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EDITED BY

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PREFACE.

Volume X. of the R.E. Professional Papers, *Occasional Paper Series*, which we now present to the Corps, contains important information concerning both the military and technical duties of the Royal Engineers. Several of the papers published in this volume were in the first instance delivered as lectures at the School of Military Engineering. These lectures are, however, from the scattered condition of the Officers of the Corps, only available for the few of its members who, for the time being, are quartered at Chatham, but many of the subjects treated on are not only of interest to the whole Corps, but such as all officers should be acquainted with, to enable them to be ready to respond to any calls likely to be made upon them in carrying out their professional duties, and it is therefore hoped that their publication, in the form of *Occasional Papers*, will be appreciated by Officers whose duties keep them away from Chatham, and who are thus enabled to profit by the information collected at the Head Quarter School.

Connected with the military duties of the Corps, we have a digest of the experiments carried on at Dungeness and Lydd, in 1880-81-82-83-84, on the effect of projectiles on masonry and earth work, by Colonel F. G. Baylay, R.A., and it is hoped that in future years we shall be able to continue these, as the information thus obtained must be of the greatest possible value to officers employed on fortifications or in field work. Captain G. S. Clarke contributes an able *critique* on the experiments carried on in 1884, which treats the subject from an Engineer's point of view.

Major-General T. Inglis again contributes a paper on "Armour Plate Experiments," which brings the subject up to the date of his retiring from the service, when he relinquished the important post which he held for so many years at the War Office.

This volume also contains a paper by Captain G. S. Clarke, R.E., and Lieut. M. Nathan, R.E., on the "Study of Fortress Warfare," translated from one of Brünners Brochures, published at Berlin in 1880, and is, we believe, the first treatise in English on a subject which is of necessity of vital importance to all Engineer Officers.

Mr. W. Anderson, of the firm of Easton and Anderson, also contributes a paper on "Hydro-Pneumatic Gun Carriages," which is not only of interest to the Corps in general, but which will be of great value to all Officers engaged in the construction of fortifications, or who may have to superintend the erection or to take charge of any of these complicated structures on existing works. Some Officers may not be able to follow all the intricate arrangements in these gun carriages, and to them we would recommend the perusal of Mr. Anderson's first course of lectures on "Hydraulics," published by the Lithographic Fund, and of which a few copies are still available.

Many of our readers may have seen accounts in the daily papers of telpher lines that have been recently constructed. We are, therefore, pleased to be able to give them a good account of this new development of the electric power from the able pen of the late Professor Fleeming Jenkin, and in doing so feel sure that we may express the regret of the Corps that he did not live to perfect this new system of electrical transport.

Mr. A. B. W. Kennedy has supplied the Corps with an interesting paper on the frequent repetitions of load, which contains a large amount of information upon the effect of constant vibration on engineering structures.

In presenting this Volume to the Corps, we must express our regret at an omission in the preface to Vol. IX. of these papers, viz., that it was not stated that a large portion of the matter contained in that volume was collected and printed while Lieut.-Col. R. H. Vetch was Secretary of the R.E. Institute.

FRANCIS J. DAY, CAPTAIN, R.E.,

Secretary, R.E. Institute, and Editor.

Chatham, November, 1885.

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PAPER I.

TELPHERAGE.

Being the substance of a lecture delivered at The School of Military Engineering, Chatham, in the Spring of 1884.

By PROF. FLEEMING JENKIN, LL.D., F.R.S.

In the first place it is necessary that I should define what is meant by this word "telpherage," and perhaps that I should defend its formation. The word is intended to designate all modes of transport effected automatically with the aid of electricity. According to strict rules of derivation, the word would be "telephorage"; but in order to avoid confusion with "telephone," and to get rid of the double accent in one word, which is disagreeable to my ear, I have ventured to give the former such a form as it might have received after a few centuries of usage by English tongues, and to substitute the English sounding "telpher" for "telephore."

In the most general sense telpher lines include such lines as were first proposed by my colleagues, Messrs. Ayrton and Perry. The word would also describe lines such as I have seen proposed in the newspapers for the conveyance of small parcels at extremely rapid rates. But to-night I shall confine myself entirely to the one specific form in which the telpher line first presented itself to my mind and which it has fallen to my lot to develop. In this form telpher lines are adapted for the conveyance of minerals and other goods at a slow pace and at a cheap rate.

The problem which occured to me was this: Was it not really possible to send vehicles, by means of electricity, along a single suspended wire or rod—in fact, to telegraph goods and passengers instead of messages? The idea is familiar as a joke, but on consideration it appeared that there might be good grounds for supposing that the idea was both practicable and useful. I am now able to show you the realisation of that idea, and the result of experiments on a large and practical scale has, I think, justified the arguments which induced me to devote much time and labour to telpherage.

We could not with steam employ a vast number of little one-horse engines to pull along a number of small trains or single waggons. There would be waste both in the production of power and great cost in the wages of the men employed at each engine.

The idea occurred to me that electricity gave us the means of distributing power in a way which steam could not do. That is to say, whereas the steam engine must necessarily be large and heavy, to work economically with electricity we can draw off the power by a large number of small engines without much greater loss than if we employed only one large motor. But distribution of power enables us to distribute the weight also. The reason why railways are so expensive is that the trains are necessarily heavy to suit the large engines employed; 400 tons is often the weight of a single train, which requires small inclines, and heavy earth-work and bridges. If, however, we can distribute the same amount of goods over a considerable length, we can have a cheap and light substructure which will carry loads comparable with the contents of one of these large railway trains but spread over a great length. To carry out this idea we must also have the means of going up gradients so as to dispense with heavy works such as bridges, cuttings, embankments, &c.

An electric current of, let us say, 50 horse-power will, as it circulates through a conductor of moderate size, drive thirty small engines each of one horse-power, which require practically no supervision, and which can be made nearly as economical in their action as a single electro-motor of 30 horse-power could be.

But if the power can be distributed economically along a line, say ten miles in length, this allows us to employ thirty small trains, corresponding each to a waggon pulled by one horse, instead of a single train such as might require 30 horse-power. If we further distribute the weight by making each train of considerable length, we are able to employ an extremely light form of road, such as a suspended rope or rod of, say, $\frac{3}{4}$-in. diameter. At a later period in the lecture I will show the amount of traffic which such a rod can practically convey. Meanwhile, I simply draw your attention to the general principles of the subdivision of power and the subdivision of weights. In distributing the power by means of electricity it was clear that considerable waste must be incurred, but the amount of that waste is easily calculated, and is by no means prohibitory. Moreover, the power, being obtained from stationary engines, or in certain cases from falls of water, could be produced at a cheap rate in comparison with that obtained from locomotives or traction engines.

When I examined the various forms of possible road by which the distributed power and distributed load could be conveyed, it seemed to me that the single suspended rope or rod offered great advantages. The smallest railway involved embankments, cuttings, and bridges, fencing, and the purchase of land. A single stiff rail, with numerous supports, from which the train might hang, seemed better, and may, in some cases, be employed; but the supports would require to be numerous—say, one post every 10 or 15 feet—and even with these spans the girder required to carry vehicles weighing 2 cwt. each would be costly. With a single suspended rod or rope we may have supports 60 or 70 feet apart. A $\frac{3}{4}$-inch rod, thus supported, will carry five vehicles, each bearing 2 cwt., without excessive strain; no purchase of land is necessary, no bridges, earthworks, or fencing. The line could be removed from the ground so far that it would not be meddled with either by men or animals,

A single wheel-path gives the minimum of friction, and the rolling stock would be much more easily managed than if we attempted to let vehicles run on double swinging ropes. On all those grounds it seemed well worth while to devise means by which trains could be electrically and automatically driven along the single suspended rod.

Before proceeding further I had better state how far this idea has been realised. The Telpherage Company (Limited) was formed last year to test and carry out my patented inventions and those of Professors Ayrton and Perry for electric locomotion. On the estate of Mr. M. R. Pryor, of Weston, in Hertfordshire, two telpher lines, on my plan, have been erected. One of these is a mere straight road, with spans of 60 feet, and various forms of rod and rope. The first full-sized train was run on this line with a locomotive which we call the bicycle-wheel locomotive. The line was found inconveniently large and high, and the experiments were continued on a line $\frac{5}{8}$-in. diameter, of round steel rods, with 50 feet span. This line is continuous, that is to say, it re-enters on itself. It is 700 feet long, and we have run a train of more than one ton at a speed of five miles per hour on this line with complete success. The insulation has given no trouble. It need hardly be said that we see our way to great improvements in details. Thus, we can make the road more uniform and stronger for its weight; we can lessen the quantity of material used, and greatly diminish the amount of skilled labour required in erection. We can improve the design of the posts. We can improve the trucks and locomotives so that they will go round sharper angles, and so forth, but the main object has been practically carried out. We have had trains, on a scale as large as I am prepared to recommend,* running at the highest speed I have contemplated.

I trust it will be clear to you from this description that what I have contemplated and realised is not an electric railway destined to

* Since this lecture, I have seen my way to run considerably heavier loads in special cases.

compete with steam railways in conveying goods and passengers at high speeds, neither is it a new form of communication destined for small parcels and high speeds; it is simply a cheap means of conveying heavy goods which, like coal or grain, can be carried in buckets or sacks, each containing two or three hundredweight. The speed on a telpher line will be that of a cart, and the object we aim at is to cart goods at a cheaper rate and more conveniently than with horses.

I will assume that you all know that an electric motor is a machine which will run so as to exert power whenever an electric current is passed through it. You also know that a machine called a dynamo, driven by a steam-engine or other source of power, will produce an electric current which may be conveyed along a suspended and insulated rod, and used to drive an electric motor.

In describing the details of my system, the first point to be explained is, how the current produced by the dynamo, and conveyed along a single line, is taken from that line and directed round the motor.

I think before going into details it may be as well to let you see the model in motion.

[Here the model was shown in action. This model consisted of two concentric octagons of wire, the length of each outer span being 5 feet. On each octagon there was a single locomotive and train, equal in length to that of the span. These trains ran well and steadily in opposite directions round the lines.]

We have here an up and a down line (Fig. 1); the little trains are about the length of one side of the octagon. The corners in this case are very sharp, viz., 45 degrees, and are only slightly rounded off. The second train, with the new locomotive, was only completed the day before yesterday, and has never run until started this evening. It hesitates a little at the corners, and wants a little helping occasionally, but, nevertheless, shows the practicability of the system.

The trains are here driven by a battery. It is a question of nice balance how much current goes through each train. If one train begins to race, it affects the other, and the largest part of my work this forenoon was, with the assistance of Captain Cordew, to put in resistance coils to enable the trains to balance. This difficulty, however, vanishes as soon as the line is worked by dynamos, which maintain a constant potential, whether you have a large or small circuit.

In endeavouring to realise this idea, the first thought which occurred to me was that of dividing the line into lengths, equal to the length of the train, so that using the train to bridge over a gap between two sections at different potentials, the current could be conveyed from the leading to the trailing wheels of the train, round the motor. This idea is employed in the model now shown; but, in the first form which suggested itself, the gaps between the sections were opened by a switch worked by the front of the train, and closed by a switch worked by the end of the train. The first model, which may have been seen by some present working in Fitzroy Street, was made on this plan. Trains driven in that way would all be coupled in series. The present model is differently arranged; there are no working parts or switches.

If A B C D E F G H and *a b c d e f g h* represent the two lines of rails, you may observe a cross connection made by gutta percha covered wire at the ends of each section (shown in dotted lines), and if the thick and thin lines be taken to denote the sections into which the line is divided, the odd sides of the outer lines are connected with the even sides of the inner line, and the even sides of the outer line with the odd sides of the inner line, we have thus two continuous circuits going right round, but not joined to each other; the rods indicated by the thick line are connected to one pole of the battery or dynamo, and the rods indicated by the thin line either to the other pole or to earth; short insulated gaps are left between the successive sections, and each section is in length equal to that of a train. So long as no train bridges a gap no current flows, but as soon as a train bridges a gap a current flows from the positive to the negative pole, from the first wheel of the train to the last, and round the motor, so that the engine is put in motion. This plan is called the cross-over system; all the trains are joined by it in parallel arc, and the current is reversed each time a train passes a gap. This reversal does not affect the working of the motor. This is the plan which has been carried out on a large scale at Weston. Its simplicity leads me to believe that it will be the plan most usualy adopted, but several other methods of driving have been devised. A spark passes between the wheels and the line each time the current is stopped; but this spark occurs between large masses of metal, where it appears to be harmless; it has given no trouble whatever at Weston. Moreover, it has been found very easy to make connection between the line and the train. The ordinary truck wheels answer admirably, so that no complicated brushes are required. There are some absolute advantages in the interruptions occurring at regular intervals, but the discussion of these would lead me too far for my present purpose.

Only one of the two continuous conductors requires to be insulated; this results in alternate insulated and uninsulated sections all along each line. Fig. 2 shows a saddle, as we call it, with an insulated attachment at the one end and an uninsulated attachment at the other, as used for a short sample line which has just been sent to Peru for the Nitrates Railway Company (Limited). The line itself is a three-quarter inch steel rod with forged ends, and the figure sufficiently shows the mode of attachment. The insulation is given by a vulcanite bell insulator. A is the uninsulated end pinned direct to the saddle. B is the insulated end pinned to the cast-iron cap C; D is a vulcanite bell insulator, on which the cap C is secured; the insulator rests on a sort of iron or pin cast into the saddle; E is a short insulated gap-piece.* All the parts are designed to stand 2·2 tons strain; the vulcanite is secured between two layers of Siemens cement. The experiments at Weston have shown that vulcanite answers perfectly, but the material is rather expensive. I have here a smaller porcelain insulator, which has been subjected to 2·2 tons strain. I believe porcelain will answer well in all respects, but it has not yet been subjected to the test of actual traffic day by day. At Weston the vulcanite was used between layers of Portland cement, the only objection to which is that it takes some time to set. The simple steel rod has been found preferable in all ways to rope. We find that there is less friction and less jar with the rod, and ample flexibility; it is also much easier to secure. Moreover, a solid rod with welded ends can be made so that the ends, where supported, are, to some extent, undercut, and this allows much greater freedom of rolling than would be compatible with the horizontal gripping wheels, especially when gripping wheels are used which, like those in the model, actually hold on to the line so as to resist being lifted.

Fig. 5 shows the posts and crossheads supporting the line. In the 1-inch example this design was fully carried out, and the posts stood the cross strain due to the overhanging load perfectly. In the five-eighth line an attempt was made to cheapen the construction, but the posts in wet weather work at the foundations. It is well that we are put on our guard against this danger. In the first design a sort of rocking saddle was employed, to allow the strain to be transmitted from one span to the next, but the flexibility of the posts provides amply for this object.

Abutment posts are required at intervals, and these can be made use of to provide compensation for changes of temperature, and to limit the stress on the rods. In straight lines I reckon about four abutment posts per mile.

* It has since been found desirable to make this gap-piece somewhat longer, and separately supported.

In the short South American line curves of 45° at the posts will be employed, as shown in the model.* At the stations, where goods are to be handled, rigid supports will be more conveniently employed. A bulb angle-iron like that shown in Fig. 4 supported every ten feet, answers well at Weston, and a siding, leading the trucks off this line, has been satisfactorily carried out. The siding leads back to the line at a point between two flexible spans. In fine, it may be said to-night that the problem of the continuous line, whether straight, curved, rigid, or flexible, has been completely solved. Drawings and specifications can be put, without further delay or experiment, into the hands of contractors.

