facing, rather than a portion of an iron fort.

The drawing, Plate VI, shows all the detail of the construction.

The iron work occupied a frontage of 28 ft., and was 12 ft. in height. The face of the work was vertical. It stood upon the granite that formed the lower courses of the experimental casemates tried in 1865.

The intervals between the guns of a work after this design would be 24 ft.; 12 ft. of this being occupied by the pier.

It contained a port suitable for guns mounted on ordinary casemate carriages.

The dimensions of the port admitted of a 9-in. 12-ton gun being elevated 9° and depressed 5°, or of a 10-in. 18-ton gun being elevated 6° and depressed 5°; while the former gun could be traversed 67° laterally, and the latter 66°.

The structure will be best described by commencing with the interior of the work, and proceeding outwards to the front wall.

The main pier, measuring 12 ft. across, 8 ft. in depth, and 7 ft. 9 in. in height, with the rear angles cut off diagonally to give room for the lateral training of the gun, was composed of brickwork in Portland cement to a height of 3 ft. 9 in. above the floor level, and of Portland cement concrete above that; all being enclosed on the sides and rear in a casing of $\frac{3}{4}$-in. iron plate.

The other pier, which, to suit the site and adjacent work, was of irregular form and half size, was similarly constituted as to masonry filling, but the casing was of $\frac{1}{2}$-in. boiler plate.

From the main pier to the old brick pier in rear, which formed part of the original experimental casemates, a very strong box girder of special form and construction was thrown at a slight incline upwards to the rear, and from this sprang the 18-in. brick arch, with a span of 20 ft., which, with the concrete filling to an average depth of 3 ft. over the crown, formed the roof of the casemate. The other springing of this main arch would, in an actual work, be from a similar girder, but in this particular case it sprang from a brick wall forming the other side of the casemate.

The front of the main arch was gradually reduced to a span of 12 ft., the crown lowering from 11 ft. to 9 ft. above the floor. It was lined with a strong hood, formed of $\frac{3}{4}$-in. plate, springing from the top of the sides of the piers, and the hood was stiffened with T and L irons on its upper side.

In rear of the left-hand pier a powder lift was formed through the arching and roof, to represent nearly the arrangement that would exist in an actual work.

The cellular structure forming the backing of the front wall in the space 12 ft. wide and 9 ft. high between the piers, and in the centre of which the port was made, was composed of vertical built-up ribs and ⊢⊣ irons, occupying a thickness of about 14 in., attached to a 2-in. plate (more fully described hereafter) on the front side, and a $\frac{3}{4}$-in. skin plate on the rear side; this cellular space, 14 in. through, was filled with Portland cement concrete.

At a distance of about 5 in. in rear of the above $\frac{3}{4}$-in. skin, another skin $\frac{3}{8}$-in. thick was secured to the rear flanges of the vertical ribs of the cellular structure, for the purpose of covering the nuts of all armour bolts and generally catching splinters.

In the heart of the cellular structure over the port, at 7 ft. 6 in. above the floor, there was inserted a horizontal beam of solid wrought iron, $6\frac{1}{2}$ in. by $6\frac{1}{2}$ in. in section and 15 ft. long. In the floor, immediately under the cellular structure, there was another wrought-iron beam, 12 in. by 3 in. in section and 8 ft. long.

To these beams were secured, by means of turned ends or feet, two massive uprights of wrought-iron, in section 13 in. by 9 in., and 9 ft. high, standing 2 ft. 6 in. apart, and forming, for a part of their height, the two sides of the port. Into and between these, again, were framed two horizontal pieces, 6 in. by 7 in. in section, and 2 ft. 8 in. long, to form the sill and lintel of the port.

Proceeding now to the composition of the compound armour over the entire front, it may be thus described :—

Over the whole front, next to the brickwork and concrete filling of the piers and the cellular structure about the port, and broken only by the port stiffeners lately described, there was a 2-in. skin, composed of large plates running horizontally, and making up the height of the front in four widths. Over a portion of its upper part, as shown in the drawings, this skin received further support from behind by means of wrought-iron brackets or struts; and immediately behind its top edge it was further supported by a plate, 16 in. by 2 in., laying flat on the tops of the struts with its edge against the skin.

Commencing at the proper right end of the front, there was an 8-in. plate standing vertically, 12 ft. 3 in. high and 4 ft. 3 in. wide, secured in front of and immediately in contact with the 2-in. skin, by means of 10 long $3\frac{1}{4}$-in. armour bolts passing through tubes in the pier to the rear side, where they were nutted. The object of the tubes just mentioned was to admit of the front armour being applied at any time subsequent to the erection of the pier, if necessary. It may be mentioned, by the way, that those bolts that came opposite to the back of the pier were carried quite through the casing, the nuts and washers being enclosed by an extra $\frac{3}{8}$-in. plate in rear. Those that came opposite the diagonal sides stopped short inside the casing, and there were hand holes formed to get at the nuts. This solid 8-in. plate may be considered as the standard, in regard to weight, for the armour and cellular backing of the rest of the front, as in all cases the front plate and its immediate iron backing were made together equal to 320 lbs. per foot superficial, which was the weight of the 8-in. solid armour.

Next to the solid 8-in. plate there was a $4\frac{1}{2}$-in. vertical plate, 12 ft. 3 in. high and 4 ft. 3 in. wide, backed by channel irons strongly riveted to the 2-in. skin on the solid pier, and so disposed as to give an equivalent in weight to a solid $3\frac{1}{2}$-in. plate. Thus the $4\frac{1}{2}$-in. armour, with its backing, made up the weight of metal in the 8-in. solid plate. In this part there were 10 $2\frac{1}{4}$-in. armour bolts arranged much as before.

Next to this came three 6-in. armour plates, all 10 ft. 4 in. long and 4 ft. 1 in. wide, placed horizontally, backed by heavy bridge rails, called sometimes "hollow stringers," placed vertically. These rails equalled in weight a solid 2-in. plate, and, therefore, with the 6-in. armour, were equivalent to the beforementioned standard 8-in. solid plate. Over a portion of these plates the 2-in. skin was backed either by the pier or the concrete filling of the roof. Over the remainder it was backed by the cellular structure filled with concrete as before described. These plates also at one end were backed by the solid port stiffeners. They were held by $2\frac{3}{4}$-in. armour bolts.

To the left of the port there was a 4-in. vertical plate, 12 ft. 3 in. by 3 ft. 4 in., backed by channel-irons of the same description as before, only placed closer together, so as to equal in weight a solid 4-in. plate; they, therefore, with the front armour, equalled the standard as before. One edge of this plate was on the port stiffener. The armour bolts were $2\frac{1}{4}$ in. in diameter. The lower part of the plate was on the cellular structure; the upper part on the concrete filling.

On the left of all there was a 4-in-plate standing vertically, measuring 12 ft. 3 in. by 5 ft. 2 in., and held by $2\frac{1}{4}$-in. bolts. About 2 ft. of the right-hand side of this plate was backed by channel-irons, arranged exactly as in the last case, and part of this 2 ft. was on the cellular structure, part on the pier; for the remainder of the plate there was nothing but Portland cement concrete between it and the 2-in. skin, which was backed by the pier. This part was scarcely intended to compare with the remainder of the front, but it was useful as it turned out.

As regards the armour bolts, there were about 87 in all, of which about 46 were reduced for a part of the shank to the lesser diameter of the screwed part, on Major Palliser's plan. The remainder were not so reduced, and were of the ordinary make. The heads of all were made by upsetting.

All the ordinary bolts that passed through the cellular structure were fitted with hexagonal cups and elastic washers under the nuts; the rest had simple plate washers.

The cellular spaces between the irons at the back of the armour plates, over the entire front, were filled with Trinidad pitch.

In order to distinguish between all the varieties of construction adopted in the front of this work, its surface was, for the purposes of the experiment, subdivided into vertical sections, marked A, B, C^1, C^2, D, and E respectively, which lettering will be found on Plate VI.

They were as follows:—

Backed by the Piers.

A. 8 inches of iron as a solid plate.

B. $4\frac{1}{2}$ inches as plate on channel irons, equivalent to $3\frac{1}{2}$ inches of solid iron.

C^1. 6 inches as plate on bridge rails, equivalent to 2 inches of solid iron.

Backed by the Cellular Wall.

C . 6 inches as plate on bridge rails, equivalent to 2 inches solid.

D. 4 inches as plate on channel irons, equivalent to 4 inches solid.

Backed partly by Cellular Wall and partly by Pier.

E. 4½ inches as plate on channel irons, equivalent to 4 inches solid.

The left-hand part of E section, for a width of 2 ft. 9 ins., was backed by Portland cement concrete only in the 7-in. space between it and the 2-in. skin.

The guns selected for the trial were as follows :—

Nature.	Weight.	Charge.	Mean Weight of Projectile.
	Tons.	lbs.	lbs.
7-in. rifled, muzzle-loading	7	22 R.L.G.	115
9-in. rifled, muzzle-loading	12	43 R.L.G. ...	250
10-in. rifled, muzzle-loading	18	60 R.L.G.	400
" "	"	48 R.L.G.	400

Occasion was also taken to fire one round from the 12-in. gun, and two rounds from the 15-in. Rodman gun, with full charges, as given before, in the trial of the structure representing Plymouth Breakwater Fort.

The guns were all placed at 200 yards. Full battering charges were generally used.

The Committee was composed of the same members as in the case of the trial of Plymouth Breakwater structure.

According to the programme, it was decided to commence the experiment with a round from each nature of rifled gun at each section of the front; then to follow with a series of solid shot from the same guns; afterwards to repeat such rounds as had not given definite results; and lastly, to fire such additional rounds as in the course of the trials should appear desirable.

The rounds fired were as follows :—

Gun.	Shot.	Shell.
7-inch	5	7
9 "	7	7
10 "	6	7
12 "	1	
15 "	2	
	21	21
Total	42	

Table VIII shows the entire practice during the experiment.

Table IX gives an abridgement of the practice.

Table X gives at one view the penetration of the various projectiles in different parts of the front.

It is almost unnecessary to add anything to the information contained in these Tables and the Plate, but, adopting in a great measure the Report of the Commtttee, the following observations may be useful :—

Exterior of the Front after Practice.

At the conclusion of the practice, the appearance of the front of the work was not much altered, except at the shot holes and their immediate vicinity. The armour plates were of very good quality, and had suffered but slightly from cracks, distortion, or bulging, and the bolts of all kinds stood well. Only 10 of the latter were broken out of a total of 87.

Interior of the Work after Practice.

In the interior of the work the piers were considerably shaken, chiefly from the explosions of the 10-in. shells inside them. They were bulged, and the rivets of their joint coverings sheared off on the sides next the port. The joints of the left pier had also opened out, and the concrete it contained was driven, through the opening, into the casemate in a pulverised state.

The cellular wall containing concrete between the piers was destroyed in rear of the parts struck by rounds 1539, 1545, 1546, 1558, and 1561; and the backing, with fragments of the projectiles, was driven destructively to the rear.

The inside skin or mantlet of $\frac{3}{8}$th-inch iron being found very objectionable, from the numerous rivets driven from it by each round, the greater part of it was removed before the completion of the practice.

The power of the Rodman gun was so insignificant, merely producing indentations 4·3 and 7·7 inches deep and about 17 inches in diameter on the face of the work, without exerting any noticeable racking effect, that only two rounds were fired from this gun.

From the Tables it will be found that the penetrations of the projectiles of all natures were less on the A section than on any other part of the front; and this superiority of resistance on the part of the work faced with the solid armour was more marked in the case of the 10-in. shells than in the cases of the smaller projectiles.

Comparison between the Two Systems of Stringers.

Sections C^1 and C^2 appeared to have a slight advantage over the B and D sections in resistance to projectiles from the 7-in. and 9-in. guns; that is, to resist these guns, the arrangement of 6-in. armour on 2 inches as stringers was better than $4\frac{1}{2}$ inches as armour on $3\frac{1}{2}$ inches as stringers. But in the case of the pier supporting these two systems, the B arrangement was superior to the others in resisting the penetration of the 10-in. shot and shell.

Resistance of the Wall between the Piers.

In the case of the wall, the differences of penetration of the 7-in. and 9-in. projectiles was not great, and both systems may be considered as affording sufficient protection against these two natures of projectiles; for though one 9-in. shot (round 1559), striking the D section where the backing was injured by a previous round (1546), passed through the wall, yet two other 9-in. shot (rounds 1555-6), striking on the wall at C^2 section, close to the junction of the wall and pier, and two 9-in. shells (rounds 1540-1550), striking fairly on the wall (at D and C^2 respectively), failed to perforate it.

The 10-in. shot and shell, however, passed readily through the wall at both sections.

Relative Resistance of Wall and Pier to 7 and 9 inch Projectiles.

On a comparison of the relative resistances given by the wall and piers to the penetration of 7-in. and 9-in. projectiles, it will be found that, generally speaking, they penetrated deeper in the structure supported by the piers than in the wall.

Relative Value of Brick in Cement, and Concrete in Cement as filling for the Piers.

The lower portions of the iron-cased piers of the work were composed of brick in cement, the remainder of concrete in cement. The resistances of these portions to penetration were very nearly alike. Thus, on E and B sections (nearly similar):—

No. of Round and Projectile.	Penetration.	
	Brick Backing.	Concrete Backing.
	Ins.	Ins.
1537 9-in. shell ..	21·3	—
1541 Do. ..	—	22·3

Port Stiffeners.

Two rounds (10-inch shot battering charge and 12-inch shot battering charge) were fired at the port stiffeners. One only struck, and glanced off without taking full effect on the position intended; so that the resistance of these stiffeners cannot yet be stated.

Effects on the Arch of the Casemate.

The brick arch of the roof of the casemate was slightly shaken at the conclusion of the practice, but was otherwise uninjured. Little direct fire had, however, been sustained by the portion of the front against which the arch abutted.

Effects of Vertical Fire on the Roof of the Casemate.

The roof of the casemate was covered with earth to a depth of 4 feet over and above the concrete-filling over the crown of the brick arch, and was subjected to the test of vertical fire from a 13-inch mortar at 900 yards range, fired at 60° and 70° elevation.

The roof was struck nine times.

The shells, which were fired, weighted up with sand and plugged, owing to the danger attending the use of live shell, penetrated in every instance to the concrete, which in some cases appears to have been slightly indented. The earth was, however, loose, and partially filled in the crater formed by the shells, as soon as made.

Comparison of the Part without Stringers with that Portion having Stringers.

The proper left of the front, for a width of 2 feet 9 inches, had no stringers between the 4½-inch armour and the 2-inch skin, the interval between these iron surfaces being filled with concrete only. Two 10-inch shells were fired at this portion. One penetrated 58 inches and bulged, but did not open, the casing of the pier in rear. The second penetrated about 72 inches, and split open the ½-inch iron casing of the pier, and drove out the concrete.

About the same depth of penetration was attained by a similar shell in the C¹ section of the east pier, where there were stringers between the 6-inch armour and the 2-inch skin; the pier itself, which had a ¾-inch iron casing, was bulged, but not opened enough to let out the concrete. In this case it would appear that the stringers did not add much to the resistance to penetration.

General Conclusions.

The following conclusions were drawn by the Committee, from the result of the practice against the casemate:—

That 8-inch solid plates on a 2-inch skin and concrete backing, offered better resistance to projectiles of all calibres than the same quantity of iron arranged partly as plates and partly as stringers in rear of the plates, supported by a similar backing.

That of the two systems of stringers experimented upon, neither form exhibited any decided relative advantage.

That Portland cement concrete, when used in large masses, as in the case of piers, should be subdivided into compartments, so as to localise and limit the destructive effects caused by the explosion of shells. As a material for backing, concrete may be considered sufficiently yielding to afford relief to the bolts, and to protect the armour plates from the distortion and buckling usually observable in rigid structures.

That, although the cellular construction adopted in this casemate did not sufficiently develop the advantages that may be derived from the employment of concrete as a backing, the Committee were not satisfied that such a combination will be found at all preferable to one of iron with wood backing for the thin walls between the piers of such casemates.

That a fixed iron screen or mantlet is a source of danger, and should not be employed.

That the system of building in tubes in the concrete backing for the reception of bolts is apparently satisfactory.

Results of the Experiment.

Speaking generally, it may be said that this experiment decided three main questions:—

1st.—That the compound construction of plate and stringer offers no advantage, as regards penetration, over the solid plate-upon-plate system.

2nd.—That a given quantity of iron in a cellular wall, does not afford greater resistance to pointed shot than the same quantity of material disposed in heavier masses; also that the cellular construction has no advantage as regards cost to compensate for the inconvenience of its greater bulk.

3rd.—That if the piers forming part of the main structure of the casemate be employed also as backing to the front armour, they must be made thoroughly secure against the action of shells.

TABLE VIII.

CASEMATE WITH IRON FRONT OF CELLULAR CONSTRUCTION.

Report of Practice on the 23rd and 24th June, and 7th and 8th July, 1868.

Photographic No. of Round.	Gun and Date of Experiment.	Charge and Powder.	PROJECTILE. — Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1530	7-inch rifled M. L. gun of 7 tons. 23 6 68	22 R. L. G.	Palliser shell head 1·5 D, 16·4 ins. 115·4 lbs. 6·92 ins. Burster 2·37 lbs.	1413	1598	73·5	Struck on the 8-in. plate (A) 1 ft. 10 in. from proper right, 1 ft. 4 in. from bottom. Indent 8·45 in. Diameter 7·25 in. by 7·25 in. Head of shell rebounded about 14 ft. Angle of penetration 88 deg. *In rear.*—Nil.
1531	"	"	" 115·3 lbs. Burster 2·25 lbs.	1410	1589	73·1	Struck on the 4½-in. plate (B) 1 ft. 3 in. from right of plate, 5 ft. 6 in. from right of target, 2 ft. from bottom. Head of shell remained in hole. It appeared that the shell penetrated about 4·5 in. straight and then turned to right. Total penetration to point 1 ft. 1·5 in. *In rear.*—Nil.
1532	"	"	" Burster, 2·31 lbs.	1382	1527	70·24	Struck on the junction of the 4½ in. (B) and the lower 6-in. (C^1) plates, 2 ft. from the bottom of the target, and 8 ft. 5 in. from proper right; head of shell remained in hole. Total penetration 8·75 in. on B (the head of the shell was knocked out by No. 1537). This shell had a low velocity, and was evidently unsteady by its wild shooting. *In rear.*—Nil.
1533	"	"	" 114·9 lbs. Burster, 2·37 lbs.	1396	1553	71·4	Struck the lower 6-inch plate (C^2 2) ft. from bottom, 13 ft. 9 in. from right of target, 5 ft. 4 in. from right of plate; head of shell remained in hole. Total penetration 10·25 in., point of shell slightly turned to right. *In rear.*—6 tap screws broken off mantlet skin-plate next the pier, the screw heads seem not to have reached the wooden targets which were placed about 10 ft. in rear.
1534	"	"	" 115·4 lbs. Burster, 2·37 lbs.	1398*	1564	71·9	Struck the 4-in. plate (D) 2 ft. 2 in. from the right edge of the plate, and 1 ft. 3·5 in. from bottom. Head of the shell remained in hole and slightly turned to the left. Diameter 7 in. by 7·2 in. Total penetration 1 ft. 1·25 in., with a depression of the plate all round the hole for a distance of about 8 inches. Maximum depth of depression 0·25 inch. *In rear.*— The mantlet skin plate bulged about 0·5 in; 7 tap screws broken near point of impact.
1535	"	"	" Burster, 2·37 lbs.	1402	1573	72·3	Struck the 4½-inch plate (E) 5 ft. 4 in. from the port, 2 ft. 2 in. from right of plate, 2 ft. 5 in. from bottom; head of shell re-

* Calculated.

Photographic No. of Round.	Gun and Date of Experiment.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet			
1535 contd		22 R. L. G.					mained in hole. Diameter 7 in. by 7·25 in. Total penetration 1 ft. 2 in No. 71 bolt started forward 0·6 in., but apparently unbroken. *In rear.*—One tap screw from left edge of mantlet skin-plate broken. No other damage.
1569	7-inch rifled M. L. gun of 7 tons. 8 7 68	,,	Palliser shell, head 1·5 D, 16·4 inches 115·4 lbs. 6·92 inches, Burster, 2·44 lbs.	1398*	1564	71·9	Struck on 6-inch plate (C^1) 6 ft. 7 in. from bottom, 2 ft. 5 in. from right of plate, lower edge of hole on upper edge of No. 1555; owing to the plate being weakened by Nos. 1544 and 1555, the shell took a downward direction. Depth 17 in. to inside of head; point of shell must have broken off, as a rod could be passed through into the concrete. *In rear.*—Nil.
1551	,, 24 6 68	,,	Palliser shot, head 1·25 D, 14 7 ins. 115 lbs. 6·92 ins.	1395	1552	71·4	Struck the 8-inch plate (A) 2 ft. 6 in. from bottom, 3 ft. 7·5 in. from right edge, 7·5 in. from left. Penetrated 8·7 in. Diameter of hole 8 in. by 7·5 in. Head of shot remained in hole. No. 60 bolt started forward 0·3 in. *In rear.*—Nil.
1552	,,	,,	,,	1417	1601	73·6	Struck the centre 6-inch plate (C^2) 5 ft. 10 in. from bottom of target, 4 ft. 6 in. from right of plate. Indent 12·6 in. Diameter of hole 7·25 in. by 7·25 in. Head of shot remained in plate. *In rear.* — Vertical stringer plate and angle iron slightly bulged. No other effect.
1553	,,	,,	,,	1397	1556	71·6	Struck the 4-inch plate (D) 10·5 in. from right edge, 1 ft. 8 in. from bottom. Penetrated 11·3 in. Diameter of hole 7·25 in. by 7·25 in. Head of shot remained in plate. *In rear.*—No. 48 bolt driven back 5 in. Skin plate bulged about 1·5 in., and angle iron round port bulged by No. 68 bolt.
1570	,, 8 7 68	,,	,,	1395*	1552	71·4	Struck the 4½-inch plate (B) 5 ft. from bottom, 2 ft. 6 in. from proper right. Diameter of hole 7·2 in by 7·4 in.; shot penetrated into the target, and turned to left partly broken up; the base of the shot was about 1·5 in. from face of target. Total penetration 16·18 in. *In rear.*—Nil.
1571	,,	,,	,, 113·5 lbs.	1410	1565	72·0	Struck the upper 6-inch plate (C^1) 2 in. from right of plate, 6·8 in. from bottom of plate. Shot broke up, but head remained in hole 5 in. to inside of head. Plate buckled 0·6 in. below hole. *In rear.*—Nil.

* Calculated,

Photographic No. of Round.	Gun and Date of Experiment.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet			
1536	9-inch rifled M. L. gun of 12 tons. 23 6 68	43 R. L. G.	Palliser shell, head 1·5 D, 21·5 ins. 249·6 lbs. 8 92 ins. Burster 5·56 lbs.	1288	2871	102·5	Struck the 8 in. plate (A) 2 ft. 5 in. from right, 4 ft 7 in. from bottom. Head of shell remained in hole. Diameter of hole 9·2 in. by 9 2 in. Total penetration 1 ft. 1 in. *In rear.*—Nil.
1537	,,	,,	,, 251 8 lbs. Burster 5·81 lbs.	1290	2906	103·7	Struck the 4½-inch plate (B) 2 ft. 3 in. from right of plate, and 3 in. from bottom. Head of shell remained in hole. Diameter of hole 9 in. by 9 in. Total penetration 21·3 in. Plate buckled horizontally about 0·2 in. This round knocked out the head of No. 1532. *In rear.*—One tap screw in pier broken.
1538	,,	,,	,, 248·7 lbs. Burster 5·69 lbs.	1274	2799	99·9	Struck the lower 6-inch plate (C1) 9 5 in. from top of plate, and 11 in. from its right edge. Diameter of hole 9 in. by 9·5 in. Indent 18·3 in. The bottom of the shell took a scoop out of No. 63 bolt, and drove it in. *In rear.*—Nil.
1539	,,	,,	,, 245·6 lbs. Burster 5 56 lbs.	1291	2838	101·3	Struck on the 6-inch plate (C2) 3 ft. 4 in. from right of C1, 1 ft. 1 in from bottom, and partly on No 78 bolt. Head of shell remained in hole 9 in by 9·25 in. Penetrated 14·5 in. The bolt stands 2·25 in. out from the plate, and is ovalled from the pressure. *In rear.*—Skin of pier slightly bulged (about $\frac{3}{16}$ inch) on left plank, and 5 tap screws broken off
1540	,,	,,	,, 249 5 lbs. Burster 5·69 lbs.	1287	2866	102·3	Struck the 4-inch plate (D) 2 ft. 3 in. from port, 2 ft. 4 in. from bottom and 11 in. from No. 1534. Diameter of hole 9 in. by 9 in. Head of shell remained in hole. Total penetration 19·8 in. The plate was buckled vertically on its right edge 0·25 in. and 0·5 in. on its left, both over 6 ft. and driven in round the shell hole. Maximum depth 0·6 in. The plate has also sprung forward at the port 0·25 in. *In rear.*—Mantlet skin-plate bulged slightly and driven back on the left of port, from in line with top of port to floor, where it has come back 3 in., and under port it has separated on left. A bolt near shell hole driven in against skin. The casing in sill and on left of port has separated slightly from the solid port forging; 22 rivets, &c., were broken off, some of which indented targets.
1541	,,	,,	,, 249 1 lbs. Burster 5·44 lbs.	1297	2906	103·7	Struck on the 4½-inch plate (E) 1 ft. 2 in from right of the plate, 6 ft. from bottom. Head of shell remained in hole. Diameter of hole 9·5 in. by 9·25 in. Total penetration 22·3 in. The shell

Photographic No. of Round.	Gun and Date of Experiment.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1541 contd.							struck half on and half off the pier, and drove up two of the channel irons 0·25 in. above top of plate. *In rear.*—Nil. On mantlet skin-plate being blown off by No. 1546, the skin was found to be bulged 1 in., and cracked vertically for 7·5 in. Washers of Nos. 56 and 85 bolts broken.
1550	9-inch rifled M. L. gun of 12 tons. 24 6 68	43 R. L. G.	Palliser shell, head 1·5 D, 21·5 ins. 249 9 lbs. 8·92 ins. Burster 5·87 lbs.	1295	2906	103·7	Struck on the lower 6-inch plate (C^2) 3 ft 10 in. from right of plate, 1 ft. 9 in. from bottom. Penetrated 16·3 in. The plate was buckled horizontally 1·2 in; the centres of this and No. 1509 are 10 in. apart, and the thin wall of metal between was crushed down on the latter. *In rear.*—13 rivets found broken. After this round the mantlet skin plate on right of, and under, port was removed. The inner skin was found to be bulged slightly in rear of last round, and the Baskcomb washer of No. 79 bolt broken.
1554	"	"	Palliser shot, head 1·25 D, 18·8 ins. 251 lbs. 8·92 ins.	1271	2812	100·3	Struck the 8-inch plate (A) 2 ft. 10 in. from right, 5 ft. 10 in. from bottom. Penetrated 15·6 in. Plate cracked through between Nos. 1536 and 1549, and the crack above No. 1536 increased 3 in. *In rear.*—Nil.
1555	"	"	"	1289	2892	103·2	Struck centre 6-in. plate on junction of C^1 and C^2 (half on and half off the pier) 5 ft, 9 in. from bottom, 2 ft. 8 in. from right of plate. Penetrated 1 5 in. The centre of shot was 1 ft. 3 in. from centre of No. 1544. No. 50 bolt on side of hole was much squeezed. Nearly all the shot remained in target partly broken up. *In rear.*—Five rivets broken off in joint plate of pier casing; the latter was a little more bulged. The India-rubber washer of No. 50 bolt was squeezed out.
1556	"	"	"	1296	2923	104·3	Struck near upper edge of lower 6-inch plate on junction of (C^1) and (C^2) 3 ft. from right of plate, 3 ft. 6 in. from bottom. Penetrated 19·3 in. No. 64 bolt was just at the lower edge of indent. Shot broke up and head remained in target slightly turned to right. The top edge of the plate was driven in 1·2 in. above indent. *In rear.*—Iron washer of No. 56 bolt broken.
1559	"	"	" 250 lbs.	1288	2876	102·6	Struck on the 4 inch plate (D) 1 foot 11 inches from port, 4 feet 4 in. from bottom. Diameter of hole 9·5 in. by 9 in. Shot passed THROUGH the target. The plate

Photographic No. of Round.	Gun and Date of Experiment.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1559 contd.							depressed round the hole about 0·75 in. *In rear.*—Shot passed through between two vertical cell plates. The 2 in. skin plate below shot hole bent back about 19 in. and driven back about 2 in. at floor line; 13 in. of skin plate above shot hole bent back at right angles. Angle iron of cell plate bulged. Bolts No. 55 and 69 broken and skin plate behind them bulged.
1572	9-inch M. L. gun of 12 tons. 8 7 68	43 R. L. G.	Palliser shot, head 1·25 D, 18·8 ins. 250 lbs. 8·92 ins.	1288*	2876	102·6	Struck on the top edge of centre 6-in. plate (C 1) 7 in. from right; top corner of plate bulged out 1·2 in. Diameter of hole 9·4 in. by 9·7 in. Shot penetrated into target and turned to right, 7 in. to base. Total penetration 25·8 in. The front lamina 2 in. thick separated away for a length of 17 in. on right top. No effect on top. *In rear.*—Nil.
1573	,,	,,	,,	1288*	2876	102·6	Struck 4½-in. plate (B) 7 ft. from bottom on No. 1543, 2 ft. 1 in. from proper right. The damage done joined that of No. 1543, and ran into the concrete, the direction was to the left. *On top.*— The channel iron on left of that pushed up by No. 1543 now pushed up 1⅜ in. *In rear.*—Nil.
1574	,,	,,	,,	1288*	2876	102·6	Struck 4½-in. plate (B) 2 ft. 3 in. from proper right of plate, 2 ft. 11 in. from top. Diameter of hole 9·2 in. by 9·4 in. Penetration into concrete 2 ft. 5 in. to base. *On top.* —Drove the channel irons up above plate; 1 and 2 were those moved by rounds Nos. 1543 and 1573, *In rear.*—Nil.
1542	10-inch rifled M. L. gun of 18 tons. 23 6 68	60 R. L. G.	Palliser shell, 27·3 ins. 400·6 lbs. 9·92 ins. Burster 9·62 lbs.	1256	4382	140·6	Struck on the 8-in. plate (A) 1 ft. 6 in. from right, 6 ft. 4 in. from bottom. Head of shell remained in hole. Diameter of hole 10·25 in. by 10·5 in. Penetration 32·1 in. (into the concrete of the pier). No. 29 bolt on right top edge of hole started forward 1·6 in. The plate buckled vertically 0·6 in. at level of shell hole Angle of penetration 88 deg. The plate also buckled 0·2 in. on its right edge, and the supporting angle iron started away 0·3 in. from the edge of the plate. Six angle iron rivets sheared. *In rear.*—Nil.
1543	,,	,,	400·5 lbs. Burster 9·5 lbs.	1258	4395	141·0	Struck the 4½-in. plate (B) 1 ft. 6 in. from its right edge, 6 ft. 2¼ in. from bottom. Penetrated 4 ft. 9·25 in. Plate buckled on its

* Calculated.