Trucks used on ordinary rope lines are designed to be pulled by ropes on a road which is necessarily straight. When trucks of this description, with wheels 8 in. diameter and 22 in. wheel-base (Fig. 6) were tried at Weston, arranged in trains, some new difficulties presented themselves. Any sudden check to the motion was followed by a rearing action, throwing the truck off the line; similar results followed the application of any sudden pull. Moreover, trucks with two rollers on a rigid frame, even with so great a wheel-base as 22 in., require curves of considerable radius if we are to avoid serious binding at the flanges. Notwithstanding these difficulties, the trains at Weston with a little care run well and lightly, but the trucks which have gone to South America are on the plan adopted in the model, and run much more safely and turn much sharper curves. They have two peculiarities—first, each wheel 7 in. diameter (Fig. 7) is pivoted on an axis, B, vertically over the centre of the wheels, A; this allows the truck to run with the freedom of a bicycle round curves; secondly, the weight carried is hung on a swinging arm, D, pivoted to the frame at a point, P, on a level with the line. The result is that any force applied in a plane containing the line acts as if applied at the line itself, and will neither lift the wheels in front nor behind. In the model the coupling, as you see, is attached to the top of the swinging arm, where the coupling rods are well out of the way. The swinging arm, moreover, relieves the locomotive from all jerk at stopping or starting.

The truck is completed by a small hook or catch embracing the rod. In case of any accident causing the wheels to leave the line this hook will prevent the truck from falling. The weight of the two-wheel stiff truck, shown in Fig. 6, with wrought-iron buckets, is 75 lb. The weight of the two-wheel pivoted trucks, with wooden bucket, is

* These curves have been found too sharp in practice for speeds over two miles an hour.

63 lb. They are both adapted to carry 2 cwt. Fig. 8 shows a one-wheeled truck tested—the results were not favourable. A special form of bucket must be designed to suit each kind of traffic. Simple iron hooks for sacks will, in many cases, be available, and these hooks can be so contrived that on being struck they will drop the sack.

The first type of locomotive which was tried on a large scale is shown in Figs. 9 and 10. The motor lies horizontally across the line, and is connected by a form of frictional gearing, which I term right angle nest gearing, with the edge of a bicycle wheel, W. The shaft of the bicycle has on it two discs, B B, one of which is fixed on the shaft, while the other can slide longitudinally on the shaft. These two discs are pressed together by a spring D.

The next point of extreme interest is the manner in which the locomotive is guided by the horizontal wheels. In a railway you have flanges to guide the locomotive, but in this model there is not the slightest guiding done by the flanged wheels C C, the guiding is done by the two horizontal gripping rollers A A which grip the rail. These rollers are supported in such a way as to be free to come together under the pressure of the spring transmitted by the discs B and B. By tightening the spring any required grip can be obtained with no injurious friction either on the cross shaft or on the spindles of the rollers. This grip is a form of right angle nest gearing. The weight of the locomotive was taken by wheels C C, fore and aft. The following defects were observed:—The frictional surfaces, both in the upper and lower nests, were too small, and the materials too soft, so that rapid wearing resulted, with a consequent increase of friction. Moreover, the grip was so powerful that the rollers A A were capable of supporting the weight, and thus a small inclination of their vertical axis was enough to cause the locomotive to rise, and even run off the line; moreover the vertical curvature in the rope or at the posts required the rollers A A to be deep, thus limiting the extent to which rocking was admissible; moreover, very broad pulleys, fore and aft, would be required even for moderate horizontal curves. Nevertheless, this locomotive ran sufficiently well on the 1-in. line during an exhibition to the shareholders last autumn. The weight for a five-eighth line of a somewhat improved form of this type, to exert one horse-power, on the average is 200 lb. with a half-horse motor. The driving wheels A A of this example are $6\frac{1}{2}$ in. diameter. The motor makes 9·23 revolutions for one of the driving wheels. One mile per hour corresponds to 473 revolutions per minute of the motor. 37 in. pounds at the motor spindle are required for a pull of 100 lb. at the rail.

Figs. 11 and 12 show a locomotive designed by Mr. A. C. Jameson, when I was personally unable to attend to work. This locomotive, which is called the belt locomotive, shows a great advance on its predecessor. The general arrangement of the upper nest grip is retained, but a most ingenious modification has been introduced by which the discs C C run on one path on the rollers A A, while the rod runs on another. In this way the dirt from the line is never conveyed to the driving disc surface between A and C. Moreover these frictional surfaces, which are points in the first form, have become lines in the second. This head answers admirably. The weight is carried by a roller, B, between the gripping discs, an arrangement contained in one of my first small models, and wrongly rejected in the first large locomotive. With this subdivision of weight the gripping wheels are much less likely to rise, and can be made very shallow. In the actual locomotive these gripping wheels are of an open inverted Λ shape, which has certainly run very well, although I prefer at present the upright V shape, which closes under the rail, as used in the model before you. Both of the gripping rollers drive, as in the first type. The cross shaft is driven by a belt on a 20 in. pulley, D, from the pulley E on the motor spindle. The friction due to the pull of this belt on the motor spindle is relieved by friction rollers. This locomotive runs extremely safely and steadily on the line; indeed, I am not aware that it has ever been thrown off.

The following are particulars of its construction:—Weight with 96lb. motor, 269lb.; wheel-base, 2ft. 6in.; diameters of driving rollers, 6in.; 4.94 revolutions of motor per one revolution of driving wheel. A couple of 60·6in. lb. on motor is required for 100lb. pull at rail; 276 revolutions of motor correspond to one mile per hour on the rail.

The only improvements I have to suggest in this design are:—1st, the addition of gear, which will give a higher speed of motor for the normal speed of four miles per hour, which we contemplate; 2nd, the addition of a swivel or bogie arm, such as is used in the model before you; 3rd, improvements in the belt connection.* Moreover, the machine requires strengthening in some places. It will, however, be seen that none of these points touch the essential features of the design, which might at once be adopted in practice. Worked with motors of the Gramme type, the additional gear would not be required.

Before the belt locomotive had been completed it was necessary to design a locomotive for the South American line, which I have several

* A pilch chain has since been applied, with perfect success.

times mentioned. I had meanwhile constructed the model which is now before you; and this little locomotive, in which the power is transmitted by ordinary spur wheels, ran so extremely well that I adopted the general arrangement for the next example on a large scale. This arrangement is shown in Figs. 12 and 13, the grip (C C and B B) is a third variety of the right angle nest, simpler than that in the belt locomotive. In this form, also, we have line contacts, and two paths for the disc and rod. Where it is desired to drive from both sides this arrangement is less powerful than that in the belt locomotive. In the South American locomotive I drive from one side only, leaving the off side roller free to revolve as it pleases; this avoids grinding at rapid curves, and the adhesion given by one wheel will be ample in a dry country, such as that where this locomotive is to work. The arrangement of the gearing E and F is obvious; it allows the locomotive to lie fore and aft instead of across the line, and this arrangement has some advantages in the adjustment of the weights. The surfaces of the gripping wheels are arranged like an upright V, so as to hold on under the line. This makes it very difficult for the wheels to leave the line, both because of their absolute hold and because the inclination of the V is such as to favour the action of gravitation in overcoming the friction of the grip, instead of opposing it as in the inverted V.

Another feature of this machine is the arm pivoted at P, and carrying the leading wheel, which is again pivoted at M in the arm, as in the case of the trucks. This arrangement allows the locomotive to traverse curves of 6 ft. radius—a very remarkable result.

The full-sized locomotive has only just been completed, and run on three spans at Messrs. Easton and Anderson's. So far as I am able to judge from the trial, it is likely to be a complete success. It will be immediately shipped for its destination, so that its performance cannot be more fully tested in this country. The following particulars will show that it is much more powerful than the belt locomotive, but it is considerably heavier:—Wheel-base, 2 ft. 6 in.; weight, about 3 cwt. 14 lb.; 15 revolutions of motor per revolution of driving wheels; diameter of driving wheels, 10 in.; 33·3 in. lb. per 100 lb. pull at rail; 504 revolutions of motor per minute for one mile per hour.

I am in doubt at this moment whether to adopt the belt locomotive or the spur wheel locomotive for the next example. It is simply a question of cost, weight, and durability. Either will do the work.

In all the arrangements it is essential that the second bearing wheel should lead, not follow the drivers in regular work. The reverse arrangement lets the rope lead on at an angle with the plane of the roller, causing an injurious grinding action.

Details of couplings have been well worked out, but space fails for their description.

As general features of the train running on the line I may mention that the deflection of the rod within reasonable limits has very small influence on the resistance. When the deflection on a 50 ft. span was about 2·4 ft., the resistance for a train of trucks, weighing in all 1,260 lb., was 22 lb.; and no sensible difference could be detected when the deflection was materially reduced. This resistance was measured by pulling a train along, span after span, by one end of a rope passing over a pulley on the leading truck, and having a weight hanging vertically from the other end of the rope; the weight thus limited the pull. This pull differs extremely little as the train moves along, for when one part of the train is descending the curve the other part is ascending. It should be noted that during this experiment no special care had been taken to oil the bearings, and I have no doubt this pull can be materially reduced.

I have ventured to dwell at some length on the mechanical problems involved in this form of telpherage, because the experiments made so far have chiefly borne on questions of mechanics. The makers of dynamos can put at our disposal apparatus which will generate day after day, with perfect certainty and regularity, currents of electricity such as will transmit the horse power generated by powerful steam-engines. These makers have already solved the chief electrical problems which present themselves in connection with telpher lines. They can give us at will constant current or constant electromotive force, high or low, as we may choose. They are now able to arrange their apparatus so that any number of incandescent lamps may be turned off or on without disturbing the regularity with which other lamps are supplied, and by the same arrangement we are enabled to start or stop any number of telpher trains without disturbing the running of others. The electrical problems of the telpher line, and those of electric lighting, run in absolutely parallel lines.

The electric motor, although it may be termed a mere inversion of the dynamo, has not as yet been brought to equal perfection, but month by month improved designs, proportions, and materials are being introduced, and the result already obtained is sufficient for our purpose. It is all the more encouraging to feel that these results will certainly be surpassed, and far surpassed, in the immediate future.

The following short summary of the problem of the transmission of power by means of electricity may interest those who have not studied the subject. There are three steps in this transmission—1st, we convert mechanical power into electricity by means of a dynamo; in doing so we incur a loss of from 10 to 20 per cent. 2nd. This electricity, in flowing along a conductor, generates heat, representing a further loss analogous to that resulting from friction in mechanical gearing. This loss, depending on the distance of transmission, the size of the conductor, and the electromotive force employed, is easily computed. 3rd. We re-convert the electricity into mechanical power by means of an inverted dynamo, which we term an electric motor. With motors in which large weights of iron and copper are employed, the loss in re-conversion need not exceed 20 per cent., but with light motors, weighing from 70 lb. to 100 lb. per horse power, such as we must employ in the locomotives, I could not undertake with certainty at this moment to effect the re-conversion without a waste of one-half. The effect of all these sources of loss is, that at the stationary engine I must exert about 3-horse power for every single horse power which is employed usefully on the line. I look forward confidently to the time when 2-horse power at the engine will be sufficient to give 1-horse power to the motor.

To put these conclusions in a more scientific form, I may assume the efficiency of my dynamo as 80 per cent., that of my light motor as 50 per cent. The waste by heat expressed as horse power is equal to $\frac{C^2R}{746}$, where C is the current in amperes, and R the resistance in ohms. The horse power represented by the current is equal to $\frac{E \cdot C}{746}$, where E is the electromotive force in volts, and C the current in amperes. It follows from the last expression that I may increase the horse power in three ways, by increasing either E or C, or both. If I increase E, leaving C the same, I do not increase the loss during transmission along the line, no matter what horse power the given line may transmit. A practical limit is set to the application of this law by the difficulty met with in dealing with electromotive forces above 2,000 volts. Marcel Duprez, taking advantage of this law—first pointed out by Sir William Thomson—has transmitted 7 or 8-horse power over seven or eight miles, through an ordinary telegraph wire, and he obtained a useful duty of 63 per cent., taking into account all the three sources of loss which I have enumerated. With small motors I cannot yet promise a result so good as this, and I merely mention it to let you understand that, in speaking of 3-horse power for one at the locomotive, I am leaving a very ample margin.

Quitting generalities, I will give some details as to the electrical and other conditions necessary, in two examples, for what may be considered as typical telpher lines :

First Line.—Length, five miles. Length of circuit, out and in, ten miles. Twenty-five trains running at once, space one-fifth of a mile apart ; speed, four miles per hour. Let each require 1-horse power on the average ; let the motor take on the average two amperes of electric current ; let the electromotive force near the stationary engine be 840 volts ; the electromotive force at the end of five miles will be about 746 volts. The total current entering the line will be fifty amperes at the near end of the line. Fifty amperes and 840 volts represent 56·5 horse power ; of this 6·5 horse-power will be wasted in heating the line ; the remaining 50 horse-power will do work in the motors equivalent to 25 horse power. In order to give this current of fifty amperes with 840 volts, the stationary engine will require to exert $\frac{10}{8} \times 56\cdot$ horse power, or, roughly, 70 indicated horse power, or somewhat less than three times the useful horse-power. Let us now examine the economical results to be obtained from such a line as this. Mr. Dowson, in an interesting comparison between the cost of horse power obtained from coal and gas, reckoned the cost per horse-power for a 100-horse power engine at the rate of £3. 6*s*. 9*d*. per annum, to include wages, coal, oil, and depreciation. Mr. Dowson would naturally be led to put the cost of steam power obtained from coal rather high than low. I will, however, adopt a very much higher figure, and assume that the power may cost as much as £6. 10*s*. per horse per annum ; this gives £455 as the cost of the 70-horse power required for my telpher line.

Let the 25 trains each convey a useful load of 15 cwt. In a day of eight hours the line will have conveyed a traffic which we may express as 600 ton-miles—*i.e.*, it will be equivalent to 600 tons conveyed one mile, or 60 tons on each line conveyed from end to end daily. If we count 300 working days in the year, the sum of £455 gives £1. 10*s*. 4*d*. per diem, and the 600th part of this is about 0·604 of a penny as the cost of the power required to carry a ton one mile.

In Great Britain we ought easily to be able to reduce this below a halfpenny per ton per mile, which proves that the apparent great waste, even of two-thirds of the power in transmission, does not involve prohibitory expense. In calculating the whole cost of transport, we must further take into consideration the cost of the installation. Taking the spans at 70 feet, I estimate this cost as follows :

	£
Line £500 per mile	2,500
Engine, boiler, and shed, at £20 per indicated horse-power	1,400
Dynamo and fittings	1,000
Twenty-five trains, I put at £100 each	2,500
Contingencies	600
Total cost	£8,000

Allowing $12\frac{1}{2}$ per cent. for interest and depreciation, this represents an annual cost of £1,000. Allowing £100 as the salary of an electrician or young engineer, and adding £455, the cost of the power, this gives a total annual expenditure of £1,555 for the daily duty of 600 ton-miles. If we continue to assume the year as containing 300 working days, the total cost of conveying one ton one mile will be found equal to 2·07*d.* If goods are to be transmitted for long distances, the same calculation applies. We should simply have stations ten miles apart, working lines five miles long on each side of them. This, then, is the practical outcome of the general principles stated at the beginning of this paper. We may expect with great confidence to being able to convey goods for any distance at the rate of 2*d.* per ton per mile by the agency of the suspended telpher line, this, however, supposes there to be a very considerable traffic.

Matters are somewhat modified when the traffic is smaller. Making similar calculations for a line one mile long instead of five, with only four trains running at once, we might employ an electro-motive force as low as 100 volts; the loss by heating would be insignificant; we should require about 12-horse power; the work done in eight hours would be 96 ton-miles. I estimate the cost of installation at £1,600, and the annual cost of working £344, without the annual salary of an electrician. This corresponds to 2·875*d.*, or less than 3*d.* per ton per mile. One very important feature in respect to the cost of telpher lines is the fact that the larger part of that cost is due to plant, such as locomotives, trains, and dynamos. This plant can be increased in proportion to the work required; thus there is a very moderate increase of cost in the rate per ton per mile for a small traffic as compared with a large one, and, on the other hand, a line laid down for a small traffic will accommodate a much larger traffic with no fresh outlay on the line itself.

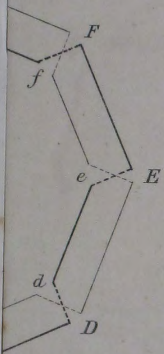
Then, again, a number of lines may be made to a common centre, there is no reason why the plant should not be common to a dozen or thirty lines which might converge on a railway station, where they would not compete with the railway, but form a number of feeders to it, and thus supply it with more traffic.