Photographic No. of Round.	Gun and Date of Experiment.	Charge and Powder.	PROJECTILE. — Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1543 contd.							right edge 0·2 in. in whole length. A channel iron in line with the shot forced up 1·5 in. above the top of plate. This round cracked the extra layer of concrete on the roof horizontally about 9 ft. back and loosened a large triangular piece of it over right top. The bitumen filling came oozing out through the shot hole. *In rear.*—Skin plate in rear of pier separated slightly, and angle iron forming pier and hood plate cracked through at a rivet hole.
1544	10-inch rifled M. L. of 18 tons. 23 6 68	60 Rifle L. G.	Palliser shell. 27·3 ins. 399·8 lbs. Burster 9·75 lbs.	1246	4304	138·1	Struck the centre 6-in. plate (C^1) 1 ft. 6 in. from right of plate, 5 ft. 9 in. from bottom, angle of penetration 86 deg. Penetrated 6 feet (into concrete pier). The plate driven in about 0·3 in. above the hole, and bolt hole of Palliser bolt No. 49 is ovaled. The right top corner of the plate started forward 0·4 in. *In rear.*—Left skin plate in flank of pier bulged at A; covering angle piece bent back from top to within 3 ft. 6 in. of ground, and all rivets in it sheared. Left face plate of pier also bulged at angle. On iron plate covering of nut No. 49 bolt being removed, the point of No. 1544 shell was found close to, and a little above, the opening.
1545	"	"	" 398·7 lbs. Burster 9·69 lbs.	1268	4445	142·6	Struck the centre 6-in. plate (C^2) 5 ft. 6 in. from right of plate, 7 feet from bottom. Diameter of hole 10 in. by 10 in. Shell passed THROUGH the target. A Palliser bolt No. 36 in the left bottom of hole was broken off 9 in. in from face of target through its head, which, as well as that of an old pattern bolt No. 23 (broken off 4·5 in.), fell in front of the target. The plate cracked in the right upper corner of port and driven down on to the lower one with sufficient force to indent the latter. *In rear.*—Shell penetrated and burst, filling the casemate with smoke; a great part of shell fell into the sea 150 yards in rear, and some pieces were picked up inside casemate. The mantlet skin plate was torn open and bent back on either side and at top and bottom of hole. The shell passed between two upright girders, the concrete between which, for a depth of 3 ft. below hole, was broken away. Palliser bolt, No. 36, with the exception of 9 in. of its head, was driven 24 ft. to the rear, and the iron washer of No. 52 bolt carried

Photographic No. of Round.	Gun and date of experiment.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of Shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1545 contd.							away. Numerous rivets and tap screws broken off and lying about the casemate. The bitumen between the stringers melted and dropped down into shell hole.
1546	10-inch rifled M. L. of 18 tons. 23 6 68	60 Rifle L. G.	Palliser shell, 27·3 ins. 400·6 lbs. 9·92 inches, Burster 9·62 lbs.	1262	4424	142·0	Struck the 4-in. plate (D) 1 ft. 8 in. from left of port, 7 ft. 3 in. from bottom of target. The shell passed THROUGH the target, bursting in doing so. Diameter of hole 10·5 in. by 10·5 in. No. 40 bolt had started 0·7 in. to the front. Angle of penetration 80 deg. (shell turned to left). The plate was buckled vertically on right edge 0·7 in. and 0·4 in. on left in line with shot, and 1 in. at 4 ft. from bottom. Bitumen oozed out of the hole. *In rear.* — Shell burst inside casemate after penetration. Almost all the mantlet skin-plate on left of port (9 ft. 6 in. by 3 ft. 6 in.) carried 36 ft. to rear. General damage very similar to that caused by last round. No. 40 bolt broken 6 in. from rear, and point of shell picked up 70 yards to rear.
1547	,,	,,	,, Burster 9·56 lbs.	1256	4382	140·6	Struck on the 4½-in. plate (E) 2 ft. 7 in. from proper left, 7 ft. 8 in. from bottom. Diameter of hole 9·75 in. by 10·75 in. Penetrated 5 ft. 8 in. into concrete of pier. It started the plate forward on the top about 0·25 in. next the 4-in. plate. *In rear.*—Pier slightiy shaken, and brickwork round edges separated from skin plate. Skin of pier on right face bulged, and 2 rivets broken off.
1565	,, 7 7 68	,,	,, 399 lbs, Burster 9·87 lbs.	1286	4576	146·8	Struck 4½-in. plate (E) 4 ft. from bottom, 2 ft. 5 in. from proper left of plate. Shell passed through into pier. Diameter of hole 10·2 in. by 10·5 in. *In rear.*—Skin-plate of face and flank of pier much bulged, opened out at angle 10·5 in. at 4 ft. from ground, 11 in. at 2 ft. from ground and 5 in. at 6 ft. high; joint cover fractured through line of rivet holes for 3 ft. 9 in. from ground; skin plate fractured for a length of 4 in. 5 ft. from ground. Nearly all concrete in pier apparently disintegrated and running through opening in pier.
1557	,, 24 6 68	,,	Palliser shot, head 1·5 D 24·5 inches, 401·5 lbs. 9·92 inches.	1251	4357	139·8	Struck the 8-in plate (A) 7 ft. 3 in. from bottom, 2 ft. 10·5 in. from right, and 1 ft. 5 in. from left. Penetrated 3 ft. 6 in. Diameter of hole 10·2 in. by 10 in No. 30 bolt at right bottom edge of indent started forward 1 in. The plate driven in on the left 0·5 in.

Photographic No. of Round.	Gun and date of experiment.	Charge and Powder.	Projectile, Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in foot tons.	Observed Effects.
		lbs.		feet.			
1557 contd.							in line with indent. Three rivets sheared in angle iron support. *In rear.*—Nil.
1558	10-inch rifled M. L. gun of 18 tons. 24 6 68	60 R. L. G.	Palliser shot, head 1·5 D, 24·5 ins. 401·5 lbs. 9·92 ins.	1269	4483	143·9	Struck on the junction of centre and lower 6-in. plates (C2) 2 ft. 8 in. from port, 4 ft. 3 in. from bottom, and between two bolts, No. 51 and 65. Shot passed THROUGH the target. No. 51 bolt only separated from the hole by 0·5 in. of metal, No. 65 bolt projected 1·1 in. *In rear.*—Shot passed through between two vertical cell plates carrying away a piece of skin plate; 20 in. of No. 51 bolt, with Baskcomb washer attached, found 21 in, to the rear; 2 ft. 6 in. of No. 65 bolt found 76 ft. to the rear. Head of shot went out to sea. Interior of casemate strewed with pieces of skin plate, rivets, &c.
1560	"	"	" 400 lbs.	1268	4459	143·1	Struck the proper right bottom edge of port, making a scoop. Shot glanced off and struck port stiffener, cutting a similar scoop out of it only 3 in. deep, and causing a crack 7 in. long in right hand inner corner. *In rear.*—Struck on right edge of port, glanced off and grazed sill, and broke up; the splinters deeply marking and breaking away the brickwork of arch on left of casemate, and knocking down two 7-in. plates, which had been placed in the open archway to close it. The angle iron at right bottom corner of port started back, several rivets broken and sheared in port hole.
1566	" 7 7 68	48 R. L. G.	" 401 lbs.	1187	3918	125·7	Struck 8-in. plate (A) 1 ft. 10 in. from bottom, 2 ft. 11 in. from right edge; shot penetrated 4·5 in. to base from face of plate. Diameter of hole 10·5 ins. by 10·25 in. Total penetration 28·9 in. No. 74 ordinary bolt broken off 4·5 in. from head, and plate cracked from indent to Nos. 1549-1551, and through the bolt hole of No. 74 to bottom of plate. The plate much cracked about the indent of No. 1549, and buckled; it forced the angle iron 2·25 in. away at the bottom, and sheared off sixteen rivets; the bottom of the plate 2·5 in. from face of B, at bottom, and 1 in. behind the same at level of No. 1551. Shot buried in target, base cracked in three. *In rear*—2 or 3 rivets in pier broken off, and brickwork foundation rather more shaken than before.

Photographic No. of Round.	Gun and Date of Experiment.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in foot tons.	Observed Effects.
		lbs.		feet.			
1567	10-inch rifled M. L. gun of 18 tons. 7 7 68	48 R. L. G.	Palliser shot, head 1·5 D, 24·5 ins. 400 lbs. 9·92 ins.	1173	3816	122·5	Struck $4\frac{1}{2}$-in. plate (B) 1 ft. 5 in. from bottom, 1 ft. 6 in. from proper left of plate. Diameter of hole 10·25 in. by 10·5 in. Penetration 23 in. to inside of core. Shot turned to right. Total penetration about 31·46 in. The plate slightly cracked down on right from No. 1532. *In rear.*—A few more rivets in pier broken, and brickwork slightly more shaken.
1568	,,	,,	,,	1170	3797	121·8	Struck 6-in. plate (C^1) 2 ft. from bottom, 1 ft. 7 in. from right edge. Diameter of hole 10·2 in. by 10·4 in. Plate cracked through on right, and from No. 64 bolt hole to No. 1550. Total penetration 39·5 in. Shot broke up. *In rear.* — Iron washer plate (lowest) in left face of pier thrown 4 yards to rear Brickwork, &c., inside pier broken up slightly. Base of skin plate bulged 2 in.
1561	12-inch rifled M. L. gun of 23 tons. 24 6 68	76 pellet.	Palliser shot, head 1·25 D. 25·2 ins. 559 lbs. 11.92 ins.	1171	5696	152·1	Struck 4-in. plate (D) between Nos. 1540 and 1553. Shot passed THROUGH the target. The plate was cracked between No. 1540 and left edge of plate, and also between No. 1553 and right edge. Nos. 1561 and 1540 formed one hole, but a skin of metal remained between Nos. 1553 and 1561, probably due to the fact that nearly all the head of No. 1553 remained in the hole. The concussion on the target broke off large fragments of the granite base, cracked in previous experiments. The pieces broken off measured about 2 ft. by 2 ft. by 1 ft. 4 in., and 1 ft. 4 in. by 3 ft. 9 in. by 1 ft. 1 in., both 21 in. deep. *In rear.*—Passed through target below No. 1559; cell plate driven back, and only holding by about 6 in. of its top. The cell plate on the left of shot hole was also bulged and broken. Left cheek of port bulged about 0·5 in. at bottom, and 7 rivets broken in it. No. 84 bolt, pieces of plate, &c., carried to the rear. The head and great part of shot buried itself in bank about 50 yards to the rear.
1548	15-inch S. B. Rodman of 19 tons. 23 6 68	$83\frac{1}{4}$ R. L. G.	Solid Cast-iron (American) spherical shot, 451 lbs., 14·89 inches.	1376	5921	126·6	Struck the junction of the upper and centre 6-in. plate (C^2) 2 ft. 6 in. above port, and 1 ft. 11 in. from the left edge of the plates. Indent 7·7 in. Diameter 17 in. by 17 in. The upper plate sprung forward at the top 1·8 in. and forced up 0·5 in.,

Photographic No. of Round.	Gun and date of Experiment.	Charge and powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1548 contd.							thus shearing No. 16 Palliser bolt 6 2 inches in. The centre plate sprung forward also 1·5 in. at port, and downwards 1 in. on left of port. The plate was cracked in indent up to No. 25 bolt, and a disc of metal about 10 in. in diameter was partly detached in centre of indent. The shot rebounded about 20 ft. Diameter of shot after firing 12·61 in. by 14·61 in. *In rear.*—Mantlet skin plate above port bent back 9 in. at bottom, and angle iron over port bulged 3 in. Stringer plate over port cracked through, washer of No. 25 bolt broken. Nearly all rivets, &c., over port broken.
1549	15-inch S. B. Rodman of 19 tons. 23 6 68	83¼ R.L.G.	Solid Cast-iron (American) Spherical shot, 452·5 lbs., 14·89 inches.	1381	5984	127·9	Struck 8-in. plate (A) 2 ft. from right, 2 ft. 8 in. from bottom. Indent 4·35 in. Diameter of hole 17·5 in. by 17 in. The plate was buckled 1 in. in its length. The supporting angle iron driven off edge of plate for a length of about 8 ft., and 10 of its rivets sheared. *In rear.*—Eight tap screws from right face of pier driven out, brickwork at base of pier cracked, and pier shaken at its junction with the Plymouth Breakwater pier.

TABLE IX.

CASEMATE WITH IRON FRONT OF CELLULAR CONSTRUCTION.

Penetration of the various Projectiles in different Parts of the Front.

Sections supported by the Piers.

Nature of Sections.	7-inch.		9-inch.		10-inch.		Remarks.
	200 Yards.		200 Yards.		200 Yards.	1000 Yards.	
	Shell.	Shot.	Shell.	Shot.	Shell.	*Shot.	
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	
A. 8-in. (solid plate)....	8·45 ‖1530	8·75 ‖1551	13·0 ‖1536	15·0 ‖1554	32·1 ‖1542	29·96 ‖1566	Penetration 42 in. for 10-in. shot with full charge, round No. 1557.
B. do. (4½-in. as plate on 3½-in. as stringer.)	13·5 ‖1531	16·18 ‖1570	21·3 ‖1537	†29 to 42 ‖1574	57·25 ‖1543	31·46 ‖1567	† 29 in. to base of shot.
C¹. do. (6-in. as plate on 2-in. as stringer.)	‡22·0 ‖1569	11·0 ‖1571	18·3 ‖1538	§25·8 ‖1572	72·0 ‖1544	39·5 ‖1568	‡ Near other indents. § Vide plan; greater strength than normal.
E. Part same as B. .... (nearly)	14·0 ‖1535	—	—	22·3 ‖1541	—	—	
E. 4½-in. plate, without stringers.	—	—	—	68·0 ‖1547 72·0 ‖1565	—	—	

* Charge reduced.

Sections supported by the Wall between the Piers.