There are many minor points that will occur which I do not propose to treat of to-day. For instance, it will be necessary to govern the speed. Owing to the extreme rapidity of the motor, a very trifling break is sufficient to check the velocity down hill. I am perfectly able to push or pull the train, which I push round here, (illustrated by model). Then the question of blocking requires to be considered. Several automatic plans have been devised, by which the driving current is stopped or diverted from a train which approaches too near its predecessor; but until trains come to run much quicker than anything I have described, if one train sticks, the very best thing that could happen to it would be that another train should overtake it and give it a push (illustrated by the lecturer, the broken down train was driven forward by the one in motion). The question of sidings also is not difficult.

There are numerous minor electrical problems involved, but time does not permit me to enter into the consideration of these to-night. It will be sufficient for electricians when I say that I see my way to governing, blocking, and breaking the trains, without ever interrupting the current used to work the motor, except between the line and rolling wheels. At this point we already know that the interruption, although accompanied by a spark, does no injury whatever. I have often been asked whether the frequent reversals involved in the cross-over system do not tend either to injure the dynamo or the motor. I made special experiments on this very point lately with a compound wound Crompton dynamo and Mr. Reckenzaun's motor with thirty-six coils. I was unable at the commutator of the motor to detect the smallest change in the motion due to the most rapid reversal. At the dynamo commutator I could just see when the reversal occured, but there was no change of a character to cause the smallest alarm. At the same time I may state that, when from any cause reversals may be thought undesirable, we are in possession of apparatus which we call "step overs," which, without diminishing the simplicity of the permanent way, enable us to send a continuous and unreversed current. These and similar electrical questions, such as the performance of Messrs. Ayrton and Perry's excellent motors, might possibly have had greater interest for electricians than some of the mechanical details discussed to night; but I have felt that the main point to establish, in bringing this invention before the public, is that we have in telpher lines a means of conveying goods in an economical manner, by lines, locomotives, trucks, dynamos, and motors, which have undergone their preliminary trials with success, and can be at once applied to the more searching test of performing work for the public. If I have established this fact, I think you will have no difficulty in believing that the subsidiary electrical problems have been, or will be, readily solved. I hope that at a future period these will be brought before you in detail on many occasions and by many men.

In conclusion, I will enumerate some of the uses to which telpher lines may be put. They will convey goods, such as grain, coal, and all kinds of minerals, gravel, sand, meat, fish, salt, manure, fruit, vegetables, in fact, all goods which can be divided conveniently into parcels of two or three hundredweight. If it were necessary, I should feel no hesitation in designing lines to carry five or six cwt. in each truck. The lines will carry even larger weights when these, like planks or poles, can be carried by supension from several coupled trucks. The lines admit of steep inclines; they also admit of very sharp curves. Mere way leaves are required for their establishment, since they do not interfere with the agricultural use of the ground. They could be established instead of piers, leading out to sea, where they would load and unload ships. With special designs, they could even take goods from the hold of a ship and deliver them into any floor of a warehouse miles away. When established in countries where no road exists, the line could bring up its own materials, as a railway does. Moreover, wherever these lines are established, they will be so many sources of power, which can be tapped at any point, for the execution of work by the wayside. Circular saws, or agricultural implements, could be driven by wires connected with the line, and this without stopping the traffic on the line itself. In fine, while I do not believe that the suspended telpher lines will ever compete successfully with railways, where the traffic is sufficient to pay a dividend on a large capital, I do believe that telpher lines will find a very extended use as feeders to railways in old countries, and as the cheapest mode of transport in new countries. In presenting this view to you, I rest my argument mainly on the cost of different modes of transport, which may, I believe, be stated approximately as follows:—Railway, 1*d.* per ton per mile; cartage, 1*s.* per ton per mile; telpher lines, 2*d.* per ton per mile. And let it be remembered that, in taking the cost of cartage at 1*s.* per mile, the first cost and maintenance of the road is wholly left out of account; whereas, in my calculations for the telpher line allowance has been made both for establishment and maintenance.

TELPHERAGE. Plate I.



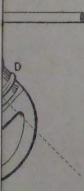


Fig. 3.

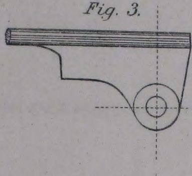


Fig. 4.

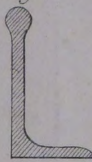


Fig. 5.

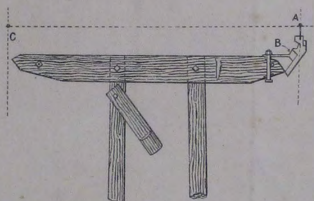
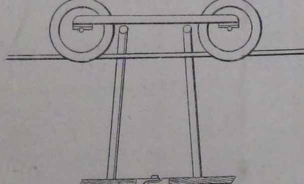


Fig. 6.



PAPER II.

THE EFFECT OF PROJECTILES ON MASONRY AND EARTHWORKS.

By Lieut.-Colonel F. G. Baylay, R.A., Chief Instructor R.M. Repository, Woolwich.

Being a Précis of the Experiments carried on at Dungeness and Lydd in 1880–81–82–83–84.

Introductory Remarks.

Before entering on the subject of the various experiments in connection with siege operations and siege artillery, which have, during the last four years been carried out at Dungeness and Lydd under the Ordnance and Siege Operations Committees, I would wish to remark that time will not admit of my doing more than bringing the main points of interest under your notice; a vast mass of detail must of necessity be passed over. I shall therefore confine myself to a brief précis of the information gained in the various experiments carried out.

Although full and detailed reports of experiments are annually printed at the War Office, they are only issued to a few heads of departments and to the officers belonging to, or associated with, the Committees charged with carrying out the experiments. Only a very small number of officers have therefore a chance of ever seeing these reports, and of those that do, but few have the time and opportunity for reading them critically and extracting, as it were, the cream of the matter.

I hope, however, that the short account of these experiments I have prepared will be found to meet the want indicated.

EXPERIMENTS CARRIED OUT AT DUNGENESS IN 1880

UNDER THE

SIEGE OPERATIONS COMMITTEE.

In referring to the experiments carried out at Dungeness in 1880 under the Siege Operations Committee, I shall necessarily have to confine my remarks to the experiments in connection with breaching revetments, and detached walls of concrete and brickwork, by curved fire.

Preliminary Experiments.

Before entering upon the main breaching experiments the Committee carried out a series of preliminary trials with the view of gaining information on the following points viz :

1. The lowest limit of effective striking velocity of shells of various descriptions on concrete and brickwork.

2. The greatest obliquity of fire permissable (having due regard to effect) with shells of different weights, and at various striking velocities.

3. The comparative efficiency of various percussion fuzes.

4. The relative effects of gunpowder, and gun-cotton bursters.

With respect to the material fired at, it may be stated that the concrete was of fair quality for concrete made with rounded shingle; it was made in the proportion of 6 parts shingle, 1 of sand, and 1 of Portland cement.

The brickwork was made with bricks of very hard quality set in Portland cement (three parts sand to one of cement).

The following conclusions were drawn at the termination of the preliminary trials:—

Subject 1.—Lowest limit of effective striking velocity, for breaching concrete or brickwork.

6·3″ R.M.L. Howitzer.—With the 6·3″ R.M.L. howitzer firing a 70 lb. shell, the lowest effective limit has been passed when the striking velocity falls to 300 f.s., because the effects produced are so slight that the expenditure of time and ammunition requisite for the formation of a breach would be excessive; with such shells it would appear, from these and subsequent experiments, that with a striking velocity of about 400 f.s. the frontal fire of this piece may be considered effective at angles of descent up to 20°.

6·6″ *R.M.L. Howitzer.*—With the 6·6″ R.M L. howitzer firing a 100 lb. shell with a 2 lb. charge (the smallest used), the striking velocity is never less at any range than 420 f.s., and with such velocity the frontal fire is effective (especially against detached walls) at angles of descent considerably above 20°.

8″ *R.M.L. Howitzer* (70 *cwt.*)—With the 8″ R.M.L. howitzer of 70 cwt. firing a 180 lb. shell, the smallest charge used is $3\frac{1}{2}$ lbs., and the lowest striking velocity at any range is 432 f.s. It is evident that since such velocity proved effective with the lighter shells of the 6·3″ and 6·6″ howitzers, it would prove still more so with the 180 lb. shell thrown by this piece, and at any angle of descent likely to be required.

Comparative efficacy of Common and Battering Shells.—Generally speaking, there would appear to be hardly any difference in penetration into concrete and brickwork between common and battering shells, and consequently the former are to be preferred on account of the greater effect produced by their heavier bursting charges.

Subject 2.—Greatest obliquity of fire permissable.

The object in carrying out these trials with oblique fire may be explained as follows:

The shorter the horizontal distance between the crest of the glacis and the face of the wall the greater the angle of descent required to enable a shell to strike any given point—say, half way down the wall—and, the higher the angle of descent, the lower the striking velocity. Again, the lower the velocity the greater the loss of accuracy and effect.

Now, in the case of a battery firing *obliquely* at a wall, it is evident that the horizontal distance between the crest of the glacis and the revetment (measured in the plane of fire) is greater than would be the case if the fire of the battery was 'frontal,' and, therefore, a higher striking velocity, with its attendant advantages, could be secured in the former than in the latter case.

From the results obtained in the trials carried out, the following conclusions were arrived at:

6·3″ *R.M.L. Howitzer.*—With the 6·3″ howitzer, when the striking velocity approaches 400 f.s. the fire may be considered effective at angles of impact as low as 60°, and even at 55°, although the shells glance, the face of the wall is prepared for the effective action of subsequent shells.*

6·6″ *R.M.L. Howitzer.*—With the 6·6″ howitzer, when the striking

* Maximum effective angles of descent. 6·3″ Howitzer, about 20°; 6·6″ and 8-inch ditto, considerably in excess of 20°.

velocity approaches 500 f.s. the fire is effective at angles of obliquity as low as 45°, and even at 40° considerable work is done on the wall.*

8″ *R.M.L. Howitzer* (70 *cwt.*)—With the 8″ howitzer, when the striking velocity approaches 600 f.s., the fire may be deemed effective at angles of obliquity as low as 40°.*

In the case of granite, it does not appear (from some experiments carried out at Shoeburyness) that much work would be done by shells striking at an angle of impact less than 60°, and, even then, from the fact of cast-iron shells breaking up on impact, the effect produced in the earlier stages of breaching would, doubtless, be very small.

Generally speaking, the obliquity of the angle of impact at which a given effect will be produced, increases both with the weight of the shell and with the striking velocity.

Comparative efficiency of various Percussion Fuzes.

With respect to the experimental fuzes tried in these experiments, it may be observed that—

Delay Fuzes.—Delay action fuzes were employed with a view of bursting the shell at extreme penetration, and in the few cases where this result was secured, the effect was very good; but it frequently happened that the shell glanced or rebounded from the wall before bursting, thus only producing the same effect as a blind shell; hence it was concluded that for breaching purposes the direct action (quick) fuse was to be preferred.

D. A. Fuze—This fuze has now been introduced into the service; used in the nose of a shell, its action is not so quick as to burst the shell before a fair amount of penetration has been attained.† It rarely fails to act on direct impact, but cannot be depended on to act on graze, when fired at angles of elevation under 10°. It is the percussion fuze almost exclusively used for common shell in the siege train at the present time.

Relative effects of Gunpowder and Guncotton Bursters.—It cannot be said that the relative efficacy of these two explosives when employed as shell bursters has as yet been determined.

In the experiments under consideration only common cast-iron shells were provided, consequently the wet guncotton discs had to be granulated and pressed by hand into the shell with a wooden drift.

* Maximum effective angles of descent. 6·3″ Howitzer, about 20°; 6·6″ and 8-inch ditto, considerably in excess of 20°.

† The amount of penetration to point of burst is naturally dependent on the striking velocity of the shell and the hardness of material fired at.

The result was that a charge of only from one-half to one-third the weight of the powder burster could be got into the shell, and what guncotton was inserted was too full of air spaces to enable it to be properly detonated. The further disadvantage arose in the range being affected by the lightness of the shells so filled. Notwithstanding these drawbacks, however, in the only instance where a direct comparison could be instituted, the guncotton manifestly produced the best effect.

The subject of shell bursters is now engaging special attention and it is probable that considerable light will ere long be thrown on this question.

Main Breaching Experiments.

In future sieges the artillery of the attack will often be called upon to form breaches under conditions of considerable difficulty, consequent upon the more general adoption of a system of narrow deep ditches with low well covered escarps and detached walls. In many cases it may be necessary to secure angles of descent for the projectiles up to 20° or even more, and the experiments now under consideration were carried out to ascertain whether high angles of descent could be secured from our rifled howitzers at long ranges, in conjunction with a reasonable amount of accuracy and striking velocity.

Breaching by 'Demolition.'—It is evident that in long range curved fire the only practicable method of destroying a concealed wall is by means of fire generally distributed over the portion intended to be breached; this system has, moreover, the advantage of causing the masonry to be well broken up, and, hence, it combines with the earth and the parapet, to form a practicable slope.

In the First Experiment (see Plate 1.) fire was opened at a range of 1,600 yards, from two sunken batteries, armed respectively with 8″ R.M.L. howitzers of 70 cwt. and 6·6″ R.M.L. howitzers of 36 cwt. (2 howitzers in each battery). The fire was directed against the counterarched portion of the main revetment, with the object of forming two practicable breaches, each battery acting quite independently of the other.

It was so arranged that each breach should be made half in concrete and half in brickwork, so as to obtain an insight into the comparative value of these two materials for resisting shell fire.

The height of the wall was 18′, and its thickness at the cordon 4′ 1½″. At the lowest calculated point of impact (10′ below the cordon) the thickness was as follows, viz.: concrete 3′ 9″, brickwork 0′ 3″. The crown of the counterarches was 4′ 3″ below the cordon.

The crest of the glacis was 4′ above the top of the wall.

Width of ditch (crest of glacis to cordon) measured at right angles to the face of revetment, 43′.

The conditions of fire, which was oblique in both cases, were as follows, viz :

8″ Howitzers.

Horizontal angle of line of fire with face of wall 54° 30′.

Projectile common shell 180 lbs. with D.A. fuze.

Bursting charge 14 lbs. (nearly).

Angle of decent 14° 18′.

Striking velocity 579 f.s.

6·6″ Howitzers.

Horizontal angle of line of fire with face of wall 60°.

Projectile, common shell, 100 lbs., with D.A. fuze.

Bursting charge 5 lb. 8 oz.

Angle of descent 14° 12′.

Striking velocity 547 f.s.

The firing was carried out in this, and in the subsequent experiments, under service conditions, *i.e.*, the officers directing the fire had to rely on their own observations for applying corrections. It is true that they had an observing party, with which they were in telephonic communication, in a splinter proof 200 yards short of the glacis, but this point was situated so low down, that it was soon found their observations were less trustworthy than those taken from the batteries.

Observations of the Effects of Fire.

It will perhaps be interesting to offer here a few remarks regarding the facilities that were found to exist for observing the effects of fire.

1. In the first place owing to the large size of the shells, and the low velocity at which they travelled, they could easily be seen throughout their whole flight with the aid of a field glass.

2. The flash of the burst of those that struck the glacis could plainly be perceived.

3. In the case of those that struck the parapet the flash was not so clearly seen, but more material was moved.

4. When the shell struck the wall high up, the strongly illuminated smoke was, towards dusk, rather apt to be mistaken for the flash itself, but fragments of masonry could generally be seen hurled into the air indicating an effective hit.

5. Those that struck the wall low down showed no flash: only a flattened out cloud of smoke accompanied by fragments of masonry.

6. The width of the breach could be fairly estimated by the amount of material that slid down from the parapet.

It is worthy of note that the weather was clear, fine, and nearly calm. Subsequent experiments have proved that, in squally weather, the efficiency of howitzer fire, especially at high angles, is very largely impaired.

After 112 rounds had been fired from the 8″ howitzers a practicable breach, 36 feet wide at the neck, was formed, and 35 per cent of the shells fired had taken effect on the wall. The distribution of the rounds was as follows:

On wall	39
On parapet	33
On glacis	29
Under	6
Over	5
Total	112

It took 300 rounds from the 6·6″ howitzer to form a practicable breach 30 feet wide at the neck, and only 24 per cent. of the shells fired took effect on the wall; the distribution of rounds was as follows:

On wall	72
On parapet	99
On glacis	103
Under	8
Over	18
Total	300

The rate at which it was found practicable to maintain an accurate fire was one round every three minutes from each howitzer (whether 8″ or 6·6″) or twenty rounds an hour per piece.

From this experiment it is seen that the heavier piece does the work required in from half to a third the time taken by the lighter, and not only so, but the actual total weight of material required to be moved up from the base of operations, is *greater* for the latter than for the former.*

Accuracy and shell power being the chief essentials for work of this nature, the importance of employing, whenever practicable, pieces in which these qualities are combined is obvious.

* 55 cwt. more material was required for the lighter howitzer than for the heavier.

It is to be observed that, from the fact of the parapet being made of shingle, which flowed down very freely as soon as the upper part of the wall was destroyed, the breach became practicable at an earlier period than would have been the case had the parapet been formed of earth; indeed the shingle ran down and formed an unbroken slope before the arch-rings were more than partially destroyed.

In the Second Experiment two breaches were formed in the plain portion of the revetment (see Plate II.), by the oblique curved fire of the 6·6″ inch and 8″ (70 cwt.) howitzers, at ranges of 2,300 and 2,500 yards respectively, the conditions of fire were as follows:

6·6″ Howitzers.

Horizontal angle of line of fire with face of wall 54° 30′.
Projectile, common shell, 100 lbs., with D.A. fuze.*
Bursting charge 5 lb. 8 oz.
Angle of descent 14° 8′.
Striking velocity, 666 f.s.

8″ Howitzers.

Horizontal angle of line of fire with face of wall, 48°.
Projectile, common shell, 180 lbs., with D.A. fuze.*
Bursting charge, 14 lbs.
Angle of descent, 12° 12′.
Striking velocity, 742 f.s.

The crest of the glacis was, as in the first experiment, 4 feet above the cordon.

The thickness of the wall was 6′ 6″ at top, and about 7′ 6″ at half way down.

Each breach was formed half in brickwork and half in concrete.

The result of the firing was as follows:

8″ Howitzers.—After 139 rounds from the 8″ howitzers, of which 33 per cent. took effect on the wall, had been fired, a practicable breach, about 30′ wide at the neck was formed.

The distribution of the rounds was—

On wall	46
On parapet	42
On glacis	44
Under	2
Over	5
Total . . .	139

6. 6″ *Howitzers.*—After 175 rounds had been fired from the 6·6″

* A few battering shells were also fired.

howitzers, the practice was discontinued, owing to there being no more common shell. The breach was only about half formed, and it was calculated that as much ammunition again would have to expended to make it practicable.

The practice of the 6·6″ howitzer at this long range (2,300 yards) was far from accurate—only 15 per cent. of the shells fired taking effect on the wall, although the atmospheric conditions were fairly favourable.

The Third Experiment was breaching the detached wall with the 6·3″ howitzer, by oblique fire at 1,000 yards.

In this case the crest of the glacis was 2′ 8″ above the top of the wall, which was 13′ 6″ high. It was made of hard bricks, set in cement, and was 2′ 3″ in thickness, with counterforts of 2′ 3″ in depth, and about 7′ 6″ apart in the clear.

The horizontal distance between the crest of the glacis and the face of the wall was 38′ 3″.

The conditions of fire were as follows:

6·3″ *Howitzer.*

Horizontal angle of line of fire with face of wall, 60°.

Projectile, common shell, 70 lbs., with D.A. fuze.

Bursting charge, 7 lb. 2 oz.

Angle of descent, 20°.

Striking velocity, 370 f.s.

When 123 rounds had been fired, of which 28 per cent. hit the wall, a gap was found to have been made in the wall 6′ wide and 2′ 9″ high, besides which the wall was very considerably injured and shaken.

With the small charge ($1\frac{1}{2}$ lbs.) used, the shells were unsteady in flight, and consequently the fire was somewhat erratic; besides which, from the fact of there being no work behind the wall on which to note the point of impact, considerable difficulty was experienced in correctly estimating the results obtained.

It is to be observed that, owing to the detached and sunken position of walls of this nature, no indications are afforded to the battery of the effect of the fire; and, moreover, as the demolition proceeds many shells will be wasted by passing through gaps already formed in the masonry.

The distribution of the rounds fired was as follows:

Under and on glacis	40
Hit wall	34
Through gaps and over	49
Total	123

Conclusions.

From the experience gained in these experiments it was deduced that the howitzers of the siege train may be successfully employed for breaching concealed revetments by curved fire up to the ranges specified below, viz:

6·3″ R.M.L. howitzer	. . . .	1,600 yards.
6·6″ ,, ,,	. . . . .	2,300 ,,
8″ ,, ,, (70 cwt.)	. .	2,800 ,, .

It must however be borne in mind that as the range increases so does the accuracy of fire, and power of making correct observations decrease.

The great efficacy of the 'reverse' system of laying was thoroughly established in these experiments.

With regard to the relative value of concrete and brickwork as a material for escarps and detached walls, the conclusion arrived at was, that concrete should only be employed for foundations and for such walls, or parts of walls, as are not likely to be exposed to breaching fire.

The Committee attached great importance to the employment of powerful pieces *of large shell power* for siege purposes, and advocated the introduction of 'jointed' pieces for use in cases where difficulties, in the way of transport, might otherwise prevent such powerful ordnance being placed in position.

The result of these experiments showed that curved fire could be successfully employed for breaching at ranges which had hitherto been considered prohibitive, on account of the excessive expenditure of ammunition which it had been thought would be found to be necessary in order to attain the required result.

Captive Balloons.

In these experiments trial was made of captive balloons with the view of ascertaining their value as a means of taking observations.

The balloons used were skilfully worked by Captain Templer and by Captain Elsdale, R.E., assisted by a body of trained sappers.

The trials made showed that a captive balloon in calm weather affords a favourable post of observation; owing, however, to the many drawbacks attending their employment, the Committee refrained from recommending their introduction into siege train equipment.

The disadvantages referred to may be stated to be as follows:

1. The fact that they can only be used in calm weather.
2. The difficulty of obtaining gas and filling them.

3. Extra transport required, and the difficulty of bringing them to the required point of observation.

4. The fact that, even when constructed to carry only one man, they offer so large a target for the enemy's fire that they could only be used at long distances from the object to be observed.

In order to ascertain how far captive balloons are liable to be injured by shrapnel fire, two rounds were fired from the 13-pr. R.M.L. field gun at a balloon anchored at a height of about 850 feet and at a range ascertained by the Watkin range finder to be 1,950 yards. The size of the balloon was: height, 42 feet; greatest diameter, 33 feet.

The first round was estimated to burst 30, and the second 50 yards short. The result was that 56 holes (some of them large rents) were made in the balloon, which slowly sunk to the ground.

It is almost needless to say that had there been anyone in the car it would have come down much faster.

It was intended to have carried out a similar trial at 4,000 yards, but a squall of wind blew the balloon down on to the sea and burst it; so the trial never came off. Having regard, however, to the large size of target offered by balloons, it is reasonable to infer that even at this distance they would not long remain uninjured if exposed to the shrapnel fire of accurate rifled pieces.

It would have been both interesting and instructive if opportunity had been afforded, in the late campaign in Egypt, of trying a captive balloon. Such countries (in which the atmosphere is generally still and clear) afford, of course, special facilities for their employment.

It would appear that captive balloons might be employed with marked advantage by the defenders of any place undergoing a state of siege. In such a case, many of the objections urged against their introduction into siege train equipment would not apply, and the advantages that would accrue to the defenders from possessing the means of gaining information respecting the concealed operations of the assailants are too obvious to need comment.

EXPERIMENTS CARRIED OUT IN 1881,

UNDER THE

ORDNANCE COMMITTEE AT DUNGENESS.

The object of these experiments was to ascertain the penetration and disruptive effect of shells fired from heavy and siege guns into concrete, earth, and sand. As the size of the target was small, and the amount of ammunition limited, it was decided to carry out the experiments at such short ranges as would enable each shot to be planted in the desired position on the work fired at.

Experiments against a Concrete Butt.

The dimensions of this butt, which was built by contract and completed in June, 1879, were as follows:—

Length 39 feet, height 12 feet, thickess 31 feet.

The concrete was composed of 6 parts shingle, 1 part sand, 1 part Portland cement.

Weight per cubic foot, 138 lbs.

The Dungeness butt may be considered a fair average example of concrete made of rounded shingle.

It is, however, worthy of remark, that the material in the interior was more full of air spaces, and consequently weaker than on the outside. In the case of concrete composed of smooth water-worn stones it would seem necessary, in order to fill the interstices, to use a larger proportion of sand than is considered requisite for concrete made with broken stones.

The concrete was laid and rammed in layers, from 9 to 12 inches thick. The want of cohesion between the layers, which was evident from the first, may be, in a measure, referred to the fact that they were not keyed together, and were consequently more easily disturbed, than would have been the case had this precaution been taken.

The concrete butt was fired at, from the land side, by the 10″ R.M.L. gun of 18 tons, and the 6″ B.L. gun of 80 cwt., at a range of 145 yards, and from the seaside by the 6·6″ R.M L. gun, at a range of 41 yards; the line of fire was at right angles to the face of the butt in each case.

The following Tables show the charges used, striking velocity, &c. of the guns fired at the concrete butt.

GUNS FIRED AT CONCRETE BUTT.

Ordnance	Charge lbs.	Weight of projectile lbs.	Velocity F. S.		Striking Energy f.t.	Range
			Muzzle	Striking		
10″ R.M.L. 18 tons	95. P²	408	1446	1424	5738	145 yards
6″ B.L. 80 cwt.	34. P.	80	1944	1893	1989	145 yards
6·6″ R M.L. 70 cwt.	25. P.	100	1509	1497	1555	41 yards

BURSTING CHARGES OF SHELLS.

Nature of Shell	10″ R.M.L.	6″ B.L.	6·6″ R.M.L.
Common	20 lb. 4 oz.	5 lb.	5 lb. 8 oz.
Palliser	7 lb.	1 lb. 9 oz.	2 lb. 1 oz.

MAXIMUM PENETRATIONS.

Ordnance	Palliser Shell	Common Shell	
10″ R.M.L. 18 tons	17′	13′ 10″	
6″ B.L. 80 cwt.	12′ 7″	10′ 9″	
6·6″ R.M.L. 70 cwt.	8′ 2″	8′ 5″	

N. B.—The shells fired for penetration were weighted and plugged.

The following conclusions were drawn at the end of the trials for penetration into concrete.

1. The Palliser shells generally attained to a somewhat higher penetration than the common shells.

2. The majority of the shells of all natures on entering the butt, exhibited a tendency to turn to the right; a few went in straight, and one or two turned slightly to the left. It was observed that a sharp turn had a marked effect in diminishing penetration.

(3) *Palliser Shell.*—None of the Palliser shells fired from any of the guns broke up, nor when filled with powder did they burst, one of the 6″ B.L. Palliser shells penetrated 12′ 7″, rebounded 8′, and entered the side of its tunnel.

(4) 10″ *Common Shell.*—Common shells were fired from the 10″ gun, both weighted and plugged, and filled, but no fuze; in neither case did they break up or burst.

(5) 6″ *Common Shell.*—The common shell fired, weighted, and plugged, from the 6″ B.L. gun did not break up; this is very remarkable as the striking velocity was close on 1,900 f.s., and what is equally curious is that one shell after penetrating 10′ 9″ into the butt rebounded clean out of it. The bush and plug had been driven into the nose of the shell.

The common shells that were fired from the same gun filled, but no fuze, burst in the butt from the heat generated from impact.

6·6″ *Common Shell.*—Of the two common shells fired from the 6·6″ R.M.L. gun weighted and plugged, one broke up, and one did not; an examination of the fragments of the shell that broke up led to the conclusion that it was a somewhat defective casting.

The common shell fired filled, but no fuze, did not burst or break up.

It is worthy of note that the projectiles entering at high velocity made tunnels through the concrete of considerably larger area than their own cross section; thus a 6″ shell would form a tunnel about 1′ in diameter, and completely pulverize the hard flint stones of the concrete throughout the whole of the tunnel so made. The higher the velocity the more was this effect observable.

It might aptly be compared to a torpedo boat travelling at great speed, carrying a lofty wave off each bow. This wide distribution of force must naturally bring the projectiles to rest sooner than would be the case if the resistance was confined to their sectional area.

It may be interesting to here observe that in recent penetration experiments carried out at Shoeburyness, with Palliser shell fired from the 80-ton gun at a range of 200 yards at concrete made of broken granite, the shell penetrated a distance of 34 feet, forming a tunnel about 2′ 3″ in diameter. The disturbing and destructive effect on the structure were very great.

The shell weighed 1,700 lbs., the charge used was 450 lbs. of prism powder, and the striking velocity about 1,586 f.s.

Experiments at Concrete Butt with Common Shell filled and fuzed.

Mean Penetrations.—The following Table gives the mean penetration of the shells fuzed with quick fuzes to the point of burst.

Ordnance	Mean penetration to point of burst	Remarks
10″ R.M.L. Gun	8′ 9″	All fuzed with the direct action, percussion (quick) fuze
6″ B.L. Gun	5′ 9″	
6·6″ R.M.L. Gun	4′ 7″	

It is observable that owing to the high striking velocities, the shells, although fuzed with a quick action fuze, attained to considerable penetration before bursting, and were thus enabled to produce large results.

The powerful shells of the 10″ gun, filled with 20 lb. 4 oz. of powder, were enormously destructive, not only forming large craters from 10 to 14 feet in diameter but starting and shaking the material over great distances and throwing down the concrete in masses.

Delay-action Fuzes.—Two common shells were fired from the 6·6″ gun filled and fuzed with delay-action fuzes. One was observed to give about a half second's delay, with the other no delay was observed, but as they both attained to the same penetration (7′ 9½″), it is reasonable to suppose that there actually was a short delay in each case, and that both shells reached extreme penetration, especially as the plugged shell from this piece entered about the same distance.

The shells with delay-action fuze fired from this gun wrought less destruction than those with quick fuzes, which may be accounted for by the fact of the shells only holding a small bursting charge, 5 lb. 8 ozs., so that when the penetration reaches a certain point they act as an undercharged mine.

From this experiment it was evident that the common shell is by far the most effective projective to employ for the destruction of concrete; in penetration (if used with a 'delay-action' fuze) it is not much inferior to the Palliser shell, and its far larger bursting charge enables it to produce very considerably increased destructive effects, especially with the higher calibres.

That quick-action fuzes are to be preferred to those with delayed action, as the former are not so quick but that the shell gets fairly in, and does good work, whereas with a delay fuze the shell may enter so far as to be unable to move the surrounding mass of concrete. This is especially the case with shells of small or medium calibre.

There however seems no reason to doubt that the powerful shell of the 10″ gun would act effectively at greater penetration than a quick fuze allows of, and would consequently, with a fuze giving small delay secure even larger results than those exhibited in this experiment.

Experiments at Earth and Sand Butt.

Penetration.—The earth and sand butt was of the following dimensions, viz:—

Frontage 84 feet exclusive of slopes.

Depth from front to rear 48 feet exclusive of slopes.

Height 8 feet (see plate III., Fig. 1).

The earth may be described as a rough loamy clay with a fair sprinkling of chalk, stones, and brickbats.

The sand was remarkably pure and free from stones or any extraneous matter.

The following pieces were employed in this experiment, and plugged prejectiles of the natures noted were fired at a range of 195 yards:—

10″ R.M.L Gun of 18 tons	Palliser and	Common
6″ R.B.L. Gun of 80 cwt.	Ditto	ditto
6·6″ R.M.L. Gun of 70 cwt.	Ditto	ditto
8″ R.M.L. Howitzer Gun of 70 cwt.	Common only	
6·6″ R.M.L. Howitzer Gun of 36 cwt. ...	Ditto	

Owing to the small height of the butt the whole of the shells fired from the 10″ gun rose out of it, with the exception of one common shell fired at earth, which was found at 34′ 6″ penetration; it had turned off to the right, and entered the shingle portion of the butt.