Nature of Section.	7-inch.		9-inch.		10-inch.		Range 200 Yards.
	Shell.	Shot.	Shell.	Shot.	Shell.	Shot.	Remarks.
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	
C². 6-in. plate on 2-in. stringers.	—	—	*14·5 ‖1539	—	Through	—	* Close together.
	10·5 ‖1533	12·6 ‖1552	16·3 ‖1550	19·3 ‖1556	— ‖1545	—	
D. 4-in. plate on 4 in. as stringers.	13·25 ‖1534	11·3 ‖1553	19·8 ‖1540	†Through ‖1559	Through ‖1546	—	† Backing injured by round 1546.

Those Figures prefixed by a ‖ denote the Photographic Numbers of the Rounds.

TABLE X.

CASEMATE WITH IRON FRONT OF CELLULAR CONSTRUCTION.

Abridgment of Results of Practice, 23rd, 24th June, and 7th, 8th July, 1868.

Round.	Projectile.	Part of Target.	Indent.	Diameter.	Buckle.	Effect. In Rear.	Effect. On Bolts.	Effect. On Washers.	Remarks.
	7-in. Shell—113 lbs. Charge, 22 lbs.								
			in.	in.	in.				
1530	Burster 2¼ lbs. Head 1·5	A	8·45	7·25	..	Nil.			
1531		B	14	7·25	..	Do.			
1532		B & C¹	8·75	7·25	..	Do.			
1533		C²	10·5	7·25	..	6 tap-screws off mantlet.			
1534		D	13·25	7·25	..	7 Do. Do.			
1535		E	14	..	·2	1 Do. Do.	No. 71 started 0·6 in. at head.		
1569		C¹	22	7·25	..	Nil.			
	7-in. Shot.—115 lbs. Charge, 22 lbs.								
			in.	in.					
1551	Head 1·25	A	8·75	7·5	..	Nil.			
1570		B	16·2	..	..	Do.			
1571		C¹	11	..	..	Do.			
1552		C²	12·6	..	..	Inner skin bulged 0·6 in.	No. 84 broken.	....	Front plate separated 2 in. from port frame.
1553		D	11·3	..	..				
	9-in. Shell—244 lbs. Charge, 43 lbs.								
			in.	in.	in.				
1536	Burster 6 lbs. Head 1·5	A	13	9·2	..	Nil.			
1537		B	21·3	9	·2	1 tap-screw off mantlet.			
1538		C¹	18·3	9·2	..	Nil.			
1550		C²	16·3	..	..	13 tap-screws off mantlet.			
1540		D	19·8	9	..	20 Do. mantlet Burst.	....	....	Vertical stringer plate cracked.
1541		E	22·3	9·5	..	Nil.			
1539		C¹ & C²	14·5	..	..	4 tap-screws off mantlet.	No. 78 driven out 2 in.	....	Pier slightly buckled.
	9-in. Shot—250 lbs. Charge, 43 lbs.								
			in.	in.	in.				
1554	Head 1·25.	A	15	..	..	Nil.			
1574		B	39·4	..	..	Do.			
1573		B	?	..	..	In hole of 1543.			
1572		C¹	25·8	..	..				
1555		C¹ & C²	17	..	..	5 rivets off pier.	....	No. 56 broken.	
1556		C¹ & C²	19·3	9·2					
1559		D	Through.			Opened out inner skin from 1546 to bottom.			

TABLE X. (Continued.)

Round.	Projectile.	Part of Target.	Indent.	Diameter.	Buckle.	Effects: In Rear.	Effects: On Bolts.	Effects: On Washers.	Remarks.
	10-in. Shell—390 lbs. Charge, 60 lbs.								
			In.	In.	In.				
1542	Burster 10 lbs. Head 1·5	A	32·15	10·25	·6	Nil.	No. 29 driven out 1 ft.		
1543		B	57·25	10	..	Top band of pier cracked.	....	....	Channel iron backing pushed up 1·5 in.
1544		C1	72	10	..	Bulged skin of pier, split band, 15 rivets off.			
1545		C2	Through.			Carried away rear skin, &c, between stringers	Nos. 36 sheared, 23 broken.	No. 52 broken.	Hole in mantlet 3 ft. by 2 ft.
1546		D	Through.			Do. Do. Do.	Nos. 40 and 84 broken.	Nos. 54 & 85 do.	Do. Do. 3 ft. by 1 ft.
1547		E	59	..	..	Bulged pier, broke 2 rivets.			
1565		E	?	10·2	..	Split pier, and let out concrete.			
	10-in. Shot—400 lbs. Charge, 48 lbs.								
			In.	In.	In.				
1566	Head 1·25.	A	29	..	..	Nil.	No. 74 broken.		
1567		B	31·46	..	..	Do.			
1568		C1	39·5	..	..	Bulged pier, 2-in. driven off, cover plate.			
	10-in. Shot—400 lbs. Charge, 60 lbs.								
			In.	In.	In.				
1557	Hd. 1·25.	A	42	..	..	Nil.			
1558		C2	Through.			Skin broken over 5 ft. by 3 ft. 4 in.	Nos. 51 and 65 broken.		
1560		C2	..	..	..	Glanced on side of port.			
	12-in. Shot—600 lbs. Charge, 76 lbs.								
1561	H. 1·25	D	Through.			....	Nos. 55 and 69 carried away.		
	15-in. Shot—451 lbs. Charge, 83¼ lbs.								
			In.	In.	In.				
1548	Hd. ·5.	A	4·35	17	..				
1549		C2	7·7	17	..	Mantlet started.	....	No. 25 broken.	

V.—Gun Shield made at the Millwall Iron Works.—Pl. VII.

Before commencing the technical description of this shield, it may be well to give some account of its origin and gradual development.

As originally designed by the Millwall Iron Company, in 1864, it was to consist of $6\frac{1}{2}$-in. front armour plates, backed by horizontal bridge rails 7 in. deep, attached to a double skin composed of two $\frac{3}{4}$-in. plates, to the rear one of which were to be riveted vertical bridge rails of smaller section than the others. The shield was to be supported by struts similar, in principle, to the War Office pattern. The material thus intended for the shield front would have been equal, in weight, to about 11 inches of solid iron.

This design was afterwards altered, and the shield, as first made, had a 9-in. front plate on the lower half, and a 6-in. plate on the upper half; but the latter was faced, over the larger part of its surface, with three layers of 1-in. plate. The 7-in. stringers, immediately behind the armour, and the two $\frac{3}{4}$-in. skins were retained; but the rear bridge rails, which before were shown only 3 inches deep, were now replaced by 7-in. rails, their ends being supported by a top and bottom horizontal flat plate attached to the struts. The struts were much the same as before, but heavier. Thus, that portion of the shield which was faced with 9 inches of armour contained an equivalent to 15 inches of iron. The portion faced with 6 inches of armour had about 12 inches of iron altogether.

The weight of the shield, as thus made, was 30 tons 1 cwt. 2 qrs.

In carrying out the work an error was made in the position and dimensions of the port, by which the space necessary for the training and elevation of the gun was seriously encroached upon.

After it had been thus completed, and when the trials of the shield called the "Gibraltar Shield," already detailed, had taken place, the Millwall Iron Company asked for permission to strengthen their shield. This was granted, and additions, which will be found included in the following description, were made to it. The total weight of the shield was now made up to 37 tons 10 cwt.; the material in the lower portion being equivalent to 23·8 inches of iron, while that in the 6-in. portion of the upper half was equivalent to 20·6 in. of iron. By these additions the space for the gun was still further restricted.

A description of the shield as set up at Shoeburyness for trial, will now be given:—

Plate VII may also be referred to.

The front was of the usual dimensions, 12 ft. 2 in. by 8 ft. It contained a port 3 ft. high by 2 ft. in width, the lower sill of it being 2 ft. from the bottom of the shield.

The shield and port were so laid out that a 9-in. 12-ton gun would train laterally 33°, elevate $1\frac{1}{2}$°, and depress 5°. A 10-in. 18-ton gun would train 31°, and depress 5°, but would not elevate at all.

However, by lowering the racers on which the gun trained a little below the bottom of the shield, a degree or two more elevation might have been obtained, at the sacrifice of depression.

Commencing with the front, there were two principal armour plates, each 12 ft. 2 in. long and 4 ft. wide, running horizontally, half the port being taken out of each. The lower plate was 9 inches thick, the upper 6 inches. Over a portion of the face of the upper plate there was a covering composed of three single 1-inch plates slightly riveted together. This covering occupied the proper right hand upper quarter of the front, and was continued over the port and a little beyond it. By this arrangement it was intended to ascertain the power of resistance of a 6-inch plate on the principle adopted in this shield, as compared with that of a 9-inch plate under similar circumstances, and also to show the effect of adding the laminated plates on the face of the 6-inch armour.

Immediately behind the main armour plates there were bridge rails or "hollow stringers," as the patentees call them, 7 inches deep, running horizontally, with their heads to the front, and their feet riveted to a double skin composed of two $\frac{3}{4}$-inch plates. The spaces between these rails were filled with timber, and each had a **T** iron bedded in the wood, with its top member to the front, so as to be in contact with the back of the front armour. To form the sides of the port there were two forged pieces about $3\frac{1}{2}$ inches thick, tongued into the back of the front armour plates, and secured to the backing of the shield as shown in the drawing. At either end of this compound mass, and at the top and bottom of the port, there were angle irons fitted and riveted to close in the whole.

In rear of the double $\frac{3}{4}$-inch skin before mentioned, and on either side of the port, there were three vertical bridge rails riveted to the skin, with their feet to the front, and above as well as below the port there were others running horizontally. The hollows of the two vertical rails next to the port were filled up solid with wrought-iron bars.

The struts forming the supports to the shield were, as usual, at either end of it, and of the usual outline. They were composed of $1\frac{1}{2}$-inch webs, stiffened with $7\frac{3}{4}$-in. by 6-in. by 1-in. angle irons. They were protected on the front by $2\frac{1}{4}$-in. plates, 21 in. wide, and were strongly riveted to sill pieces, 17 in. by $2\frac{5}{8}$ in., in the floor, running to the front under the shield, and to the rear abutting against, and connected by plates with, a cross beam in the floor, $12\frac{1}{2}$ in. by $2\frac{5}{8}$ in., and 13 ft. long.

At the top and bottom of the shield in rear, there were two 2 in. plates, laid flat-ways, with their edges bearing against the skin. The lower of these was 20 inches, the upper one 16 inches wide, and to them were riveted angle irons, bearing against the back of the skin and against the bridge rails. These plates were attached at their ends to the struts.

Taken thus far, this account describes the shield as first completed and sent to Shoeburyness. The subsequent additions, already referred to, were as follows :—

In rear of the inner set of bridge rails a plate $1\frac{1}{4}$ inch thick was added to all the centre part of the shield, with an opening left in it for the port; attached to this, both above and below the port, and stretching from strut to strut, there was a sort of double-box girder, about $13\frac{1}{4}$ in. deep, made up of ⊢⊣ girders with one or more of their front flanges cut off, as shown in the plate, and $1\frac{1}{4}$ in. plates riveted to their back flanges.

On either side of the port there were vertical single-box girders, similarly composed, and framed into the double boxes. On the back of these there was an additional 1 in. plate riveted, and this overlapped the $1\frac{1}{4}$ in. plate on the back of the horizontal box girders. On either side of the port, and between it and the vertical boxes, there was a sort of washer piece, about 12 in. wide and $2\frac{1}{2}$ in. thick.

All these box girders, as well as the spaces between the rear set of bridge rails, were filled with timber.

The total weight of the shield as before stated was $37\frac{1}{2}$ tons.

The armour bolts were 34 in number. The greater part of them were made under the patent of a Mr. Parsons. Their outside diameter was $3\frac{1}{2}$ inches, and they had conical heads, the larger diameter of which was 5 inches. The head and shank were bored out to within a short distance of the thread, the cross section of the bore being made equal to the ring of metal cut away between the threads of the screw. The end of the bore at the head was plugged to make it solid again.

The object of this construction was the same as that of Major Palliser in reducing the shank of his bolt externally; Mr. Parsons, however, expected that the strength of his bolt to resist transverse, and shearing, strains would be less diminished than in Major Palliser's plan.

On either side of the port there was one hammer-headed bolt, which did not come through the front armour.

It was originally intended that, at that part where the three layers of 1-in. plate were added on the face of the shield, bolts, hollow all through, should be used to secure the 6-in. plate, and that through these tubular bolts should pass the lesser bolts to hold on the three 1-in. plates. The object of this was to test a method by which it was thought that an iron front could be at any time strengthened by adding fresh layers of armour, without any great outlay in alterations to the fastenings. But this plan had to be abandoned, except in the case of two bolts, because Mr. Parsons' principle would not admit of the bolts being made hollow throughout.

The bolts generally were provided both with wood-washers fitted to shallow iron cups, and hexagonal cups with india-rubber washers in them.

The trials took place at Shoeburyness, on 16th July and 22nd September, 1868.

The guns used were the 9-in., 10-in., and 12-in. rifled muzzle-loading guns, and the 15-in. smooth-bore Rodman gun.

They were placed in battery at 70 yards from the shield.

The 9-in. gun fired 5 rounds, with charges reduced to represent full battering charges at a range of 400 yards, and 3 rounds with full battering charges.

The 10-in. gun fired 1 round with a charge to represent 400 yards, and 2 rounds with full battering charges.

The 12-in. gun fired 4 rounds with charges to represent full battering charges at 200 yards.

The Rodman fired 1 round with a charge of 50 lbs. English powder to represent 60 lbs. American powder, and 1 round with $83\frac{1}{4}$ lbs. English to represent 100 lbs. American powder.

There were thus 17 rounds in all, not counting a 10-in. shell and a 9-in. shell which broke up in the guns, fragments only striking the shield.

Putting, for the present, out of the question altogether the radical defects in the laying out of the shield, and dealing only with the actual resistance it offered in the trial, it must be admitted that it was more than a match for the guns.

The Committee, composed as for the iron casemate trials, said in their report, that at the end of the first day's firing, that is, after 13 rounds from the 9-in., 10-in., and 15-in. guns, the shield was in a perfectly serviceable condition, and complete penetration had not been effected. After the second day's practice, when the 4 rounds from the 12-in. gun had been fired, they said that on the whole the resistance of the shield, even against the 12-in. gun, had been satisfactory.

Speaking of the front of the shield, after the first day's firing, it was found that the greatest penetration effected on a sound spot was 22 in. (Round 1594.) At this round the 9-in. armour plate, which at a previous round had commenced to separate into two $4\frac{1}{2}$ in. plates, was now split into halves for the greater part of its length, these halves separating again in places into $2\frac{1}{4}$ in. plates.

In rear, the damage was described as follows :—

One bolt (No. 5) driven out and projected 10 yards to the rear. Two hammer-headed bolts driven back; several of the cup washers broken; the angle iron of the strut on the right side, and of the base plate, cracked; the plate below the port slightly bulged, and several rivet heads sheared off.

The hollow bolts gave the Committee entire satisfaction, the unusual weight and solidity of the shield being, however, in their opinion, greatly in favour of the fastenings.