The following Table shows the mean penetration :—

Ordnance	Striking Velocity f.s.	Penetration			
		Palliser		Common	
		Earth	Sand	Earth	Sand
10″ Gun	1416	All rose out of butt		34′ 6″*	All rose out of butt
6″ Gun	1875	All broke up	12′ 3½″	All broke up	All broke up
6·6″ Gun	1452	14′*	Not found	14′ 6″*	11′*
8″ Howr.	921	None fired		19 ′5″	13′
6·6″ Howr	841	None fired		16′	13 9″*

Some very remarkable results were obtained in this practice, viz. :—

1. All the projectiles fired from the 6″ B.L. gun broke up on impact, with the exception of the Palliser shell fired into sand; whereas similar projectiles fired from the same piece, under almost exactly the same conditions as regards striking velocity, into solid concrete, did not break up.

2. It was observed, wherever the means existed for comparing results, that the penetration into sand was considerably less than into earth. In the latter material the penetration would vary with the quality of the soil, and be considerably influenced by the extent to which it was saturated; whereas in sand the penetration might be expected to be more constant.

3. The displacement of material from the impact of shells striking with high velocity, and which did not break up, was also much greater in earth than in sand.

In the case of plugged howitzer shells striking with low velocity, the effect on either material was insignificant.

4. All but one of the projectiles fired into sand had turned completely round, whereas none of those fired into earth had turned more than half round, except one 10″ shell, which had left the earth and entered the fine shingle portion of the parapet. This greater tendency to turn round in sand has doubtless an influence in restricting penetration.

* One round.

5. The 6·6″ gun and howitzer fired the same projectiles, viz., shells of 100 lbs. weight, and as the striking velocity of the former, (1452 f.s.) was considerably in excess of that of the latter (841 f.s.) it was but reasonable to expect greater penetration from the gun than from the howitzer shell; but the contrary was the case, *apparently*—*i.e.*, the howitzer shells were found further in the butt. This result is, however, it is believed, to be attributed to the fact of 68 rounds of filled and fuzed shell having been fired into the butt between the penetration trials of the two pieces named; consequently projectiles already in the butt may have been considerably disturbed by the bursting shells.

6. The penetration of the 6″ B.L. Palliser shells into sand (12′ 3½″) was curiously small considering their high striking velocity (1875. f.s.).

Trials for Disruptive Effect.

The same pieces fired, filled, and fuzed shells for disruptive effect, as were used in the penetration trials, viz.: 10″, 6″, 6·6″ guns, and 8″ and 6·6″ howitzers.

For these trials the butt was reduced to a thickness of 30 feet exclusive of slopes; the projectiles used against it were filled common shells with quick fuzes, except in one series, when common shells with delay-action fuzes were fired from the 8″ howitzer.

The following Table gives the striking velocities, bursting charges, and amount of earth or sand displaced by the rounds fired from each piece.

The sections through the parapet give a good idea of the effects produced. (Plate IV.)

TABLE OF ORDNANCE, SHOWING BURSTING CHARGES OF SHELLS, STRIKING VELOCITIES, AMOUNT OF MATERIAL DISPLACED, &c.

Ordnance	Charge	Projectile		Bursting Charge	Fuze	Striking Velocity	No. of Rounds fired	Nature of Parapet	Material displaced	*See* Plate IV.	Remarks (range 195 yards)
		Nature	Wgt.								
	lbs.		lbs.	lbs.					cubic yds.		
10″ Gun	95. P.^{2}	Common shell filled	408	$20\frac{1}{4}$	Direct action (quick)	1416	3	Earth	63	Fig. 1	Through in 2 rounds; effect almost entirely produced by 2 rounds.
10″ Gun	95. P.^{2}	Do.	408	$20\frac{1}{4}$	Do.	1416	3	Sand	24	Fig. 2	
6·6″ Gun	25. P.	Do.	100	$5\frac{1}{2}$	Do.	1452	12	Earth	17	Fig. 3	2 rounds fired with R.L. fuzes were blind; they displaced, however, 3·7 yards of earth.
6″ B.L.	34. P.	Do.	80	5	Do.	1875	10	Earth	16	Fig. 4	Shells broke up on impact.
6″ B.L.	34. P.	Common shell plugged	80	Nil	Nil	1875	10	Earth	12	Fig. 5	Do. Do.
8″ Howitzer	$11\frac{1}{2}$ R.L.G.^{2}	Common shell filled	180	14	Direct action (quick)	921	10	Earth	54	Fig. 6	Through in 8 rounds.
8″ Howitzer	$11\frac{1}{2}$ R.L.G.^{2}	Do.	180	14	Delay action	921	10; only 5 effective	Earth	27	Fig. 7	Through in 7 rounds; 3 blind, 2 burst with delay *en ricochet*; 1 burst on impact, 4 with delay in parapet.
8″ Howitzer	$11\frac{1}{2}$ R.L.G.^{2}	Do.	180	14	Direct action (quick)	921	10	Sand	18	Fig. 8	
6·6″ Howitzer	5 R.L.G.^{2}	Do.	100	$5\frac{1}{2}$	Do.	841	10	Earth	12	Fig. 9	

From these experiments it appeared that—

1. Parapets of sand exhibit a higher degree of resistance to shell fire than those of earth, both the penetration into, and the dispersion of, the material being less in the former than in the latter case.

2. Shells of small capacity, whether striking with high velocity or not, are comparatively but feeble instruments for the destruction of earth works; whereas, per contra, shells of large capacity are very effective even when their striking velocity is low.

3. The fact that velocity is a far less important factor than shell power, points to the advisability of employing howitzers in preference to guns for work of this nature; the advantages of large shell power, compared with weight of piece, belonging especially to howitzers.

4. The action of the experimental delay-action fuzes was very uncertain. A comparison of the series with 'delay' fuzes from the 8″ howitzer, with a similar series from the same piece with 'quick' fuzes, tends to show that the destruction of earthen parapets is more rapidly and completely effected with the latter than with the former. In the case of shells with 'delay' fuzes, unless the angle of impact is very considerable, the shell is apt to scoop up and get clear of the parapet before bursting. This would be the case with all impinging on the superior slope, except when fired at high angles of elevation, and of those that strike the exterior slope, the first will probably enter well and effect a large displacement of earth from the heart of the parapet,* in the rounds immediately following the shells if striking about the same spot will probably burst in or near the former crater, and add but little to the effect already produced.

As soon as the partially-demolished parapet falls into easy slopes, the angles of impact of subsequent shell will be too small to enable them to penetrate, and they will consequently rise, burst clear of the parapet, and produce but little effect.

It would therefore appear doubtful whether, even if a thoroughly good delay fuze be secured for the service, shells so fuzed could be employed with advantage for the destruction of earthworks, except in the sole instance of high angle fire for the destruction of overhead cover, when it is a desideratum that shells should burst at extreme penetration.

It is possible that good results might be secured by a combined fire of shells, some with quick, and some with delay fuzes, each nature being used according to the requirements of the case for purposes of breaching earthworks.

* Shells that acted in the manner indicated, moved an immense quantity of earth far more than any single shell with quick fuze did.

Although a longer delay is requisite to enable the full effect to be got out of shells that strike with *low* velocity than is required for those striking with *high* velocity, still, in no case, as a matter of fact, is more than a short delay either necessary or desirable.

5. The highly destructive effects produced by the powerful shells of the 10″ gun would appear to indicate the importance of mounting a few heavy and accurate pieces, of large shell power, in a few selected positions on the land fronts of fortifications, provided efficient means could be secured for their protection.

6. It is noticeable that there was no very marked difference between the effects produced by the ten rounds of plugged shell and the ten rounds of filled and fuzed shell fired from the 6″ B.L. gun, owing to the whole of the shells, in both cases, breaking up on impact. Those that had powder in them had somewhat the best of it, as the powder did ignite and produce a certain amount of explosive force though only to a very limited extent.

Caking of Powder in Shells.—An opportunity was afforded during these experiments of examining a blind filled common shell, which had been fired from the 10″ gun at the earthen parapet.

On removing the base plug, and cutting away the serge bag, it was found that the bursting charge had been set back with such force into the base of the shell as to have become transformed (in that portion next the base) into so hard a mass, that even after having had water standing on it for a quarter of an hour, it resisted a sharp pointed knife like a piece of slate. It is curious that the bursting charge did not set forward into the nose of the shell on impact, and only to be accounted for on the supposition that the shell was brought comparatively slowly to rest in loose earth.

The fuze (direct action) had acted, and it is probably owing to the fact of the bursting charge not having set forward on impact, and to there consequently being a considerable air space between the highly compressed burster and the fuze, that the flash of the latter had not sufficient power to pierce the serge bag in which the bursting charge was confined.

Effect of Common Shell fired from High Velocity Guns of medium calibre.—Before these experiments were carried out, it was urged by some that the high velocity guns of medium shell power, such as the 6″ B.L., would prove more effective for the destruction of earth works than low velocity pieces of large shell power, such as the 8″ howitzer; the idea being that with the former pieces the parapet would be cut through in long grooves from the top downwards, and if the shells could maintain their original course after impact, it is quite likely that this result might be secured; but the fact is, that a shell with a flat trajectory, striking high up on the exterior slope, is, unless it quickly bursts, deflected upwards, and can consequently do but comparatively little work through the medium of the energy.

It is almost needless to remark that those that strike on the superior slope have only a grazing effect.

If, on the other hand, the shells are planted low down in the parapet, they are smothered to a great extent, or in other words, have not the power to throw the superincumbent mass of earth clear away, and what earth they do lift, to a great extent falls back again.*

It is true that in the experiments under consideration the high velocity gun was heavily handicapped, from the fact of all its shells breaking up on impact, when although the powder ignited there was no power of burst.

There are also two other things that tell against the high velocity gun, and they are these:—

1. As long as shell L.G. powder is used for bursting charges it will become more or less caked into a solid mass in the shell from the shock of firing, and the higher the velocity the more does the bursting charge become so caked, and consequently the greater the loss of explosive power. This is of course assuming that a sufficiently strong shell is secured to withstand the shock of impact without breaking up, for should the shell break up the condition of the bursting charge can hardly influence the result to an appreciable extent.

2. The shells with flat trajectory will always have a far greater tendency to scoop up out of the parapet than those fired from howitzers, and this will especially tend to detract from their effect when the disturbed earth of the parapet begins to fall into easy slopes.

We have, at present, no data to enable us to state at what angles of impact, on ordinary earth works, shells will enter fairly into the work, instead of scooping up. On water we know that they will not ricochet when the angle of descent is as high as 11° or 12°, and it would be interesting to have similar information regarding their behaviour on earthen slopes.

One great advantage that high velocity guns have over howitzers except at short ranges, is their superior accuracy, especially under unfavourable atmospheric conditions. At long ranges in squally weather this has an enormous influence on the percentage of hits obtainable by the two classes of pieces respectively.

The idea that heavy earthworks are almost indestructible by

* The height of the parapet and the amount of 'shell-power' largely influences this question.

artillery fire can no longer be entertained. We have seen how the 18-ton gun cut through a parapet 30 feet thick, exclusive of slopes, in two rounds, and the 8″ howitzer did the same in 7 or 8 rounds; it is therefore perfectly evident that no earthwork can for long withstand the fire of powerful shell pieces, provided the following three essentials to effective fire are existent, viz.:

1. The means of accurately observing the point of impact so as to be able to correct the laying.

2. An accurate shooting piece.

3. Large shell power.

Earth Works of Coast Defences.—In the case of the earthworks of coast defences it may be observed that they will always have this in their favour, viz.: That they are only liable to be fired at by ships which, although possessed of heavy ordnance of large shell power, must always labour under the following disadvantages; viz.:

1. Difficulty as to range, especially when the vessels are on the move.

2. Obscuration from smoke.

3. The difficulty, not to say impossibility, when several guns are firing at the same time, of any one in charge of a gun ascertaining the point and impact of his own shot.

4. The fact of the guns being fired from a moving platform.

Consequently the two first essentials (accuracy of observation and of fire) can only exist to a very limited extent, and what shells do take effect will be scattered about over the works instead of hitting consecutively on the same spot, and hence the concentration of effect essential for breaching will be wanting.

I should not have referred to the subject of coast defence here had I not thought that it would prove of interest in connection with its bearing on the recent naval action with the forts at Alexandria.

EXPERIMENTS CARRIED OUT AT LYDD,

UNDER THE

ORDNANCE COMMITTEE IN 1882.

The main object of the experiments carried out at Lydd, in 1882, under the Ordnance Committee, was to gain information on the following points, viz. :—

Fire at Service Ranges.

1. The efficacy of high angle common and shrapnel shell fire of howitzers, when employed for searching effect, from batteries of the 1st and 2nd artillery positions against an enemy's *matériel* and *personnel* respectively.

2. The relative efficacy of the common shell fire of the various siege train pieces, using maximum charges, at low angles, when employed for breaching visible earthworks, from batteries of the 1st and 2nd Artillery positions.

3. The efficacy of the high angle common shell fire of the different siege train howitzers when employed for the destruction of the overhead cover of field magazines and blindages.

4. The relative penetration into earth of similar projectiles with varying velocities.

5. The most efficient means of anchoring siege carriages.

6. The suitability for service purposes of certain trail planks and wheel plates.

The following targets were provided for these experiments, viz. :—

1. A two-gun sunken battery of modern type, with a screen 50 yards in front.

2. An earthen parapet 60 feet long, 9 feet high, and 30 feet thick, to represent a portion of the parapet of a permanent work.

3. An expense magazine, with 5 feet of earth overhead.

4. A blindage with 7 feet of earth overhead.

The ordnance employed were :—

6″ B.L. gun, Mark II., of 81 cwt.			
6·6″ R.M.L. gun of 70 cwt.			
6·6″	,,	howitzer of	36 cwt.
6·3″	,,	,,	18 ,,
8″	,,	,,	46 ,,
8″	,,	,,	70 ,,

The following is a *précis* of the results obtained in the experiments :—

SERIES 1 AND 3.

High-angle common shell of howitzers for searching effect from batteries of the 1*st and* 2*nd artillery positions* (2,400 *and* 1,600 *yards*).

Target.—In these series the target fired at was a gun portion in a screen battery: such a work as might reasonably be expected to be thrown up by the besieged, under the protection of their advanced works of defence. The area within which searching fire of this kind could prove effective being so small (22′ + 15′), and the accuracy of some of the pieces employed being far from great, especially at the longer range, the results secured in the way of destructive effect within the gun portion were naturally but small, and at the termination of the series it was fairly evident that even under the most favourable conditions no large measure of success would be likely to attend the employment of fire of this nature, even from the most accurate of our siege train howitzers. The effects obtained were more marked on the parapet and traverses than in the gun portion, and the conclusion arrived at was, that the fire of a screened battery would be more rapidly silenced, and the work itself be more effectually opened up and demolished by the fire of howitzers, using maximum charges at low angles (so as to secure the greatest accuracy and destructive effect for their projectiles), than by a high angle fire with low charges from the same pieces.*

SERIES 2 AND 4.

High angle shrapnel fire of howitzers for searching effect from batteries of the 1*st and* 2*nd Artillery positions* (2,400 *and* 1,600 *yards.*)

The attention of the Siege Operations Committee had been directed to the subject of the high angle shrapnel fire of howitzers in 1880,

* The average dimensions of the craters formed in the earthwork by the shells in these series were :—

8″ howitzer ... ... Crater 4′ radius, $3\frac{1}{2}'$ deep.
6·6″ howitzer ... ... Crater $2\frac{1}{2}'$ radius, 2′ deep.

The comparatively quick action of the D. A. fuzes prevented the shells attaining to a greater penetration, the S. V. being low.

but they were unable to carry out any experiments of a satisfactory nature in this direction from the want of a suitable fuze.

The first trials made by them were with the M.L. fuzes, having loose strands of gun cotton tied round the priming; with this arrangement, and portions of the rim of the gas checks filed away in grooves, it was thought that perhaps the fuzes would ignite, but the result was not a success.