After the second day's practice, the Committee reported that the object of this further trial was to test the resistance of the construction against the 12-in. gun of 23 tons, especially in the neighbourhood of the ports; and, with this view, two 12-in. Palliser shot were fired, one at each side of the port, and so directed as to hit at about 12 in. from the edges, where, owing to the splay of the port necessary to allow for traversing, the structure did not derive immediate support from the iron hollow stringers in rear. Although the first round (No. 1596), which struck so close to the proper left edge of the port, did considerable damage, the effect was not greater than was to have been anticipated under such circumstances.

The injuries produced by this day's practice will be seen in the detailed report of rounds 1596, 1597, 1598, and 1599.

As the results of a trial of this nature are intelligible only when put in comparison with others obtained under similar circumstances, reference should be made to the report of the trial of the target representing H.M.S. " Hercules," at her water line, particularly the third round, with chilled shot from the 13-inch gun, (p. 125, Volume XVI of these Papers); remembering that that target contained by weight, per foot superficial, only about two-thirds of the present one. Also, the effects may be compared with those produced on the 20-inch portion of the Plymouth Breakwater target already reported in this paper, the greater part of the present shield exceeding by weight the strengthened portion of that target. There has been as yet no other shield tried in this country which, either in respect of cost or quantity of material employed, can, with any fairness, be compared with the present one.

Speaking of the defects in the laying out of this shield, as already noticed, the Committee considered that the port did not admit of a sufficient amount of training and elevation for practical purposes.

To correct this, it would be necessary to enlarge the port, place it higher up in the shield, alter its splay, and otherwise modify the central parts of the shield, as well as the struts; in doing which a somewhat extensive departure from the present design would be involved.

In this view of the matter, and looking to the quantity of perishable material used in the construction of this shield, it is to be feared that the experiment will not of itself afford the means of determining the best construction for the gun shields of the future.

TABLE XI.

Gun Shield made at Millwall Iron Works.—Report of practice on 16th July, 1868.

Photographic No. of round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, Total Weight, and Diameter.	Striking velocity.	Total Energy in Foot Tons.	Energy per Inch of Shot's Circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1581	9-inch rifled M. L. gun of 12 tons.	37 R. L. G.	Palliser shot, head 1·25 18·8 inches, 249 lbs. 8·92 inches.	1254	2715	96·9	Struck on lower plate (9-in.) 3 ft. 6 in. from right, 1 ft. 7 in. from bottom. Head of shot remained in target. Total penetration 10 inches. Diameter of hole 9·2 in. by 9·5 in., ripple round hole averaging 1·5 in., with outer lamina flaked away in places. Horizontal buckle 0·5 in. below shot hole. Whole structure driven back 1·4 in. on right, 0·5 in. on left. *In rear.*—No other effect except that the India rubber was squeezed out of the Baskcomb cup washers of the bolts near the place of impact.
1582	"	"	" 249·5 lbs.	Not obsvd.	2715	96·9	Struck upper plate (6 in.) 3 ft. 2 in. from left, 2 ft. 11 in. from top, shot remained in target (partly broken up) base projecting. Total penetration 14·3 in., plate buckled horizontally 0·5 in. between port and left side below and above the indent. The buckling of this plate left a space between it and the cheek plate on left side of port. The target moved back 0·4 in. on left, and forward 0·5 in. on right. *In rear.*—Baskcomb cup washer of No. 15 bolt broken; washer plates of Nos. 7, 8, 10, and 12 bolts bent; India-rubber squeezed out of all bolts on left of shield.
1583	"	"	" 250 lbs.	1251	2713	96·8	Struck upper right corner (on the 6-in. plate faced by three 1-in. plates) 21·5 in. from top, 1 ft. 6 in. from right. The shot struck partly on No. 5 bolt, which broke off 10 in. in, the head of the bolt was thrown to the front about 75 yards, opened out to 9 in., the remainder of the bolt was visible in point of indent. Penetration 12·8 in. A small bolt (*i.e.*, one of those attaching the 1-in. plates) was broken off at head, just above the indent. The front 1-in. plate broken through, all round No. 1 bolt, peeled up from the others nearly up to No. 9 bolt, and cracked horizontally for a length of 10 in. from left of that bolt. On the right of the target, the front 1-in. plate was cracked horizontally at 6 in. and 12 in. from top. The 2nd at 18 in., and the 3rd at 3 in., 11 in., and 20 in. The 6-in. plate had sprung forward 0·7 in. from the stringer backing, on the top of target. The 6-in. plate was

Photographic No. of round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, Total Weight, and Diameter.	Striking velocity.	Total Energy in Foot Tons.	Energy per Inch of Shot's Circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1583 contd.							buckled 0·5 in. on its whole length, and there was a separation of 0·25 in. between right strut and top plate. The shot rebounded 9 ft., with half of the cylindrical portion broken longitudinally. *In rear.* — No. 5 bolt driven back 6 in. Rivet head on left of No. 5 bolt sheared and thrown 6 yards to rear, the heads of the rivets below No. 17, and above No. 10 bolts, also sheared. Baskcomb cup washers of Nos. 19 and 29 bolts broken, and the India-rubber squeezed out of all bolts near shot.
1584	9-inch rifled M. L. gun of 12 tons.	37 R. L. G.	Palliser shot, head 1·25 18·8 inches, 251 lbs.	1234	2650	94·6	Struck the 9-in. plate 3 ft. 9 in. from left, and 2 ft. 2 in. from bottom. Pentrated 9·9 in. Shot rebounded 10 in. from target with the body broken. Diameter of hole 9·4 in. by 9·2 in., and plate buckled in 0·5 in. round it, and consequently bolts No. 21 and 24 stood away that much from plate. The target was now back 1·5 in. on left and 1·2 in. on right fromits original position. *In rear.*—Baskcomb cup washers of Nos. 18 and 24 bolts broken. A piece of one of them was projected 40 yards to right rear. India-rubber squeezed out of all bolts near shot hole.
1586	"	43 R. L. G.	Palliser shell, head 1·5 20 inches, 250·75 lbs. 8·92 inches, Burster 2·75 lbs.	1310	2984	106·5	Struck the top of the 9-in. plate 2 ft. 10 in. from right, and 3 ft. 7 in. from bottom of target. Diameter 9 in. by 9·4 in. Indent 12 in. The stringer backing was visible at the joint of the 1-in. plate, owing to the 9-in. plate being broken away there. The plate was driven up 1½ in. above the indent, and cracked through to the top edge. This driving up of the 9-in- plate had rippled up the front 1-in. plate. Horizontal buckle of 9-in. plate 0·7 in. below indent. The shell burst, and head flew back on the right side of the target. The target was now 2·3 in. on left, and 1·3 in. on right back from original position. *In rear.*—Hammer-headed bolt driven back about 1·5 in.; slight shaking at joints of shield; no other effects.
1587	"	"	" 248·6 lbs. Burster 2·625 lbs.	Not obsvd.	2984	106·5	Struck the 6-in. plate 2 ft. 6 in. from left, 1 ft. 7 in. from top. Head of shell remained in target. Total penetration 10·4 in. Plate driven in 0·5 in. all round the indent. The concussion broke off the heads of 2 more small bolts fastening the three 1-in. plates.

Photographic No. of round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, Total Weight, and Diameter.	Striking velocity.	Total Energy in Foot Tons.	Energy per Inch of Shot's Circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1587 contd.							On top, the upper horizontal stringer was cracked in web for a length of about 10 in. *In rear.*—Nil.
1588	9-inch rifled M. L. gun of 12 tons.	37 R. L. G.	Palliser shell, head 1·5 20 inches, 248·6 lbs. Burster 8·92 inches, 2·625 lbs.	Not obsvd.	—	—	Shell burst in gun. The fragments indented the target in places.
1589	,,	,,	,, Burster 2·687 lbs.	,,	2715	96·9	Struck on the junction of the 6-in. and 9-in. plates, 3 ft. from left, and 3 ft. 11 in. from bottom. Diameter 9 in. by 10 in., of which 6·5 in. was on the 9-in. plate. Indent 12 in.; horizontal buckle below indent 1·2 in. The 6-in. plate was bulged up and out, with a lip projecting 2 in. The 9-in. plate was separated into two 4·5 in. thicknesses, the separation extending from left side of port up to and for 1 ft. 1 in. beyond the indent, namely, for a length of about 3 ft. 6 in. On the left cheek of the port, the front mould had slipped 0·4 in. to right of rear mould. On the left of the target the plates had buckled away from backing. *In rear.*—Hammer-headed bolt driven back about 1 in. No other apparent effect.
1590	,,	43 R. L. G.	Palliser shot, head 1·25 18·8 inches, 251 lbs. 8·92 inches.	,,	2984	106·5	Struck on the 6 in. plate faced with the three 1 in. plates on the left edge of No. 1583, 21 in. from right and 21 in. from top; the two indents formed into one with a horizontal diameter of 1 ft. 3 in. Shot buried in the target, 6 in. in to base, making a total penetration of 24·8 in. The front 1 in. plate a great deal bulged, and the cracks from No. 9 bolt extended to 21 in. The shot, on entering the backing, broke and forced out a piece 12 in. long of the 3rd horizontal stringer, and drove it, together with a T iron, 20 yards to the right; and in doing so broke away, on the right, the side plate for a length of 3 ft. 10 in. down the angle iron, the strip broken off standing out from target. The top horizontal stringer was forced up about 1 in. in 2 ft., and buckled forward 2 in. in 3 ft. 6 in., and broken through at the lower flange. The 2nd horizontal stringer was also forced up and cracked longitudinally in both flange and web, and one of its rivets sheared. The 4th stringer and T iron was somewhat jammed down, and the wood packing splintered.

Photographic No. of round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, Total Weight, and Diameter.	Striking velocity.	Total Energy in Foot Tons.	Energy per Inch of Shot's Circumference in Foot Tons.	Observed Effects.
1590 contd.		lbs.		feet.			*In rear.*—No. 5 bolt driven out and carried 10 yards to the rear, passing through 2-in. wooden target. It was found behind the "Samuda" target, with its head broken off, and the washer shifted to the front. Baskcomb cup washers of Nos. 9, 11, and 19, and small bolt above No. 9 broken, and the wood packing on the right of the small bolt splintered. On the right side, the angle iron of strut broken in half just above No. 1 bolt, and cracked through at opposite angle, at a rivet. The strut had moved back 2 in. from the vertical 2-in. plate between it and the shield. Angle iron bulged 0·5 in.
1591	10-inch rifled M. L. gun of 18 tons.	54 R. L. G.	Palliser shell, head 1·5, 27·3 inches, 399 lbs. 9·92 inches, Burster 10 lbs.	Not obsvd.	4027	129·2	Struck the bottom edge of the 9-in. plate 4 ft. 9 in. from right; it cut a scoop out of the plate. Shell, after striking, was deflected down and passed out under target. The target was now back 1·5 in. on both sides from original position. *In rear.*— Shell passed under shield, and burst in doing so, excavating a hole 5 ft. by 2 ft. 6 in. by 14 in. deep, in which were fragments of the shell, and of the wood packing between stringers. The chilled iron block resting on foot plate of left strut was thrown over, and the wooden target in rear shield blown to pieces, and thrown about 15 yards to rear. The angle iron of base plate was cracked through a rivet hole, and one rivet head sheared off.
1592	"	60 R. L. G.	" 397·75 lbs. 9·92 inches. Burster 9·75 lbs.	"	4519	145·0	Struck on the junction of the 9-in. with the 6-in. faced with the three 1-in. plates, 3 ft. 1 in. from right, 4 ft. from bottom, and on upper half of indent No. 1586. The head of the shell remained in target. Total penetration 19 in. The two holes were knocked into one, with a major diameter of 1 ft. 3 in., 3 in. of which was on the upper plate and the plates were then 1·2 in. apart; the 9-in. plate was cracked round the hole. The head of the shell remained in hole. In the port, the 9-in. plate was buckled forward 0·5 in. from stringer backing. *In rear.* – Hammer-headed bolt was now driven back 6·25 in. Baskcomb washers of Nos. 12 and 23 bolts broken; a rivet head on left of No. 25 bolt sheared off. The additional backing piece (viz., that added to the shield since its arrival at Shoeburyness) seemed to have started slightly to the rear.

Photographic No. of round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking velocity.	Total Energy in Foot Tons.	Energy per Inch of Shot's Circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1593	10-inch rifled M. L. gun of 18 tons.	60 R. L. G.	Palliser shell, head 1·5 27·3 inches, 397·69 lbs. 9·92 inches. Burster 9·69 lbs.	Not obsvd.	—	—	Shell burst in gun. Head struck target with a "splash" on lower edge of 9-in. plate 6 ft. 9 in. from right; splash measured 14 in. by 12 in., and about 4 in. deep. The shock broke off the left hand top small bolt of the three 1-in. plates. *In rear.*—Nil.
1594	"	"	" 399·12 lbs. Burster 9·62 lbs.	"	4519	145·0	Struck the 9-in. plate below the port 6 ft. 1 in. from right, 12 in. from bottom. Penetrated 22 in. The shock broke off a piece of the front 4·5 in. mould on bottom right of indent. The separation of the front 4·5 in. mould was now continued along the bottom and right side of port and on top of plate up to No. 1586, and along the bottom from bolt No. 30 nearly to No. 31, a length of about 6 ft. In sill of port this front mould was 0·5 in. above the rear one. In addition to the separation of the 9-in. plate into distinct 4·5-in. plates, each of these latter was separated into two 2·25-in. plates, visible on the top of the plate on each side of the indents Nos. 1586 and 1592; these separations did not extend for more than a few inches in each case. The head of the shell remained in target. Horizontal buckle of 9-in. plate 2·2 in. on right and 2 in. on left of indent. The target was now 3·5 in. on left and 3 in. on right back from original position. *In rear.* — Plate below port bulged between Nos. 26 and 27 bolts, and a rivet head sheared off. Baskcomb cup washer of No. 27 bolt broken; 7 rivets broken out of angle iron of base plate, which is cracked in two places through rivet holes.
1585	15-inch Rodman S. B. gun.	50 R. L. G.	Spherical solid shot (American) 451·5 lbs. 14·89 inches.	1156	4182	89·4	Struck the 9-in. plate 2 ft. 6 in. from left, and 1 ft. 7 in. from bottom, taking a scoop 4·5 in. wide out of No. 24 bolt, and making an indent of 3 in. Indent and buckle 3·9 in. over 40 in., buckle in whole length of plate 1·2 in. Target now back 2·8 in. on left and 1·2 in. on right from its original position. Nos. 24, 28, and 31 bolts stood out from plate 1·1 in., 0·5 in., and 1 in. respectively, in consequence of the latter having been driven in round the indent. The shot rebounded 6 ft., partly broken and set up to 12·4 in.

Photographic No. of Round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per Inch of Shot's Circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1585 contd.							*In rear.*—Shield driven back on left, overturning chilled iron block which was resting on strut foot plate, and breaking bolt holding down the iron. Baskcomb cup washer of bolt above No. 18 broken.
1595	15-inch Rodman S. B. gun.	83¾ R. L. G.	Spherical solid shot (American). 455 lbs. 14·89 in.	Not obsvd.	6542	139·9	Struck the proper right top corner of port on the 6-in. plate faced with the three 1-in. plates. The shot was partly on the target and partly on the open port. The shot glanced downwards, after striking, and broke up. The front 1-in. plate stood out from target about 2 in. at bottom and 1 in. at top; the other 1-in. plates were turned back in the indent on to the 6-in. plates, which were broken through upwards from proper right of port. A rod could be passed about 10 in. up the crack. The shot, in passing in, broke away the angle iron lining from the top inside of the port, and did some damage to the backing. The port stiffener had been driven back, so that the dovetailing pieces were quite out of the 9-in. plate on the right, and nearly so on the left. *In rear.*—Shot broke up and grazed lower port sill, deeply scoring it (over a length of about 2 ft.), and cracking it in 3 places. Lamina of 1-in. plates, and pieces of shot remained in port sill. The ground in rear of shield was strewn with pieces of shot, some of which went out to sea. The upper port liner was driven down about 6 in. on the right, and the wood packing over it splintered. Both the foot plates of struts were bent up, showing that the shield must have commenced to revolve round the rear beam. The foundations of the shield were much shaken.

TABLE XII.

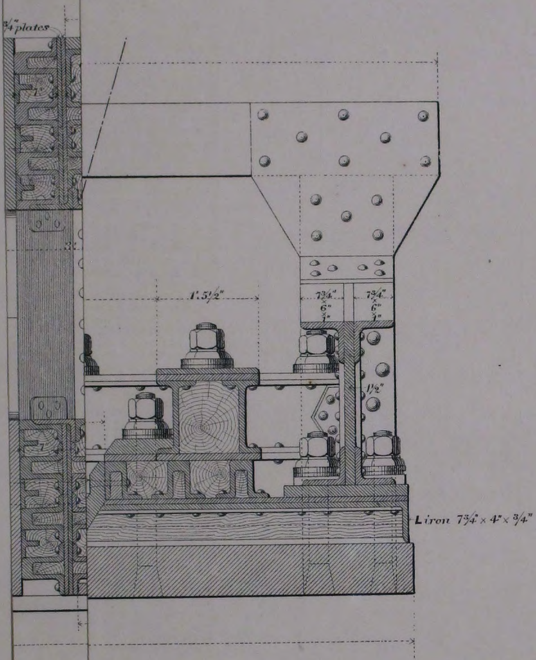
Gun Shield made at the Millwall Iron Works.—Report of practice on 22nd Sept., 1868.

Photographic No. of round.	Gun.	Charge and Powder.	PROJECTILE. — Nature, Length, Total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1596	12-inch rifled M. L. of 23 tons.	74·5 Pellet.	Palliser shot, cored. Head 1·25 25·2 ins. 601 lbs. 11·92 ins.	1171	5714·5	152·60	Struck 9½ in. to the proper left of port, and 13 in. from the bottom of the upper 6-inch plate. Shot deflected to the left, and broke away the edge of port, the greatest thickness of the shield being there about 18 in. The shot passed through, breaking up into very small langridge, some of which was thrown some distance to the rear. *In rear.*—The sill of port was filled with the debris of the shot and plate. The angle iron in top of port, loosened by round 1595, fell down into the port. The left port stiffener for a length of 18 in. from the top was broken off and thrown to rear. Vertical hollow stringer on left of port exposed and bulged about 3 in. The inner top part of the strengthening girder box cracked across at 19½ inches from the left.
1597	,,	,,	,, 596 lbs.	1154	5503·8	146·97	Struck 15 in. to the right of port, and 16½ in. from the top of the lower 9-inch plate. Portion of the shot remaining in the hole. Penetration 15½ in. A 4½ in. lamina of the 9-in. plate broken away over the indent. A portion of it, 4½ in. by 20 in. by 16 in. thrown 26 yards to the front. Rear lamina split into two. The lamination of 9-in. plate in sill of port (*vide* round No. 1594) opened out somewhat. The rear lamina in sill of port 2 in. from the backing, and at the side of port a gape of 6½ in. between 9-in. plate and backing. The right port stiffener much bulged, and eight rivets in it broken. The backing in rear of shot hole seemed disintegrated. *In rear.*—No. 20 bolt driven back 7 in. The shot struck very nearly on this bolt. The vertical washer plate in rear of the strengthening piece separated about 2 in. from shield at bottom. Back vertical and horizontal girders bulged at right bottom corner, and cracked in two places; the cracks running from the edge to the nearest rivet hole. 9 rivets broken, chiefly in strengthening piece. Baskcomb washer of one bolt broken. Whole shield driven back 9 in. on the right.

Photographic No. of round.	Gun.	Charge and Powder.	PROJECTILE. Nature, Length, Total Weight, and Diameter.	Striking Velocity.	Total Energy in Foot Tons.	Energy per in. of shot's circumference in Foot Tons.	Observed Effects.
		lbs.		feet.			
1598	12-inch rifled M. L. of 23 tons.	74·5 Pellet.	Palliser shot, cored, Head 1·25 25·2 inches, 600 lbs. 11·92 inches.	1171	5705·1	152·35	Struck 20 in. from the left, and 27 in. from the top of the upper (6-in.) plate. Left top edge of indent touches No. 1587. Indent 33 in. The head of the shot remained in hole, and made daylight visible through the shield over the top of the shot. Cracks developed from No. 1587 to top of plate, from Nos. 1587 to 1582 through bolt hole, and from No. 1582 to bottom of plate. The plate buckled 1½ in., and projected beyond the 9-in. plate below 1½ in. on the right, and 1½ in. in port; on left side, the skin plate driven back 18 inches at the top (but holding at the centre). The backing exposed. It appeared to be destroyed in the vicinity of the shot hole, the hollow girders being broken and the wood smashed. The left strut much distorted, and the angle iron cracked through in two places at top. *In rear.*—Inner angle iron of left strut broken away for a space of 4 ft. 3 in. by 8 in., and thrown about 8 yards to the rear, carrying with it 2 ft. 6 in. of No. 8 bolt with nut and washer. Rear strengthening girder box driven back 6 in. at left top corner, and much damaged; 7 rivets in it broken. No. 10 bolt apparently stretched about 4 in.
1599	”	”	” 596 lbs.	1181	5764·2	153·93	Struck 23½ in. from right, and 18½ in. from bottom of 9-in. plate. Shot remained in plate, base projecting about 2 in.; indent 23·2 in. The shield driven bodily back 6 ft. on the right, and forward 1 ft. on the left. The top of the shield overhanging the bottom on the right side 10½ in. Crack 1·3 in. wide, from No. 1599 to bolt hole; the crack between Nos. 1581 and 1591 opened out to 3 in. Front lamina of 9-in. plate nearly broken off between Nos. 1581 and 1599. The skin plate on the right side (loosened by No. 1590) thrown about 3 yards to the right. *In rear.*— The whole of the foundation disarranged; one of the chilled iron blocks resting on foundation plate, thrown 5 yards to the rear. The right foundation plate bent up nearly at right angles, split across the angle, and all the rivets in it sheared. The angle iron in front of right strut cracked vertically for about 2 in.

Pl: VII.

IADE



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VI.—Iron Concrete as a Backing Compared with other Substances.

Soon after the experiments with the Plymouth Fort structure, already described, the want of more information than we then possessed, as to the relative value of different materials for the purposes of backing to armour plates, came to be strongly felt; and this necessity was the more apparent as the great advantage of introducing other substances between the layers of armour in the "plate-upon-plate" construction was brought to notice.

Accordingly, after some preliminary trials on a miniature scale, it was determined to have an experiment to settle the matter completely.

To avoid the delay and expense of erecting an entirely new target, advantage was taken of an iron-plated wall which had been set up at Shoeburyness, in 1864-5, but which, for one reason or another, had been very little used.

This structure may be thus described:—

A masonry wall, 12 ft. long, 10 ft. 6 in. high, and 10 ft. thick, was built of six courses of granite blocks, 7 ft. and 5 ft. deep alternately, backed by brickwork in Portland cement.

Into this wall were built some long $2\frac{1}{2}$-in. tie bolts, which, by the way, were so contrived that, so long as they were not wanted, they could remain entirely embedded in the masonry, but, when occasion might require, they could be drawn out to the front for a length of 12 inches.

Against the face of this wall, and about 4 in. from it, were set up, vertically, four box girders, 3 ft. 9 in. apart from centre to centre, each 11 ft. 6 in. long, 7 in. deep, and 10 in. wide. They were strongly made of $\frac{3}{4}$-in. plate and angle-irons.

Each girder was held back by three of the $2\frac{1}{2}$-in. tie bolts already mentioned, which, being drawn out from the wall and passed through the girders, were nutted on their front side.

In front of these girders, and at a distance of 4 inches from them, were set up three tiers of $4\frac{1}{2}$-in. armour plates, each 12 ft. long and 3 ft. 6 in. wide, thus making the front 12 ft. long and 10 ft. 6 in. high.

Each plate was held by eight $2\frac{1}{2}$-in. bolts, which had conical heads in the armour, and these, passing through the vertical box girders, were nutted at the back of them, that is, between the girders and the masonry.

Thus the armour was secured by a set of short bolts to the box girders, which were themselves held to the masonry by the long tie bolts.

Lastly, the 15-in. space between the armour and the granite wall was, at the time of erection, filled with Portland cement concrete.

To prepare this target for the experiment now in question, the Portland cement concrete backing was removed from behind the two upper armour plates, and in this space were introduced, as separate backings, the following substances:—

1st.—Iron concrete, composed of 112 parts by weight of iron borings, 42 of asphalte stone, 42 of bitumen, and 7 of pitch.

2nd.—Teak in two layers.

3rd.—Stafford blue bricks set in asphalte.

4th.—Stock brickwork set in Portland cement.

The old Portland cement concrete left behind the lower armour plate formed the fifth substance for comparison.

The practice took place on the 15th January, 1869.

The gun used was the 7.-in. M. L. rifled gun at 70 yards, with 9 lb. 15 lb., and 22 lb. charges. Table XIII shows the results. An examination of the effects will show that the Portland cement concrete backing gave rather the best support to the armour in this trial; but, then, it must be remembered that this concrete had had four years to set, and the other materials were quite fresh. The iron concrete resisted nearly as well as the Portland cement concrete as regards penetration, and was very little disturbed by four shots in a small space.

The resistance of the Staffordshire blue bricks in asphalte was very nearly equal to the iron concrete, and it was not much broken.

No reliable result was obtained with the stock brickwork in Portland cement, and the teak was decidedly inferior to the Staffordshire blue bricks in asphalte, and, therefore, to the iron concrete and the Portland cement concrete.

The result also showed that this method of protecting masonry walls by means of armour plates, with an interval behind them filled with some moderately hard substance, is likely to prove very successful.

The effect upon the fastenings was very satisfactory, not a single bolt having been broken during the trials. The plates also stood very well. It may be mentioned that on a subsequent occasion the Portland cement concrete was removed from behind the lower plate, and a backing of iron concrete made with gas tar only instead of asphalte, for cheapness sake, was inserted in its place, and nearly as good a result was obtained as with the asphalte and iron. On this occasion the 7-in. shot, fired at 70 yards with a 15 lb. charge, penetrated in one round (1,704) 15·2 in., and in another round (1,705) 22 in., against the penetrations of 13·5 in. and 18·5 in. in rounds 1,608 and 1,613, and the gas tar concrete was not much separated or cracked in either round.

Targets on the "Warrior" and "Chalmers" principles, and iron concrete as backing.

The next opportunity of trying the effect of iron concrete as a backing to armour plates occurred, somewhat indirectly, in connection with two large targets set up at Shoeburyness, in the beginning of 1869.

The original intention of these targets was to afford the means of deciding some questions affecting the manufacture of Palliser chilled projectiles, but the opportunity was taken to institute a comparison between the late Mr. Chalmers' principle of construction, and that of an ordinary armour-clad ship with simple timber backing.

The entire front to be experimented upon was 40 ft. long and 9 ft. high. Of this, a 25 ft. length was the counterpart of the target, set up in 1866, to test the value of the Palliser projectiles. It is described at p. 131, volume XVI of these Papers, as being composed of 8-in. armour plates, backed by 18 in. of teak, on a skin and framing similar to that of "H.M.S. Warrior," except that the ribs were placed at closer intervals.

It is this target which on the former occasion proved to be, as intended, so nearly a match for the projectiles from the 9-in. gun of 12 tons, at 200 yards, with battering charges, as it just let through the shells and stopped the shot of this gun, when fired direct.

The present target has proved to be of the same strength, as nearly as possible.

The remaining 15 ft. of the front was devoted to the "Chalmers" construction. This may be described as composed of 4½-in. front armour plates, with a compound backing, on one half of the target 10 in. thick, and on the other half 13½ in. thick, made up of horizontal ⅝th-in. iron and steel plates, 3¾ in. apart, with teak between them. The layers of this backing were held together by vertical 1¼-in. rivets, about 14 in. long. Behind this compound backing came the intermediate armour plate, 2 in. thick, the alternate plates of this being made of steel and iron. Behind this was a cushion, in one part 6 in. deep, in the other 9¼ in. deep, composed of timber planks and ½-in. angle irons and bars, running horizontally. The angle irons of the cushion were riveted to the ¾-in. skin, which was supported by ribs, 7-in. deep, at 1 ft. 9 in. intervals. Thus, what with the difference in the depth of the compound backing, and the use of steel for some of the plates of this backing and for half of the 2-in. inner armour, this target really presented 8 different constructions.

However, there really was not so very much difference between them as regards strength, and very little indeed as regards weight; it having been specially provided that this target should weigh per foot superficial the same as the 25 ft. length already described. The weight of both was as nearly as possible 510 lbs. per ft. superficial of the front presented.

It has been already stated that the 8-in. "Warrior" portion was nearly a match for the 9-in. projectiles at 200 yards.

It is not intended to give the detail of the practice against these targets. It will be sufficient to say that on the first day's trial—4th February, 1869—the inferiority of the Chalmers' construction was shown in so unmistakeable a manner as to render further comparison quite unnecessary. The shot and shell, (rounds 1,619, 1,620, 1,640, 1,641, 1,642, and 1,644,) that could barely get their points through the skin of the one, passed completely through and through the other, in whatever part they hit, (rounds 1,616, 1,617, 1,621, and 1,622.)

As the "Chalmers" target was thus proved to be useless for further comparison in its own proper condition, it was proposed to turn it to some useful account in testing the qualities of iron asphalte as backing. Accordingly the lower plate of this target, which had not been fired at, was taken off, the compound backing, 10 in. thick on one half and 13½ in. on the other, was removed bodily; iron concrete, composed of 46 per cent. of cast-iron turnings, 46 per cent. of asphalte, and 8 per cent. of tar, was inserted in its place; and the armour plate bolted on again.

The result was that the portion of the target which had the deeper mass (13½ in.) of iron concrete successfully resisted both the shot and shell (rounds 1,660 and 1,665) from the 9-in. gun at 200 yards, which before had passed so easily through the target, the shell just showing its point through the skin, the shot stopping 2 in. short of the skin. The portion on which the backing of iron concrete was only 10 in. deep let both shot and shell, (rounds 1,662 and 1,667) through the target; but it must be observed that the velocities were on this occasion higher, in the proportion of 1,300 and 1,304 to 1,282 and 1,283, than when the "Chalmers" backing was tried. Some shells were aimed to strike the target obliquely, but they hit where no reliable result could be obtained. However, the experiment conclusively proved the iron concrete to be very much superior to timber and plates combined as a backing in one instance, and quite equal to, if not better than it, in the other instance.