The suspending wire of the hammer of the detonator in the B.L. fuzes was too strong to be sheared by the comparatively feeble shock of discharge resulting from the use of the small charges, which it was necessary to use to secure the required angle of descent for the shells, and an idea for some time prevailed, that if the suspending wire was so far reduced in thickness as to shear with certainty with these small charges, there might be a chance of the wires shearing from the shock of ramming home.

Subsequent trials, however, led to the belief that the wires might be reduced to ·015 in thickness with safety; and the 15 seconds B.L. wood time fuses issued for the 1882 experiments had the hammers of their detonators suspended with wire of this gauge.

The shrapnel shells were of the usual type, and contained:—

8″ howitzer, 70 cwt., 260 iron sand shot, 8 to the lb.
6·6″ „ 36 „ 318 lead bullets,* 14 to the lb.

The bursting charges were:—

8″ howitzer shell 14 oz. F.G. powder.
6·6″ „ „ 11½ „ „ „

At the 2,400 yards range the shells had the following angles of descent and velocity at the point of burst:—

8″ howitzer, angle of descent 25° S.V. 556 f.s.
6·6″ „ „ „ „ 20° „ 573 „

and at 1,600 yards,

8″ howitzer, angle of descent 24° S.V. 433 f.s.
6·6″ „ „ „ „ 25° „ 432 „

Experiments had been previously carried out to ascertain at how low a velocity bullets of rather more than an ounce in weight (14 to the pound) might fairly be considered effective against men.

The firing took place, with varying velocities, at 2″ and 1″ deal targets, and the following results were noted:—

2-inch Target.

At 520 f.s. the bullets will penetrate.
At 420 „ they will lodge—penetration 1·25 inches.

* Hardened with antimony.

1-inch Target.

At 364 f.s. the bullets will penetrate.

At 296 „ they will lodge (very nearly through).

From these results it was concluded that bullets of this weight, striking with a velocity even as low as 300 f.s., would prove fairly effective against an enemy's *personnel*, and that with a like striking velocity the heavier (2 ounce) iron 'sand shot' of the 8″ howitzer shrapnel would prove far more so.

Targets.—The targets used were three rows of deal targets, some in each row 2″ and some 1″ in thickness; they were inclined at 60° to the horizon, so as to afford a fair measure of the penetration attained to by the bullets. Pl. III. Fig. 2, shows the arrangement of the targets.

The practice in each instance commenced with a few rounds of common shell filled and fuzed with D.A. percussion fuzes, to act on impact, to enable the range to be correctly obtained.

It was endeavoured throughout the practice to burst the shell close up, and so get a concentrated effect on the gun portion.

As the supply of ammunition was limited, and it was desirable to ascertain how far shells of this nature were capable of proving effective under favourable conditions, the results of each round were telephoned up to the battery.

The following *précis* shows the results obtained. No account was taken of balls that struck but failed to lodge, or of splinters.

PRÉCIS OF RESULTS.

2nd Series—2400 yards.

Howitzer	Means		Totals				No. of Rounds fired	Remarks
	Position of Burst		Bullets Through or Lodged					
	Short	Height above plane	1st row	2nd row	3rd row	Total		
	yards	feet						
8″	22	27	16	95	123	234	18	4 rounds ineffective—burst beyond
6·6″	32	51	29	151	187	367	20	4 Do. do.
4th Series—1600 yards.								
8″	18	24	42	150	161	227	14	2 rounds ineffective—burst beyond
6·6″	35	30	13	43	50	106	13	4 Do. do.

Having regard to the small area of the target fired at, these results may fairly be considered as very satisfactory, and had the time fuzes exhibited greater regularity in burning, considerably larger results would doubtless have been secured.

The following are the conclusions that were drawn with regard to these series :—

Conclusions.—The results obtained warrant the belief that fire of this nature could be successfully employed against troops, covered by works, in a great variety of cases, such as :—

(*a*) The keeping an already formed breach clear of an enemy's working parties.

(*b*) Preventing the assembly of masses of troops in rear of retrenchments thrown up for the defence of a breach, and, indeed, for searching out the interior of any works unprovided with overhead cover.

It is worthy of note that high angle shrapnel fire may be maintained upon a work about to be assaulted, almost up to the moment that the assaulting columns reach the counterscarp of the ditch, and had fire of this nature been brought to bear on the formidable earthworks at Plevna, it is more than probable that it would have exercised a most important influence in favour of the assailants.

Series 5.

High angle common shell fire of howitzers from the 1st Artillery position, 2,400 yards, for the Destruction of the Overhead Cover of Field Magazines and Blindages.

The following were the pieces employed in this series, and the angles of descent and striking velocities were as stated against each, respectively :—

Howitzers	Angle of Descent	Striking Velocity, f.s.
6·6″ howitzer	32°	477
8″ howitzer, 70 cwt. . . .	32°	486
8″ howitzer, 46 cwt. . . .	33¾°	407

Targets—Field Magazine.—In the covering mass of earth, instead of there being, as usual, only *one* magazine, *two* were constructed to double the chance of getting hits directly overhead. The timbers over one magazine consisted of one layer of oak, 12′ × 12″ × 12″, and over the other, of two layers of fir, 12′ × 10″ × 10″. The earth overhead was 5 feet deep in the centre of the mass.

Blindage.—One layer of fir, 12′ × 10″ × 10″, with seven feet of earth on it, constituted the overhead cover of the blindage.

30 rounds of filled common shell with D.A. percussion fuzes were fired from each of the three howitzers, with the following results:—

The 8″ howitzer of 70 cwt. struck the magazine six times in 20 rounds = 30 per cent.

The 8″ howitzer of 46 cwt. struck the blindage four times in 30 rounds = 13 per cent.

The 6·6″ howitzer struck the magazine 11 times in 30 rounds = 36½ per cent.

Inaccuracy of high-angle Howitzer Fire in squally weather.—Besides the above, the 8″ howitzer of 70 cwt. fired 10 rounds at the magazine without hitting it; this practice, however, was carried out in a bad light, and altogether under such unfavourable atmospheric conditions, that it cannot be taken as a fair criterion of the shooting of the piece.

Penetration of Shells.—The penetration of the shells which took effect varied from 3′ to 3′ 6″, and although all the shells burst, the only damage done was the displacement of a considerable amount of the earth, the breaking through of several capsills in the magazines, and the partial disturbance of the layer of beams in the roof of the blindage.

It is worthy of note that no two shells hit on exactly the same spot; had this occurred, it is most probable that the overhead beams of the magazine would have been penetrated by the shock of impact, followed by the burst of the shell, as in the centre of the previously-formed craters the depth of earth remaining over the beams was only from 1′ 6″ to 2′.

The quick action of the fuzes prevented the shells (on account of the low velocity with which they struck) from entering deeper before bursting.

The following are the conclusions which were drawn on the termination of the series:—

Conclusions.—With regard to fire of this nature directed against particular objects, it appears that to prove effective the following conditions are required.

1. The position of the object fired at must be ascertainable either from the battery, or from some selected post in communication therewith, and from which the effects of the fire could be observed.

2. Pieces of considerable accuracy and shell power must be employed.

3. A favourable state of the atmosphere.

With respect to 1. It would rarely occur on service that this essential condition could be secured. Magazines especially, would always be so placed as to be screened from the direct view of the enemy.*

With regard to 2. It would appear that the 8″ howitzer of 70 cwt., and the 6·6″ howitzer, are the pieces in the present siege train best adapted for this nature of fire.

In rough and gusty weather, when velocities are low and times of flight long, the range and accuracy become so much affected that the fire necessarily becomes ineffective. This was practically demonstrated in this series.

Series 6.

Relative efficacy of the common shell fire of the various Siege train pieces using maximum charges at low angles, when employed for Breaching visible Earthworks from Batteries of the 1st Artillery position. Range 2,400 yards—20 rounds filled common shell, D.A. fuze from each piece.

The following Table shows the pieces employed, bursting charges of Shell, &c., &c.

Ordnance	Charge	Wgt. of Shell	Bursting Charge	Angle of Descent	Striking Velocity	No. of Effective Hits	Earth displaced	Remarks
	lbs.	lbs.	lbs.	°			cubic yds.	
6″ B.L. gun	42. P.[2]	100	6½	3¼	1286	6	14·13	
6·6″ R.M.L. gun	25. P.	100	5½	5½	982	5	9·2	
6·6″ R.M.L. howitzer	5 R.L.G.[2]	100	5½	13	700	2	Insignificant	
8″ R.M.L. how., 70 cwt.	11½ R.L.G.[2]	180	14	9	809	5	17·6	
8″ R.M.L. how., 46 cwt.	11½ R.L.G.[2]	186	15	16½	596	0	Insignificant	
6·3″ R.M.L. howitzer	4 R.L.G.[2]	70	7	16½	592	1	Do.	

From the results obtained in this Series it became evident:—

1 That when the object fired at is ill defined and at a great distance, it is far preferable to lay 'reverse' by means of French's sights than to lay 'forward' in the ordinary way. In the former case a constant line can be easily maintained, the object laid on being clearly defined and

* This being the case, what they do require, in the way of overhead cover, is more *protection against chance shells* than such a thickness of overhead cover as would enable them to withstand a continuous bombardment.

unobstructed by smoke or mirage; and as regards elevation, the fact of its being given by the quadrant* excludes personal error, which is so apt to interfere with 'forward' laying, especially if the sights are coarse (as they were with the 6″ B.L. gun) and the object laid on is hard to see.

6″ *B.L. Gun.*—This may be held to account for only six effective hits being scored by this piece, the accuracy of which is well known, and certainly sufficient, under favourable conditions, to secure better results even at this long range.

2. That, at such long ranges, the 8″ howitzer of 46 cwt. (no longer in the siege train) and the 6·3″ howitzer are not possessed of sufficient accuracy to enable their fire to be effective, while that of the 6·6″ howitzer is only so in a very moderate degree.

3. That even at 2,400 yards the 8″ 70 cwt. howitzer was able to secure larger effects in breaching the earth work than either of the guns employed, owing to its fairly accurate shooting and large shell power.

4. It could not be definitely decided whether the shells fired from the 6″ B.L. gun broke up or not, but the idea prevailed that a proportion of them certainly did so.

Series 7.

Relative efficacy of the common shell fire of the various Siege Train pieces, using maximum charges at low angles, when employed for Breaching visible earthworks from Batteries of the 2nd Artillery position—range 1,200 yards—20 rounds filled common shell D.A. fuze from each piece.

The same pieces were employed in this series as in Series 6, and with similar charges and projectiles.

The subjoined Table shows the angles of descent, striking velocity, &c.

Ordnance	Angle of Descent	Striking Velocity	No. of Effective Hits	Earth displaced	Remarks
6″ B.L. gun . .	° $1\frac{1}{2}$	1552	16	26·0	Shell all broke up.
6·6″ R.M.L. gun .	2	1139	13	22·6	
6·6″ R.M.L. howitzer	$5\frac{1}{2}$	763	8	26·6	Very broad crater; hence large displacement of earth.
8″ R.M.L. 70-cwt. howitzer	4	876	17	46·0	Through in 7 rounds, 6 of which were effective.
8″ R.M.L. 46-cwt. howitzer	$7\frac{1}{4}$	653	9	20·6	
6·3″ R.M.L. howitzer	7	665	15	18·0	

* If elevation in 'reverse' laying is given by the sights, it is always obtained on a well defined mark or object.

In this series it is worthy of remark that:

At this comparatively short range all the pieces employed may be considered effective for breaching visible earthworks, but the 8″ howitzer of 70 cwt. is far more so than any of the other pieces. The fact of the parapet (30 feet thick, exclusive of slopes) being breached in six effective rounds, shows the great disruptive power of the shells thrown by this piece, and warrants the belief that no exposed earthwork could for long withstand their fire at this range.

Much larger results would doubtless have been secured by the 6″ B.L. gun had not all the shell broken up on impact.

The 8″ howitzer of 46 cwt. produced less than half the effect of the 8″ howitzer of 70 cwt., owing to its far inferior accuracy.

Series 8.

Penetration of similar projectiles with varying velocities into an earthen parapet. Range 1,200 *yards.*

It is worthy of note that, in this series, the three pieces employed all fired common shell of the same weight and had approximately the same calibre. The 6·6″ gun and 6·6″ howitzer take the same projectiles.

The following Table shows the pieces employed, angles of descent, striking velocity, &c. &c.

Ordnance	Charge	Wgt. of plugged shell	Angle of descent	Striking velocity f.s.	Mean Penetration
		lbs.			
6″ B.L. gun II.	42 lb. P^2	100	$1\frac{1}{2}°$	1552	Shell all broke up on impact.
6·6″ R.M.L. gun	25 „ P	100	2°	1139	18·65′
6·6″ R.M.L. howitzer	5 „ R.L.G.[2]	100	$5\frac{1}{2}°$	763	14.25′
6·6″ R.M.L. howitzer	2 „ R.L.G.[2]	100	16°	482	9·0′

In this series the main points to be noted are:

1. That the whole of the plugged common shell fired from the 6″ B.L. gun broke up in the butt at a striking velocity of 1,552 f.s.

2. That, even with so small an angle of descent as 2°, none of the five common shell fired from the 6·6″ R.M.L. gun which hit the exterior slope rose out of the butt, although the striking velocity was as high as 1,139 f.s. Had the parapet been of *sand* instead of clay, some, if not all, of these shells would, in all probability, have scooped

up and risen out of the butt; because sand offers very considerably greater resistance to penetration than earth or damp clay, and the greater resistance to penetration the greater the tendency of the projectiles to be deflected upwards.

3. That all the howitzer shells which hit the exterior slope entered the butt and remained there, as did also one shell out of three which struck the superior slope at an angle of descent of 16°.

GENERAL SUMMARY OF RESULTS.

At the termination of these experiments it was evident that a great deal of light had been thrown on many phases of siege artillery fire, regarding which little or nothing had previously been known in this country; for instance:

Series 1 and 3. (1.) The very small results obtainable by the high angle common shell fire of our howitzers, if directed against areas of very limited extent, was made apparent.

Series 2 and 4. (2.) That important results are likely to be secured by the employment of the high angle shrapnel shell fire of howitzers, under a variety of conditions, was fairly conclusive.

Series 5. (3.) The comparative inefficacy of the high angle fire of howitzers, with common shell, and 'quick-action' fuzes, for the destruction of earthen overhead cover (owing to the very limited penetration of the projectiles at the point of burst), was clearly demonstrated.

Series 6 and 7. (4.) Relative efficacy of our various Siege Train pieces when employed for breaching visible earthworks.

In these series, the fact that only the most powerful and accurate pieces of the siege train could be profitably employed at the long ranges, at which the batteries of the 1st Artillery positions would, in all probability, have to be established, was clearly brought to light; as was also the complete unsuitability of cast-iron common shells for guns of high velocity, from the breaking up of the projectiles on impact.

The results obtained in the series referred to also warrant the belief that powerful shell pieces, made in separate parts for convenience of transport, could with advantage be introduced into the Siege Train.

Series 8. (5.)—The information gained in the penetration trials was valuable not only as showing the penetration of similar projectiles with varying velocities in clay parapets, but also as a means of shedding some small light on the question as to the angles at which projectiles will impinge on, and enter, slopes of that material without scooping up or ricochetting.

These trials clearly showed that much larger effects might be produced in high angle fire, directed against earthen overhead cover, with shells having delay-action fuzes, than when quick fuzes are employed, as they evidenced the fact that the shells in the fire directed against the magazine and blindage had not nearly attained to maximum penetration at the point of burst.

(6). Considerable experience was gained with regard to:—

(*a*) The best means of securely anchoring the various descriptions of siege carriages.

(*b*) The trail planks and wheel plates submitted for trial.

(*c*) The various sights and fittings of the pieces employed in the experiments.

It is, however, unnecessary in a short *précis* of this nature to enter in these details.

N.B.—The whole of the works fired at were made of clay; had they been made of a sandy loam they would doubtless have exhibited considerably higher powers of resistance.