TARGETS COMPOSED OF THREE 5-IN. PLATES, WITH IRON CONCRETE BETWEEN THEM.

First Target.

In paper XV. of last year's volume (1869) an account was given of the experiments bearing upon the use of "plate-upon-plate" construction for armour, as distinguished from the "solid plate" system. On that occasion, as well as in the description of the trials of the Plymouth Breakwater Fort structure, in an earlier part of the present paper, it was shown that three 5-in. plates in contact are capable of offering better resistance than a solid 15-in. plate. It was also said that much advantage was to be expected from the separation of such plates, and the introduction of some sort of concrete between them. To determine this point, the following experiments were set on foot:—

First, a small target was made out of three pieces of 5-in. armour plate, measuring repectively 5 ft. by 3 ft. 9 in., 5 ft. by 3 ft. 3 in., and 7 ft. 6 in. by 4 ft. 3 in. These were set up, one behind the other, in the order in which they are mentioned (the last named being the front plate), with intervals of 6 in. between them.

They were held together by six armour bolts, each 32 in. long, screwed at both ends. The outside diameter of the thread of these bolts was 3 in., and their shanks were reduced to 2·8 in.

The front end of each bolt was provided with a spherical nut, which fitted into a cup-shaped hole in the face of the armour plate.

The bolt holes in the middle and rear plates were 4 in. in diameter. Those in the rear plate tapered towards the rear to 3½ in. The back part of the holes in the front plate also tapered. The edges of all the bolt holes were rounded.

The rear end also of each bolt had a spherical nut, fitting into a cup-shaped washer, formed by coiling and welding a 1¼-in. by ½-in bar, the interior of the coil being bored out to suit the spherical form of the nut. This welded washer was further strengthened, on its outside edge, by means of another coil made out of a similar bar, but in this case the coil was left unwelded. The outside of the welded coil was chased with a thread, pitched quicker than the inclination at which the coils were round, and the interior of this unwelded coil being similarly threaded, the two were screwed together. There was a ¾-in. elm washer under each of the iron cup washers.

This arrangement of nut and washer is one which was proposed by Lieutenant

English, R.E., and is merely a development of the plan adopted, at his suggestion, in the Plymouth Breakwater Fort experimental structure. The construction of the washers being novel and peculiar, some explanation may be useful.

The object of the outer coil is of course to strengthen the inner one against the bursting strains brought into play when the nut is drawn powerfully into it; and the reason of its being made without welding is that, in this condition, there is strong reason to believe the iron is better able to resist sudden strains than if it had been subjected to the welding process. The coil, in this state, is also more free to expand, and so, although the inner coil may burst, the outer will hold its walls together till it has itself been stretched to the utmost. This gradual action, too, is intended to relieve the bolt in much the same way as it would be if a mass of elastic material were interposed.

The thread by which the two coils are screwed together is made of quicker pitch than their own winding, in order that, when the outer coil is strained from the inside, and so made to unwind itself from both ends, its several turns are obliged to follow the thread of the screw, by which, as a little consideration will show, they become squeezed closer and closer together as the expansion proceeds.

This action has really taken place, to a greater or less extent, both in experiments with falling weights at comparatively low velocities, and in the trial of the target now under notice, as well as on other occasions.

Returning to the description of the target itself, the 6-in. intervals between the armour plates were filled with a compound made up of cast-iron borings, asphalte, bitumen, and pitch, mixed together hot, in much the same way as that used in the front part of the roof of the structure representing Plymouth Breakwater Fort, and other targets, already described.

The target was set up so that the ends of the front plate rested against the edges of two armour plates standing end on to the front, with their rear edges bearing against the face of an old ship's side. These plates formed the only support of the target, if indeed we except, as for all practical purposes we may, a packing of loose timber logs inserted behind the target, merely to prevent the rear plate from being thrown down altogether in the event of the armour bolts not doing all expected of them. This method of supporting the target by its front plate only was expressly arranged with the view of throwing the greatest possible strain upon the bolts. It also had the effect of confining the concrete at the ends of the target. A mass of old iron was placed on the top of the target, to prevent the iron concrete being driven out in that direction.

The trial took place on the 4th February, 1869. The gun used for the occasion was the 12-in. rifled muzzle-loading 600-pounder, placed at 20 yards, with a charge reduced to represent full battering charge at 200 yards.

The object was to get a round at this target that would compare with round No. 1512, on the three-plate portion of the Plymouth Breakwater structure, as well as with rounds 1517 and 1509, against 15-in. solid plates, reported in last year's volume, at pages 204 and 205.

On reference to the Table of practice against the Plymouth target, it will be seen that the 12-in. shot on that occasion buried itself to a depth of 12 in., that is, up to the front stud, and in rear produced a long crack 2¾ in. wide, and 10 in. deep.

On the present occasion the shot having a 1·5 diameter head, struck with a slightly reduced velocity—that is, 1,165 ft. per second (against 1,177 ft. on the former occasion)—representing an energy equal to 5,694 foot tons, or 152 foot tons per inch of shot's girth. The number of the round was 550. The shot buried itself in the target, until its base projected 1½ in. beyond the face of the front plate. The front plate was cracked from the shot hole to the bottom of the plate, and it was buckled 4·1 in. In rear no effect whatever was observable on the back plate beyond a slight general bulge of about 2·3 inches. No bolts were broken. The inner welded coils of all the washers were cracked, and the unwelded outer coils had unwound themselves a little. The wood washers were crushed.

The old armour plate, against which the proper right end of the target rested was thrown down, and the load of loose iron on the top was displaced.

On taking the target to pieces it was found that the shot, in passing through the front plate had broken away the back of it, over an area of about 2 ft. in diameter, and to a depth of 2·5 in. in the deepest part; that it had raised up a remarkable bulge, or rather a truncated cone, 6 in. in height, on the back of the middle plate, the area of its base being about 20 in. in diameter, and that of its top, which pressed against the front of the rear plate, about 10½ in. by 7½ in. Through the centre of the iron concrete, forming the flat top of this bulge, the point of the shot protruded sufficiently to produce an impression in the face of the rear plate, ¼ in. deep, and of exactly the size of a sixpence. The middle plate was also buckled about 4·5 in.

With regard to the bolts, they were found to be reduced in diameter from 2·8 in. to 2·7, 2·6, 2·62, 2·75, 2·25, and 2·75 in. respectively, and they were elongated from 32 in. to 34·375, 34·5, 34, 33, 32·625, and 33·5 in. They were bent from ·3 to ·9 in. in their length. The bolt holes in the middle plate were drawn into an oval form, measuring 5 in. by 4 in.

As to the iron concrete, this answered very well indeed. So large a shot entering so small a target could not fail to break up and displace the greater part of the filling material, but that which did remain in front of the shot was extremely hard and solid, and forming a good support to the middle plate extended the effect upon the rear plate over a large surface, and so produced results, which compared with those obtained in the other instances above mentioned, that is, with 15 in. of plates in one and three thicknesses, cannot but be regarded as highly satisfactory.

The other results obtained with the concrete, through its giving the bolts a better opportunity of drawing out than they can have in a structure where the iron surfaces are directly in contact, and also from its relieving the plates of much of their tendency to crack when so placed, are of much importance.

Altogether, this experiment was a highly successful one.

Second Target.

It will readily be understood that at the parts about the embrasure in an iron wall, the object is to get the necessary strength in the least possible compass. The next step taken, therefore, in this matter was to set on foot an experiment to ascertain whether equally satisfactory results could be obtained with a less thickness of iron concrete than was used in the last target. Also, as the distribution of the material in that target had been arbitrarily settled, it was desirable to know whether that could be improved upon; and, further, it became necessary to consider the best means of retaining in its place the concrete immediately about the embrasure in iron fronts and shields.

To settle these three points a new target was made, which may be described as follows:—

It presented a front measuring 6 ft. in length by 5 ft. in height. The armour plates were all 5 in. thick. The target may be divided into two parts. The proper right half of it was thus arranged. First came the front plate, then 1½ in. of iron concrete; next the second plate, then 6½ in. of concrete; and, lastly, the rear plate. The proper left half was made up of the front plate, 6½ in. of concrete, the second plate, 1½ in. of concrete, and the rear plate. Thus the one half was the reverse of the other. The entire thickness was every where 1 ft. 11 in., the aggregate thickness of concrete used being 8 in. The front and rear plates were each in one piece. The intermediate armour was necessarily in two pieces.

The target was held together by eight through-bolts. The upper four were screwed all their length. The lower four had plus threads at either end, the outside diameter of which was 3 in.; their shanks were reduced to 2·8 in. On their front ends all were provided with spherical nuts fitting into cup-shaped holes in the front plate, and in rear they had spherical nuts and coiled washers of very nearly the same pattern as in the last target. Between the coiled washers and the armour there were elm washers, bound round on their outer edge with hemp, so that the hemp was between the outer unwelded coil and the plate. The holes in the middle thickness of armour were 4 in. in diameter. Those in the front plate tapered towards the front from 3¾ in. to 3¼ in.; those in the rear plate tapered towards the rear from 4 in. to 3½ in. The edges of all the bolt holes were rounded.

As to the means of retaining the concrete on the sides of the target, representing as it were the sides of an embrasure, two methods were tried.

That to retain the 6½ inches of concrete on the proper right end of the target consisted of two vertical channel-irons, of section 5 in. by 2 in. by ½ in., placed back to back, and so making an ⊢⊣. This was set in so as to be flush with the edge of the target; the ends of the channels passed through old plates laid under and on top of the target, and were keyed there.

That to retain the 6½ inches of concrete on the proper left end of the target consisted of a piece of 2 in. plate, 12 in. wide, standing vertically against the end of the target, with its edge to the front. It was held by three 2-in. bolts, 3 ft. 6 in. long, running horizontally into the concrete behind the front armour. The inner ends of the bolts were screwed into flat washer pieces, 3½ in. thick; the outer ends were provided with spherical nuts, fitting into cup-shaped holes, in the 12 in. by 2 in. plate.

The target was set up for experiment a short distance in front of an old ship's target, from which it was blocked out, by means of vertical iron planks on edge, against which the rear plate of the target rested at each end. There was also a vertical block of timber, 18 in. by 6 in., supporting the centre of the rear plate, to make up, in some degree, for the intermediate armour being in two pieces.

There was an old piece of 3½ in. plate laid under the target, and another piece on the top of it, and these were bolted together by some vertical bolts, the upper ends of which were held back by eye-bolts to the ship's side, to prevent the target falling forwards when struck.

The experiment took place on the 4th and 14th June, 1869. The gun, the range, charges, and projectiles, were all the same as in the other three-plate target experiment last described, excepting only that in the second round, the shot had a 1·25 instead of 1·5 diameter head.

The first round No. 1,664 was fired at the proper left portion of the target. The shot struck direct, 21 in. from the proper left, and 23 in. from the top, but turned, on penetrating, towards the left side of the target, at an angle of 35°. The shot hole in the front plate was oval, measuring 16½ in. by 12¼ in., and was very much bruised on one side by the after part of the shot. The front plate was buckled 2¼ in. horizontally, and 1¼ in. vertically. The rear of the front plate was broken away, at the shot hole, over an area of 29 in. by 20. in. The front of the centre plate was indented 4½ in., the impression being oval, and measuring 10 in. by 9 in. There were cracks in this impression; and on the rear of the plate a forked crack, 12 in. long, running horizontally. There was no impression made on the front of the rear plate, but at the back of it there was a horizontal crack 8 in. long, on a bulge 3½ in. high. The total penetration was 1 ft. 9 in., measuring along the axis of the shot. The 12-in. by 2-in. piece on the side of the target to retain the concrete was forced out 3½ in. at the top, 2½ in. at the centre, and 1 in. at the bottom, and it let some of the concrete out. The 2-in. bolts holding this retaining piece were slightly elongated, and the centre one, which was very nearly in the path of the shot, was bent 6 inches. The two through bolts just above the shot were broken.

The other round (No. 1679) was directed at the proper right portion of the target, and struck direct, 22 in. from the top, and 22 in. from the right. It turned up at an angle of 20°, and also inclined about 6° towards the proper right of the target. The shot hole in the face of the front plate was 12½ in. by 12½ in., and no cracks were observable. The shot remained sticking in the target; and at the rear of the front plate a cone, 24 in. in diameter at the base, formed round it. There was a shallow crack on the back, extending to the right edge of plate. The indent in the centre plate was about 18 in. by 18 in., and the plate split horizontally across, through the shot mark. The point of the shot protruded through an opening of about 4 in. in the shot mark. The back of the centre plate was bulged over an area 24 in. in diameter. The face of the rear plate was indented $2\frac{1}{2}$ in. by $3\frac{1}{2}$ in., and 1 in. deep. On its back there were no effects observable. The total penetration was 1 ft. 8 in. The channel-irons, intended to hold in the concrete between the centre and rear armour plates, were bulged out about 6 inches, and twisted. The two armour bolts above the shot were broken.

The total buckle of the rear plate, from the effect of the two rounds, was about $4\frac{1}{2}$ in. taken horizontally, and 3 in. vertically. The flat plate laid along the top of the target was bulged upwards about 3 in. in the centre. The four upper armour bolts were broken, as already stated, apparently by cross strains, the fractures being crystalline; one of them was bent about 4 in. Two of the front nuts were cracked; the outer coils in the upper washers were slightly stretched and unwound, but well closed up; the lower coils were quite unaltered; all the wood washers were crushed up.

It cannot be said that the results obtained in this experiment were so entirely satisfactory and conclusive, as in the first three-plate target, for the deflection of the shot, after entering the target on this occasion, makes it difficult to compare their effects with each other, and with previous results. On the whole, however, although the loss of 4 in. of iron concrete had probably somewhat reduced the resisting powers of this arrangement of plates, yet there was sufficient left to give very good resistance in both rounds.

As regards the two methods of placing the concrete, there was not much to choose between them. It is probable, however, that by placing the greater mass between the second and third plates, the best result will be obtained, so far as the rear plate is concerned, although there will be more tendency to crack in the front plate, than if the greater mass of concrete were placed immediately behind it. Perhaps, after all, it will be generally best to divide the concrete into equal masses.

As to the two plans of retaining the iron concrete, enormous strains had to be met in each case, and neither of them acted its part completely. Probably, something answering to the channel-irons, but of much stronger section, will make the best frame for keeping the concrete in place around an embrasure.

The experiment was, altogether, a very instructive one, and the fact of two rounds from the 23-ton gun, with battering charges, at 200 yards, having been fired with good account at so small a target, makes it a very remarkable trial.

A MASONRY WALL STRENGTHENED BY MEANS OF IRON CRAMPS AND BOLTS.

This experiment, though less important than others recorded in this paper, will be briefly noticed in order to dispose of the only remaining piece of construction of the group of experimental works in masonry and iron set up at Shoeburyness in the year 1864-5.

The object of the trial was to ascertain whether, for works of secondary importance, a masonry wall of cheap construction, that is to say, one composed of such material as concrete and brickwork, can be so combined with iron in the cheaper forms, such as flat bar and railway rails, as to give resistance to artillery fire superior to that gained by the same amount of money laid out on a wall chiefly composed of harder masonry, such as granite, protected by armour plates.