Full descriptions of anchorages will be found in the Para. of 'Changes in Material,' quoted below:

Howitzers... ... ... Para. 4430, dated 1st March 1884.
6·6″ R.M.L. Gun on H.P. carriage „ 4568, „ 1st Nov. 1884.

The anchorage for the 5″ steel B.L. gun on steel lattice-girder carriage is the same as that of howitzers, except that to keep the tie-rod from rising a beam is placed over it just inside the interior slope of the gun-portion.

EXPERIMENTS CARRIED OUT AT LYDD,

UNDER THE

ORDNANCE COMMITTEE IN 1883.

As the report on these experiments is not yet issued, I am unable to speak as fully with regard to them as I should otherwise have been enabled to do; but from the fact of my having been present at the experiments, I am in a position to afford some information on the subject.

The following were the main points sought to be determined :—

(*a*) The relative efficacy of the guns and howitzers of the siege train when employed to dismount or silence the guns of a fortress by frontal or enfilade fire.

(*b*) The destructive effect of steel common shell, with compressed gunpowder bursting charges fired from high velocity guns.

(*c*) The searching effect of high angle shrapnel fire with improved time fuzes.

(*d*) The efficacy for the destruction of earthen overhead cover and the high angle fire of howitzers with common shell and time fuzes, bored long (to imitate the action of delay percussion fuzes).

(*e*) The searching effect of shrapnel shell fired at high angles with low charges, and the destructive effect of common shell fired at low angles with ordinary charges; the observations for the correction of fire being conducted, as far as possible, to represent the conditions practicable on service.

Targets.

The following targets were provided :—

1 An earthen sunken 2-gun battery of modern type, with shingle screen, 50 yards in front.

2. An earthern parapet 60′ long, 9′ high, and 30′ thick, to represent a portion of the parapet of a permanent work.

3. An expense magazine with 5′ of earth overhead.

4. An earthen parapet 9′ thick, with two traverses each 30′ thick at the bottom, and 20′ at the top, and three gun portions to represent

the face of a salient strongly traversed, with a view to protection against enfilade fire (*see* Plate V.)

5. Wooden dummies to represent guns on overbank carriages. 6′ wooden dummies to represent detachments 6′ × 6′ × 2″ wooden targets, and 6′ × 3′ × 1″ ditto, ditto.

Ordnance.

6″ B.L. guns of 81 cwt. (Mark II.) on naval carriage and slide.
6″ B.L. (wire) Armstrong siege gun of 60 cwt. on H.P. carriage.
5″ B.L. gun on O.B. carriage, with hydraulic buffer.
6·6″ R.M.L. gun of 70 cwt. on H P. carriage.
8″ „ howitzer of 70 cwt. on travelling carriage, with hydraulic buffer.
6·6″ „ „ on travelling carriage, with hydraulic buffer.
6·3″ „ „ (wire-jointed Armstrong) on travelling carriage.

FIRST SERIES.—1ST ARTILLERY POSITION.

In order to test the relative efficacy of the guns and howitzers of the siege train, when employed to dismount or silence the guns of a fortress, by frontal fire at 2,400 yards range, the following pieces were employed. The targets being dummy overbank guns with detachments behind an earthen parapet 30′ thick exclusive of slopes.

Table of Ordnance employed in Series 1.

Ordnance	Charge	Weight of filled Shell	Bursting Charge	Angle of Descent		Striking Velocity
	lbs.	lbs.	lbs.	°	′	f.s.
6″ B.L. Armstrong Wire Gun, of 60 cwt., on H.P. carriage	25. P.[2]	80	5	4	36	1050
5″ B.L. Gun, on O.B. carriage .	16. P.	50	3½	4	15	1070
6·6″ R.M.L. Gun, H.P. carriage .	25. P.	100	5½	5	38	982
8″ R.M.L. Howitzer, trav. carriage	11½ R.L.G.[2]	180	14	9	12	809
6·6″ R.M.L. Howitzer, trav. carriage	5 R.L.G.[2]	100	5½	13	12	700

It appeared on consideration that the most effective means of dismounting or silencing guns mounted on overbank, or disappearing carriages, at such a long range (nearly 1½ miles) would be to breach the parapet covering the guns. This effected, the dismounting of the guns and destruction of their carriages would speedily follow, and, furthermore, the gun portions would be rendered untenable, and exceedingly difficult to repair.

The other alternative is to endeavour to dismount the guns by hitting them direct; brief consideration will show that there are many objections to this plan. *In the first place*: a gun end on, is at such a distance hardly visible, and presents a remarkably small target.

Secondly, unless hit direct, by the projectile itself, on the muzzle or on one of the trunnions it is not likely to be dismounted. Splinters cannot be expected to prove effective in this respect, though it is of course possible that a very heavy fragment, such as the base of a shell, might knock off a trunnion.

Thirdly, in fire of this nature all the shots that pass over, or on either side of the gun fired at, are absolutely thrown away, and those that graze on the superior slope do but little harm to the work.

Fourthly, even if dismounted the chances are that the besieged would, ere long, replace it by a gun from their reserve, or from one of the fronts not threatened, which they would hardly attempt if the gun portion had been opened up.

It almost needless to remark that with guns mounted on the disappearing principle, and which are only visible and exposed during the short time they are in the firing position, the reasons for preferring the former method (breaching the parapet) apply with special force.

In the series under consideration twenty rounds of filled common shell with D.A. percussion fuzes were fired from each piece, with the view of breaching the parapet immediately in front of the guns which it was sought to dismount, and the following results were obtained :—

Series 1.—Table showing pieces arranged in order of accuracy.

Ordnance	Percentage of Hits obtained
6″ B.L. Armstrong Wire Gun . . .	76 per cent.
5″ B.L. Gun	72 „
8″ R.M.L. Howitzer	47 „
6·6″ R.M.L. Gun	41 „
6·6″ R.M.L. Howitzer	25 „

The very marked superiority, in respect of accuracy, of the latest type of B.L. high velocity gun over the R.M.L. gun of older type, is brought prominently out in this series, as is also the superior practice of the 8″ compared with that of the 6·6″ R.M.L. howitzer.

The following Table shows the pieces arranged in order of effects produced.

Series 1.—Table of effects produced in Series 1.

Ordnance	Earth displaced	Remarks
8′ R.M.L. Howitzer . .	cubic yards 56	Parapet nearly cut through.
6 B.L. Armstrong Gun . .	13·8	
5′ B.L. Gun	8·6	
6·6″ R.M.L. Gun . . .	*Vide* remarks	Effect much distributed over parapet.
6·6″ R.M.L. Howitzer . .	Do.	Effect insignificant.

The value of large shell power for the destruction of earthworks is in this series made very apparent; it is, however, believed that a proportion of the shells from the high velocity guns broke up on impact, which would in a measure account for the comparatively small amount of earth they displaced.

3rd Series.—2nd Artillery Position.

This series was carried out with the same object in view as the 1st Series, viz., to dismount or silence an enemy's guns by frontal fire, but at the comparatively short range of 1,200 yards; in this series, however, the target was an earthen sunken 2-gun battery, with a shingle screen fifty yards in front; dummy overbank guns, with gun detachments being placed in the gun portions attacked.

It might not infrequently happen that the batteries of this nature would be thrown up by the defenders under cover of their advanced works, or between detached forts, and in attacking them, the only feasible method (unless the screen could be cut down by shell fire), would be to endeavour to demolish the work itself, as the exact position of individual guns would be concealed from view.

It was suggested by Colonel R. J. Hay, R.A. (now D.A.G., R.A., H.Gds.), the President of the Sub-Committee of the Ordnance Committee charged with the carrying out of these experiments, that the fighting capabilities of batteries might be increased by the establishment of anchorages in the traverses, and the laying of platforms in the rear of the same, so as to give an alternative positon for the pieces with which the battery was armed; and that this would be so does not admit of doubt, for when the parapets in front of the gun portions proper were wrecked, the guns from them could be retired to the positions in rear of the traverses.

In the case where the original armament of the battery had been put "hors de combat" by the enemy's fire other pieces might be fought from behind the traverses, and the fighting power of the battery be thus largely prolonged.

Series 3.—The following Table shows the pieces employed, striking velocity, &c., &c.

Table of Ordnance employed in Series 3.

Ordnance	Charge	Weight of filled Shell	Bursting Charge	Angle of Descent	Striking Velocity	Remarks
	lbs.	lbs.	lbs.			
5″ B.L. Gun . .	16. P.	50	3½	1° 30′	1341	Range 1,200 yds.
6·6″ R.M.L. Gun .	25. P.	100	5½	2 5	1139	
6·6″ R.M.L. Howitzer	5 R.L.G.[2]	100	5½	5 30	763	
6·3″ R.M.L. Jointed Howitzer	7 R.L.G.	64	7	No record		

Twenty rounds of filled common shell, with D.A. percussion fuze, were fired from each piece, and the following results were obtained:—

Table of effects produced in Series 3.

Ordnance	Earth displaced	Remarks
	cubic yds.	
5″ B.L. Gun	7·5	Several shells broke up on impact.
6·6″ R.M.L. Gun . . .	10·4	Just through parapet; dismounted dummy gun.
6·6″ R.M.L. Howitzer . .	7·5	Dismounted dummy gun.
6·3″ R.M.L. Jointed Howitzer	12·75	Effect widely distributed.

With regard to this series, it is worthy of note that:—

5″ *B.L. gun.*—1. Nearly all the shells fired from the 5″ B.L. gun were unsteady in flight, and hence the fire of the gun was deficient in accuracy. It is supposed that this was caused by some defect in the rotating rings of the shells.

The few shells that hit, and burst properly, produced very fair results.

6·6″ *R.M.L. howitzer.*—2. The 6·6″ R.M.L. howitzer exhibited a want of accuracy as regards range which largely detracted from the results.

6·3″ jointed howitzer.—The 6·3″ jointed howitzer was curiously inaccurate in line, consequently, although the shells fired from this piece moved a considerable amount of earth, the effect was too widely distributed for the parapet to be breached.

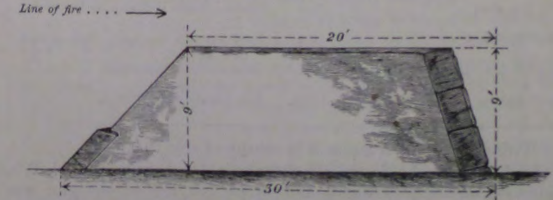
General remarks.—4. It may be stated generally, that the cast-iron common shells of pieces of the calibres employed do not contain sufficiently powerful bursting charges to secure large results, when employed for breaching earthworks, even at so comparatively short a range as 1,200 yards, when, of course, a large percentage of hits is obtained.

Series 2 and 4.

With regard to Series 2 and 4, which were carried out with the view of ascertaining the relative efficacy of the guns and howitzers of the siege train when employed to dismount or silence the guns of a fortress by enfilade fire at ranges of 2,400 and 1,200 yards respectively, it is as well to observe that the time and means at disposal did not admit of the construction of really formidable traversed works for target batteries, and the only material available was clay of a soft plastic nature, to a great extent saturated with moisture, and therefore ill adapted to resist shell fire.

The traverses of the elevated target battery, which were of the same height as the parapet (9′), were 30′ thick on the ground line, 20′ thick at top, and revetted with gabions, as shown in the subjoined diagram.

Section through Traverse.



The gun portions were 15′ in breadth, and contained dummy guns and detachments, the guns being, in some cases, arranged to represent guns on hydro-pneumatic carriages rising into the firing position, and in others similar pieces in the loading position.

The following Tables show the pieces employed in each series, with the angle of descent, and striking velocity of their projectiles.

Table of Ordnance employed in Series 2.

Ordnance	Charge	Angle of descent	Striking Velocity f.s.	Remarks
	lb.			
6″ B.L. Armstrong Wire Gun	25. P.[2]		1050	Range 2,400 yds.
6·6″ R.M.L. Gun . . .	25. P.	5° 38′	982	
8″ R.M.L. Howitzer . .	11½. R.L.G.[2]	9° 12′	809	
6·6″ R.M.L. Howitzer . .	5. R.L.G.[2]	13° 12′	700	

Table of Ordnance employed in Series 4.

Ordnance	Charge	Angle of descent	Striking Velocity f.s.	Remarks
	lb.			
8″ R.M.L. Howitzer . .	11½. R.L.G.[2]	4° 0′	876	Range 1,200 yds
6·6″ R.M.L. Howitzer . .	5. R.L.G.[2]	5° 30′	763	
6·3″ R.M.L. Jointed Howitzer	7. R.L.G.	3° 50′	857	

Twenty rounds of filled common shell, with 'quick-action' percussion fuzes, were fired from each piece in each series.

The following conclusions were drawn at the termination of these two series:

1. Relative efficacy of guns and howitzers in enfilade fire.—The curved fire of howitzers has naturally a marked advantage over the flat trajectory fire of guns in respect of 'searching effect'; but at the same time, unless the traverses are *higher** than the parapet (over which the pieces, forming the armament of the face enfiladed have to fire), it was evident that such pieces would be speedily dismounted by the fire of *guns*, which, would presumably, be only employed for purposes of enfilade *at long ranges*, when their trajectory becomes considerably curved.

The superior accuracy of the fire of guns, over that of howitzers, at long ranges, is an argument to be urged in favour of the employment of the former nature of piece under these conditions.

* Objection might be taken to such a form of construction on a face liable to be attacked frontally, as affording, at all times, a clear indication of the position of each piece.

2. For the demolition of heavy traverses large shell-power is a desideratum, indicating the employment of howitzers.

3. Howitzer shells which hit on the superior slope of the parapet, or on the top of traverses, attain to more penetration and are consequently more effective than the grazing shells of flat trajectory pieces of the same calibre which impinge on similar places.

With regard to the howitzers employed in these series the following conclusions were drawn :—

8″ *R.M.L. howitzer.*—The shell power and accuracy at 1,200 yards, of this piece are such, that the guns on any face enfiladed by it, would, *unless very specially protected*, be speedily silenced; and the same remark applies, though to a considerably less extent, to the lighter howitzers employed, the chief points noticeable in the practice with which appear to have been :—

(*a*) 6·3″ *R.M.L. jointed howitzer.*—The want of accuracy in *line* exhibited by the 6·3 inch jointed howitzer.

(*b*) 6·6″ *R.M.L. howitzer.*—The variations in *range* in the practice with the 6·6 inch howitzer.

It is to be hoped that opportunity will ere long be afforded of gaining further information with regard to the best means of securing protection against oblique and enfilade fire. There would appear to be no reason to doubt that the breadth of the gun portion might in many cases well be reduced and more cover be thus gained for the guns.*

How far traverses might, with advantage, be increased in thickness and in height is a question I do not feel competent to offer an opinion upon, but much would necessarily depend on local circumstances.

Series 5.—Trial of Steel Shells.

The following are the objects sought to be attained by the employment of steel, instead of cast iron, as the material for common shells :—

1. To secure a projectile of such strength as not to break up on impact when fired from high velocity guns at such objects as common shells are used against.

2. To procure larger capacity for the bursting charge, while retaining the same weight for the filled projectile.

This second condition is rendered possible, owing to the superior strength of steel (as compared with cast iron), enabling a very considerable reduction to be made in the thickness of the shell, without an undue sacrifice of strength. It must, however, be borne in mind

* The minimum dimensions that could, without inconvenience, be adopted, would have to be decided by a series of practical trials; this yet remains to be done.

that by so doing we materially increase the length of the projectile, and this, if carried beyond certain limits, is apt to produce instability in flight and consequent loss of accuracy, as the spiral of rifling of most of our service pieces was calculated for projectiles of from 3 to 3½ calibres in length only, and steel shell may be expected to reach, or even exceed, 4 calibres in length.

In the new field and medium guns now in process of manufacture it is, I understand, intended to give a somewhat sharper spiral to the rifling, in anticipation of steel shells being, ere long, largely introduced into the service.*

Compressed Powder bursting charges.

Owing to the loss of explosive force which results from the mealing and caking of bursting charges of 'Shell L. G.' powder, especially when velocities are high, trial was made, in these experiments of bursting charges of previously compressed powder, which not only enabled far more powder to be inserted in the shell, but also afforded the means for securing rapid and thorough ignition of the burster, by having it made up with a cylindrical hole through its centre from end to end, in the line of the axis of the shell and fuze.