For this purpose £5 10s. was fixed upon as the sum to be laid out on each portion of the wall consisting of one square foot of front face with all behind it; and this, by the way, is about the cost of a single 8½-in. plate without any backing or support.

The granite wall faced with armour plates, elsewhere described in this paper, was calculated to cost a like sum.

The following may be taken as a description of the cramp wall :—

Its entire thickness was 11 ft. 2 in., and its height 7 ft. 8 in. Its length was 14 ft. 3 in.

It was made up of 5 tiers in height, each 1 ft 6½ in. high. There were 19 cramps of various sorts as described below, in each tier. The width of each cramp was 9 in., and they were all made of 2 in. iron.

Taking one tier by itself it might be said to consist of a 14-in. by 5-in. rolled armour plank laid horizontally on its edge, backed by a pile of six double-headed railway rails, laid flatways, and running horizontally the whole length of the plank. The small hollows between the rails were filled with bars of suitable section.

The plank with its backing of rails was then wrapped round, as it were, by the cramps in succession in the following manner :—

Starting with the lower end of a cramp, which turned up a few inches behind the railway rails, it passed from thence under the rails and under the plank, round in front of it, over its upper edge, and over the top of the pile of rails. From this point one sort of cramp had its end turned down a short distance behind the rails. Another sort tailed a distance of about a foot into the wall, and then had its end turned up a few inches. Another tailed about 2 ft. into the wall, and was also turned up.

Immediately behind the cramps of the description first mentioned there were vertical railway rails in couples 9 in. apart, the intervals between the pairs being about 14 in. These uprights extended the full height of the wall, and had slots in them at intervals of 18 in. in their height, through which iron keys passed; the lower key passed *under* the tail of the cramp of the lowest tier; the remainder *over* the tail parts of the cramps of the successive tiers, so tying the whole together from top to bottom of the wall.

The turned up ends of the other cramps held horizontal railway rails that ran longitudinally the whole length of the wall, and these again were grasped by the turned ends of rails running from front to rear and acting as ties; some of these ties extended to the very back of the wall, others went back a long distance into it, and all had turned down ends.

The front part of the masonry wall itself was composed of Portland cement concrete for a thickness varying from 2 ft. 6 in. to 5 ft.; the remainder was of brickwork in Portland cement.

Very little use having been made of this wall since its erection, it was decided to make its trial serve another important purpose, viz., that of testing the qualities of a number of Palliser projectiles, made in the Royal Laboratory Department, of various mixtures of iron, and by different modes of manufacture.

As an exact analysis of this practice would not lead to any good, the present account will be confined to a general description.

The trial took place on 16th February, 1869. The 7-inch gun was used at 70 yards range. Nine shot were fired with 9 lbs. charges, and eight with 18 lbs. charges, making, with two previous shot, 19 rounds in all. The penetrations of the shot fired with 9 lbs. charges varied from 5·4 to 6·8 in. giving an average of 5·9 inches. The penetrations of those fired with 18 lbs. charges varied from 8·5 to 12·5 in., giving an average of 10·3 in.

The cramps cracked a good deal at the welds in their bends, and in some instances the entire front end of the cramp broke off. The planks also were broken in some places, and the cramps started out more or less wherever hit. Otherwise the penetration was not great, and the general stability of the wall not much disturbed. Still the construction involves too many parts, and is not to be recommended.

An instance of the remarkable qualities, that the Palliser chilled projectiles may possess, occurred in the course of this practice, when a shot fired with a 9 lbs. charge, entered the iron of the wall to a depth of 6 in., and, bounding back a distance of 25 feet, was found to be so perfectly uninjured, and unaltered in form, that it was fired a second time, with the same charge, against the same wall, and again did excellent work, penetrating this time to a depth of 5·4 in.

MANUFACTURE OF BROAD ARMOUR PLATES.

As the construction of iron fronts and shields, especially the latter, came to be thoroughly considered, it was felt that much advantage would be gained if armour plates could be made of greater widths, than had hitherto been found practicable; in fact, if they could be produced of dimensions large enough for one single plate to occupy the entire face of a shield.

Practically the width of armour plates had been limited to about 6 ft., in consequence of the difficulty of dealing with wider masses of iron in the furnace; and so great was this difficulty, that although the leading armour-plate makers were really anxious to undertake the manufacture of broad plates, and were prepared to set up rolls of the necessary size, the appliances with which they were already provided being ample in almost all other respects, yet the uncertainty and waste attending the treatment of broad plates in the furnace seemed to place an insuperable obstacle in their way.

So the question might have remained for a long time to come, but for a way of solving the difficulty which fortunately occurred to Lieut. English, R.E.

Up to that time, the moulds made for the last rolling of an armour plate were necessarily of about the width required in the finished plate, the extension produced in the process of passing through the rolls being almost altogether in a longitudinal direction. Under this system, therefore, the moulds to make a finished plate, 8 ft. broad, would have been themselves 8 ft. broad, and it was the difficulty of getting up the proper heat throughout a pile of such wide moulds, without excessive burning of the metal on the outer parts, that constituted the sole obstacle above alluded to.

The plan suggested by Lieutenant English was to keep the moulds within the width hitherto found practicable, that is, about 6 ft., and on bringing the pile out of the furnace, first to roll it out for width by passing it through the rolls in the direction of its width, and then turning it half round to roll it as usual for length. This simple expedient, if not affording the only way of meeting the difficulty, has at any rate proved very successful. The first plate made in this way was rolled by Sir J. Brown and Co., at the Atlas Works, Sheffield, on the 19th February, 1869, out of a pile of five moulds, each 6 ft. by 7 ft., by $3\frac{1}{2}$ in. They were first passed through the rolls in the direction of the 7 ft. dimension, until this was increased to 8 ft. Then the plate was swung round, and the rolling continued in the other direction, until it was reduced to a plate 16 ft. long, 8 ft. wide, and 5 in. thick. The weight of metal in this mass was about $10\frac{3}{4}$ tons. Out of this was afterwards cut a plate 12 ft. long and 8 ft. wide, that is, of the size required to cover the entire face of an ordinary gun shield.

To give some idea of the magnitude of the operations involved in the manufacture of such a plate, it may be stated that the rolls used were 18 ft. in length over all, 11 ft. between the standards, and 34 in. in diameter, and that each roll weighed about 19 tons.

The plate produced on this occasion was purchased by the War Department, and sent to Shoeburyness for proof.

Although the results given, when the plate was hung entire in a swinging frame and struck by 7-in. Palliser shot, were somewhat contradictory, yet this was evidently caused by the plate being improperly held at first, for, subsequently, a sample was cut from it of the dimensions of an ordinary proof plate, and this, being subjected to the usual proof, was classed A 1, that being the highest of the 9 figures of merit awarded in the Shoeburyness proof. Other broad plates have since been made by the same company on this plan, and have been equally well classed in proof.

In conclusion, it may be stated that there is now in course of construction an experimental casemate-shield, which is based upon the principles that have given the best results in the foregoing trials, and otherwise embodies all that the most recent experience recommends.

The trial of this may be expected to take place at Shoeburyness, early in the year 1870.

T. I.

TABLE XIII.

Iron concrete as a backing, compared with other substances.

Report of practice on 15th January, 1869.

Number of round.	Charge and Brand of Powder.	PROJECTILE. Nature, Length, Weight, and Diameter.	Striking Velocity.	$\frac{Wv^2}{2g}$ in Foot Tons on Impact.	Foot Tons per inch of shot's circumference.	Observed Effects.
	lbs.		feet.			
1602	9 R. L. G. Date 28 5 67	Palliser cored shot, 1·25 D. 115·0 lbs. 14·68 inches, 6·92 inches.	948	717	33·0	Struck centre plate *(iron concrete backing)*, edge of hole 8 in. from top of plate, 5 ft. 2 in. from proper left of target, and 7 in. from edge of girder. Indent 5·6 in. deep, diameter 7 in. by 7·25 in.; bottom of indent cracked; plate bulged 0·7 in.; slight crack from old shot hole (1154); concrete squeezed up 0·5 in. at top of target; shot broke up, head rebounded 12 yards from target. At the back of plate a bulge 11 in. by 12 in., with star crack showing daylight. Iron concrete indented 2 in. over an area 12 in. by 12 in.
1603	,,	,, 114·5 lbs. ,,	950	716	33·0	Struck bottom plate *(Portland cement concrete backing)* 6·5 in. from top of plate, 5 ft. 4 in. from proper left of target, and 9 in. from edge of girder. Depth of indent 4·85 in., diameter 7 in. by 7 in.; small cracks at bottom of indent; plate buckled 0·4 in.; shot broke up, head rebounded 14 yards. At the back of plate a bulge of 1-in., over 16 in. by 10 in., and a crack.
1604	,,	,, 114·0 lbs. ,,	953	718	33·0	Struck centre plate *(teak backing)* 5 in. from top of plate, and 2 ft. 6 in. from proper left. Depth of indent 7·8 in., diameter 7·5 in. by 7·5 in.; plate broken through and wood visible at bottom of indent; indent very much cracked; buckle 0·5 in. Shot broke into several pieces. Area of damage at the back of plate 14 in. by 14 in. Rear mould broken away over lower portion, and nearly so over upper portion. Hole through centre. Wood indented 5 in. and much splintered.
1605	,,	,, 115·0 lbs. ,,	948	717	33·0	Struck centre plate *(backing of brickwork in asphalte)* 13·5 in. from top of plate, and 10 in. from proper right, on edge of outside girder. Depth of indent 5·6 in., diameter 7 in. by 7 in.; indent much cracked, and plate broken through, showing backing; buckle 0·2 in. horizontally, 0·5 in. vertically; plate cracked through its thickness from indent to right edge; front plate of girder cracked through a rivet hole. Backing forced out at side. *Not a fair test of resistance owing to want of lateral support.*

Number of round.	Charge and Brand of Powder.	PROJECTILE. Nature, Length, Weight, and Diameter.	Striking Velocity.	$\frac{W v^2}{2 g}$ in Foot Tons on Impact.	Foot Tons per inch of shot's circumference.	Observed Effects.
	lbs.		feet.			
1606	9 R. L. G. Date 28 5 67	Palliser cored shot, 1·25 D. 114·5 lbs. 14·68 inches 6·92 inches	950	716	33·0	*Last round repeated.*—Struck the plate 23 in. from the top, and 2 ft. 1 in. from proper right. Depth of indent 5·9 in., diameter 7 in. by 7·25 in., cracks in indent; buckle 0·9 in.; edge of indent 5·5 in. from 1154, and 10·5 in. from last round; cracks in 1605 much opened, and fresh crack, 6 in. long, from 1605 towards 1606; two rivets in girder broken, and rear angle iron and plate cracked in rivet hole; brick pushed up at top. At the back of the plate a horizontal crack 10 in. long, in a bulge 12 in. by 10 in., and a vertical crack 6 in. long. Brickwork indented 1·5 in. over an area 12 in. by 12 in., but otherwise little disturbed.
1607	"	" 115·0 lbs.	948	717	33·0	Struck top plate *(backing of brickwork in cement)* 11 in. from top, and 1 ft. 11 in. from proper right. Depth of indent 9 in. from front of plate to inner lip, diameter 7·25 in. by 7·5 in.; buckle 0·3 in.; plate completely broken through, and backing broken up. Brickwork not set, and result scarcely reliable, as the backing was forced out at the top.
1608	15 "	"	1275	1296	59·6	Struck centre plate *(backing of iron concrete)* 11·5 in. from bottom, and 5 ft. from proper right, 3 in. from edge of girder. Penetration 13·5 in., diameter 7·5 in. by 7·25 in.; edge of hole 5 in. from 1155; buckle 0·2 in. Head of shot deflected upwards 10 deg. and to left in the direction of 1155. The result does not give reliable information regarding strength of backing, as the part struck was weak. The shot's point projected 9 in. beyond the back of the plate, and indented the iron concrete to that depth, driving into it a piece of plate 5 in. by 5 in. by 2½ in.
1609	"	"	1275	1296	59·6	Struck bottom plate *(Portland cement concrete backing)* 12 in. from top, and 21 in. from proper right, buckle 0·2 in. Penetration 13·3 in. Shot in target broken up, 1·38 in. of base projecting in front of plate, and point 7 in. beyond back of plate. Area of damage on the back of the plate 16 in. by 15 in.
1610	"	" 114·5 lbs.	1276	1293	59·5	Struck centre plate *(teak backing)* 12 in. from bottom of plate, 2 ft. 4·5 in. from proper left; edge of hole 10 in. from edge of girder, and 10 in. from 1604. Pene-

Number of round.	Charge and Brand of Powder.	PROJECTILE. Nature, Length, Weight, and Diameter.	Striking Velocity.	$\frac{W v^2}{2 g}$ in Foot Tons on Impact.	Foot Tons per inch of shot's circumference.	Observed Effects.
	lbs.		feet.			
1610 contd.						tration 22 in., diameter 8 in. by 7·5 in., buckle 0·2 in. Shot broke up in hole. The 2nd, 3rd, and 4th tiers of granite in rear of target were cracked through diagonally across the blocks. Point of shot passed through the wood, and indented the granite. Hole in wood 13 in. by 13 in., and pieces of the plate driven in. Wood a good deal split.
1611	22 R. L. G. Date 28 5 67	Palliser cored shot, 1·25 D. 114·0 lbs. 14·68 inches 6·92 inches	1450	1662	76·5	Struck bottom plate *(Portland cement concrete backing)* 1 ft. 4·5 in. from top, and 1 ft. 10·5 in. from proper left. Penetration 20 in., diameter 7·5 in. by 7·5 in., buckle 0·1 in. Shot broke up, head in hole. Area of damage on the back of the plate 13 in. by 13 in.
1612	"	" 115·0 lbs. "	1445	1665	76·6	Struck top plate *(iron concrete backing)* 1 ft. 7·5 in. from top, and 5 ft. 5 in. from left. Penetration 24·5 in., diameter 7·5 in. by 7 in.; shot broke up in hole; a large quantity of concrete driven out at top of target. Lower tier of granite cracked through its thickness diagonally at 4 ft. 6 in. from front. Result scarcely reliable, as the concrete was not enough confined at the top.
1613	15	" 114·0 lbs. "	1278	1291	59·4	*For comparison with* 1608. Struck centre plate *(iron concrete backing)* 5·5 in. from bottom, 5 ft. from proper left, and 5 in. from a girder. Penetration 18·5 in., diameter 7·5 in. by 7·25 in., buckle 0·2 in. Four shots had struck this plate in a space of 2 ft. 6 in. by 2 ft. 6 in. Area of damage at the back of plate 13 in. by 13 in., and hole of that size in the iron concrete.
1614	22	" 115·0 lbs. "	1445	1665	76·6	Struck top plate *(teak backing)* 15 in. from bottom, and 18 in. from left. Penetration 25 in., diameter 7·5 in. by 7 in., buckle 0·1 in. Wood backing driven out at top 7 in.

PRINTED BY JACKSON AND SON, "JOURNAL" OFFICE, WOOLWICH.