To give an idea of the extra weight of powder that can be inserted in a steel shell by these means, two or three examples are quoted below.

Table showing comparative capacity of shells for loose and for compressed powder bursters :—

Diameter of Shell (Steel)	Length in Calibres	Capacity for Loose L.G. Powder	Capacity for Compressed Powder
		lb. oz.	lb. oz.
6 inches . . .	3½	10 3	16 0
	3⅓	7 12	12 4
	4¼	10 0	17 8

The following brief account of the method employed at Waltham Abbey in making up the compressed bursters used in the experiments may prove of interest :—

Pressure 2·47 *tons.*—About 2 lb. of 'grain powder are placed in a machine, and subjected to a pressure of 5,554 lb. to the square

* A spiral of 1 turn in 30 calibres is generally considered sufficient to properly rotate a shell 4 calibres in length; with longer projectiles a somewhat sharper spiral (say 1 in 25) would probably be found necessary. Most of our present medium guns have a spiral increasing to 1 in 35.

inch, the result being a cylinder about 2″ high, and possessed of a density of 1·8.

A cylindrical perforation about half an inch in diameter runs through the centre of each cylinder so made.

Moisture 1 *to* 1·3 *p.c.*—The amount of moisture is from 1 to 1·3 per cent.

Three or four of these cylinders are then placed on a spindle, secured in a lathe, and turned to fit the interior of the shell.

After being sewn up in a serge bag, they are inserted in the shell by removing its screw base.

If introduced into the service a suitable machine for moulding them into the required shape would be designed, the mode of preparation described being merely a temporary expedient.

The steel shells provided for the experiments may be classed under two heads, viz. :—

(*a*) R.L. cast steel (provided by contract).

(*b*) Armstrong forged steel.

Both kinds had removable screw bases, and the Armstrong shells were fitted with a screwed-in point of hard steel.

The following table shows the bursting charges, &c. :—

Ordnance	Nature of Shell	Nature and Weight of Bursting Charge	Weight of filled Shell	Nature of fuze
		lb. oz.	lb	
6″ B.L. Gun	Armstrong Forged, Light . . .	Compressed . . 16 0	80	Base percussion special . .
6″ B.L. Gun	Armstrong Forged, Heavy . .	Compressed . . 16 0	100	Base percussion special . .
6″ B.L. Gun	R.L. Cast, Light .	Compressed . . 12 4	80	Base percussion special . .
6″ B.L. Gun	R.L. Cast, Heavy .	Compressed . . 17 8	100	Base percussion special . .
6 3″ Howitzer	Armstrong Forged .	Loose Shell L.G. and P mixed . . 12 8	64	Base percussion special . .

In addition to the above a few shells of forged steel, with their bases welded on, were furnished for the 6″ B.L. Armstrong wire gun; these were fired (filled with loose L.G. shell powder in the usual way), and with percussion fuzes in the point.

Fuzes (*special*).—The following special (or experimental) fuzes were used in the experiments.

1. R.L. base percussion.

 (*a*) Quick action.

 (*b*) Delay action.

These fuzes were screwed into base of the shell from the outside in the usual way.

2. Armstrong base percussion; quick action.

These fuzes were screwed into the base of the shell *from the inside* before closing the shell; an undesirable arrangement for several reasons.

Preliminary Rounds.—A few preliminary rounds were fired at an earthen parapet before regularly entering upon the experiments in order to gain, if possible, some information with regard to the fuzes which it would be desirable to supply, and the following conclusions were drawn :—

Conclusions drawn at termination of preliminary rounds.—1. It appeared evident that a quick-action percussion fuse in the base of a shell, where it is in immediate contact with the powder at the moment of impact, causes a much more instantaneous burst than a D.A. percussion fuze in the nose of a shell; in the latter case there is doubtless, when ordinary powder bursters are used, a considerable air space (from the powder having set back on firing) between the fuze and the serge bag, and consequently a small but appreciable interval of time elapses between impact and burst, which admits of the shell attaining to greater penetration before bursting than when base fuses are used. Whether this difference would be equally marked in the case of D.A. fuzes in the nose of shells having compressed bursting charges remains yet to be proved. At any rate, it was manifest that with shells having quick-action base percussion fuzes, and compressed powder bursters, the burst was so instantaneous on graze or impact as, in the former case, to blacken the scoop in which the shell grazed, and in the latter to burst the shell before it had penetrated more than, if as much as, its own length. The consequence was that the powerful effect of the bursters was almost entirely neutralised, and generally the only result obtained was a flake of earth blown away from the surface of the parapet.

2. That the compressed powder burster is capable of exerting great explosive force was evidenced in one round, fired with an Armstrong forged steel shell (light pattern) containing 16 lbs. of powder. In this case the shell, from some unexplained cause, *did* penetrate six feet before bursting, and displaced over 600 cubic feet (22 cubic yards) of earth. As, however, nearly all the shells burst on the surface, it appeared desirable to use a fuse of somewhat slower action, or with a *slight* delay, to enable the power of the shells about to be used in the main experiments, to be fairly developed.

3. That the R.L. heavy cast-steel shells, which were $4\frac{1}{4}$ calibres in

length, were too unsteady in flight for accurate shooting. This may have been due either to

a—Their great length.

b—The position of their centre of gravity.

c—The position of the rotating ring, or to a combination of these causes.

At any rate, both the rounds fired went wide of the mark, striking about 180 yards short.

On the termination of the preliminary trials the main experiments were entered upon, fuzes with delayed action being provided for some of the shell.

Series 5.—Main Experiments with Steel Shells.

First Trial, 6″ *B.L. gun*, 1,200 *yards*.—In the experiments with each nature of steel shell 15 rounds were fired at a clay parapet 9′ high and 30′ thick, exclusive of slopes, at a range of 1,200 yards.*

Steel Shell—First Trial.

Nature of Shell	Bursting Charge	Fuze	Striking Velocity, f.s.	Earth displaced cub. yds.	Remarks
Armstrong Forged (heavy)	Compressed 16 lbs.	Base, Quick	1,388	34	Not through by 6′

The comparatively small effect (considering the power of the shell) is attributable to the extremely quick action of the fuzes, which prevented the shells attaining to sufficient penetration for fair results to be obtained.

Steel Shell—Second Trial.

Nature of Shell	Bursting Charge	Fuze	Striking Velocity, f.s.	Earth displaced	Remarks
R. L. Cast (heavy)	Compressed $17\frac{1}{2}$ lbs.	R.L. Base Delay	1,388	Effect small	Shell unsteady, only 4 hits

* A few rounds were fired with steel shell from the 6″ B.L. Armstrong Wire Gun at 2,400 yards, which need not here be referred to.

6″ *B.L. gun*, 1,200 *yards*.—Only 4 hits were obtained in the 15 rounds, owing to the unsteadiness of the shells in flight, due, presumably, to their great length ($4\frac{1}{4}$ calibres).

Of those that hit the parapet 1 (a bad and spongy casting) broke up, and the other 3 rose out of the parapet and burst in the air owing to the fuze giving too long delay.

STEEL SHELL—THIRD TRIAL.

Nature of Shell	Bursting Charge	Fuze	Striking Velocity f.s.	Earth displaced Cub. yds.	Remarks
R. L. cast (light) .	Compressed $12\frac{1}{4}$ lbs.	R.L. Base Delay	1,494	55	Parapet breached

6″ *B.L. gun*, 1,200.—Of the 15 shells fired, 1 broke up on impact (defective casting), 8 rose out of the parapet and burst in the air (delay too great), 6 burst in the parapet, moved the greater part of the 55 cubic yards of earth displaced, and breached the work.

6·3″ *jointed howitzer*, 1,200 *yards*.—15 rounds were fired at the earthwork with steel shell filled with a mixture of P. and shell L.G. powder. Quick-action base fuzes were used, and their action was so instantaneous, that the effect was all on the surface of the parapet.

An attempt was made to delay the action of the burst by inserting layers of cotton cloth, steeped in a solution of saltpetre, between the fuze and the burster; but although this material burnt very well in the open air, it was extinguished in the shell by the pressure to which it was subjected by the setting back on to it of the bursting charge, and consequently no satisfactory results were secured.

In these experiments we have seen that, however powerful the shells may be, their effect is liable to be almost entirely neutralised if used with an unsuitable fuze. The same difficulty that presented itself in former experiments in 1881 was again experienced with respect to ‘delay-action’ fuzes; I refer to the difficulty of securing an amount of delay suitable to the conditions of fire.

The higher the striking velocity of a projectile the greater its penetration in a given period of time; therefore when the striking velocity is high, only a *very short* delay is needful, or indeed desirable, because we do not want the shell to have time to rise out of the parapet before bursting; moreover, the higher the velocity the flatter the trajectory, and hence the greater the tendency of the shell to turn up on impact.

We see, therefore, that an amount of delay which might be very suitable for howitzer shells, would, in all probability, be entirely unsuited for shells striking with high velocity.

The time that a shell takes to penetrate a given distance must also in large measure be dependent on the amount of resistance to penetration afforded by the material fired at; thus soft plastic clay offers far less resistance to penetration than the same material when hard, dry, and sunbaked.

The only case in which comparatively long delay is desirable is in the instance of shells fired at high angles for the destruction of overhead cover when it is necessary, for good effect, that they should burst at extreme penetration; and shells impinging at high angles exhibit no tendency to rise out of earthworks.

It is evident that in the case of shells fired from high velocity guns the delay can *hardly be too short*; although that *some* delay, or slowness of action in the fuze, *is essential*, is fairly evidenced in these experiments, from the fact that, failing this, these powerful shells could do little beyond blowing a flake of earth off the surface.

It would be interesting to try a series of steel shells fired from B.L. guns with reduced charges, so as to get considerable angles of impact, when the tendency of the projectiles to rise out of the earth would be far less, and the existing difficulty, with regard to the securing a sufficiently short delay in the action of the fuzes, might hence possibly be overcome.*

It is, of course, *possible* that a percussion fuze may some day be devised, having the means of regulating the delay with nicety, but it is hardly likely that any *time* fuze could be made to act with certainty within the narrow limits of time required.

I have entered at some length into the steel shell trials, because I thought that the subject, being an entirely new one, would be likely to prove of considerable interest.

Series 6.—Cast-Iron Common Shell.

6″ B.L. guns, 1,200 *yards*.—Series 6 consisted of 15 rounds of common cast-iron shell filled with L.G. shell powder in the usual way, and fused with D.A. fuzes in the nose. This series was fired for comparison with the steel shell trials previously described.

* It is suggested that a few rounds fired in the manner indicated with 'delay' fuzes would displace the greater part of the earth required to be moved to form a breach; after which a few rounds at high velocity, with quick fused shells, would serve to clear out the partially-formed breach.

The following Table shows the results obtained :—

Nature of Shell	Bursting Charge	Fuze	Striking Velocity f.s.	Earth displaced Cubic Yds.	Remarks
Cast-iron common	Shell L.G. $6\frac{1}{2}$ lbs.	D.A. Quick	1388	50	Parapet breached

Most of the shells broke up on impact, but a few which did *not*, burst at good penetration and formed large craters; the best result being 201 cubic feet (about one-third of the greatest displacement observed in the steel shell trials).

It appeared that a cast-iron shell which breaks up on impact moves more earth than a steel shell which bursts on the surface; on the other hand, a cast-iron shell which bursts properly in the work does far less work than a steel shell of the same calibre acting in the same manner.

6·3″ *jointed howitzer.*—A similar series was fired from the 6·3′ jointed howitzer, but the results obtained were not sufficiently great to call for any special remarks.

Series 7 and 8.

8″ howitzer, 70 cwt., 6·6″ howitzer 36 cwt. 20 rounds fired from each piece in each series.—Series 7 and 8 were carried out in order to test the relative efficacy of cast-iron howitzer shrapnel of the usual type and similar steel-bodied shells; and also to ascertain the increase in efficiency resulting from the use, in this nature of fire, of improved time fuzes.

The pieces employed were the 8″ R.M.L. howitzer of 70 cwt. and the 6·6″ R.M.L. howitzer of 36 cwt. The range was 1,600 yards, the angle of descent from 25° to 26° and the remaining velocity of the shells at the point of burst about 470 f.s.

Targets.—The objects fired at were 3 rows of targets arranged in a gun portion of a sunken screened battery in the same way as in the Shrapnel Experiments in 1882. Pl. III. Fig. 2.

The contents of the shells are given in the subjoined Tables.

TABLE OF SHRAPNEL SHELLS.

Material	Nature of Shell	No. and Nature of Bullets	Bursting Charge	Remarks
Cast-iron	8″ howitzer	260 2-oz. iron 'sand' shot	14 oz. F.G.	
Do.	6·6″ howitzer	318 mm. bullets, 14 to the lb.	$11\frac{1}{2}$ oz. F.G.	
Steel .	8″ howitzer	228 2-oz. iron 'sand' shot	1 lb. $14\frac{1}{2}$ oz.	
Do.	6·6″ howitzer	241 mm. bullets, 14 to the lb.	1 lb. 5 oz.	

The following Table gives the effect produced on the Targets.

EFFECT ON TARGETS.

Series	Howitzers	Bullets			No. of Rounds	Range
		Through	Lodged	Total		
Series 7, Cast-iron shrapnel	8″	129	32	161	20	1,600 yards
Ditto	6·6″	56	78	134	20	
Series 8. Steel shrapnel	8″	220	14	234	20	1,600 yards
Ditto	6·6″	391	109	500	14	

With respect to the steel shrapnel it is to be observed that their action is like that of a small cannon firing a charge of case shot, because the steel body is so strong that it does not break up on the ignition of the large bursting charge, and the result is a very considerable acceleration in the velocity of the bullets. This is doubtless an advantage, and it appeared moreover that they were steadier in flight (probably from the centre of gravity being further forward) and made better practice than the cast-iron shrapnel which however contain more bullets.

A reference to the results obtained would certainly lead to the conclusion that the steel are very superior to the cast-iron shrapnel; but it must be borne in mind that the latter were fired with 15 seconds wood time fuzes,* and the former with 15 seconds Armstrong metal time fuzes; and the fact of the Armstrong fuzes having exhibited much the greatest regularity of burning, would in a large measure account for the greater number of hits scored by the shells fuzed with them.

In short, it would be premature, without further trial, to pronounce definitely in favour of either description of shell; especially when it is considered that a single shell, bursting in a favourable position, will often score such a large number of hits as to entirely alter the complexion of the case.

It is worthy of remark that the Armstrong 15 seconds (so called) metal time fuzes was found to burn only 12 seconds, full length, at such velocities as obtained in these trials. A longer burning fuze would, therefore, be requisite for high angle shapnel fire at ranges in excess of 1,700 yards.

Series 9.

This series was carried out to test the efficacy, for the destruction of the earthen overhead cover of field magazines, of the high angle fire of howitzers with common shell, and time fuzes bored long (to imitate the action of delay percussion fuzes).

The trial was carried out with the 8″ and 6·6″ R.M.L. howitzers at a range of 2,400 yards; the charges used giving angles of descent of from 33° to 35°, and striking velocities of about 480 f.s.

The fuzes used were the 30 seconds wood time, with detonator and thin (·012 inch) suspending wire.

They were unbored so as to burn to full length.

It will be recollected that in the preceding year (1882) a similar series was carried out under the same conditions, except that D.A. percussion fuzes were used, with the result that the penetration of the shells to point of burst never exceeded 3′ 6″.

With shell so fuzed the practice was comparatively ineffective; *i.e.*, the magazine proved capable of resisting the penetration of *any single shell*, and it appeared unlikely that it would be exploded unless, at least, two shells were to successively impinge on exactly the same spot over the magazine itself.

In this series the vertical penetration, of the shells with unbored time fuzes were as follows:—8 inch howitzers, 6′ 6″ right down on to the baulks of timber forming the roof of the magazine which, when repaired, had had an extra 18″ of earth put on, increasing the amount of earth overhead from the usual 5′ to 6′ 6″.

* With detonators having thin suspending wire ·012″ gauge.

6·6″ *howitzers.*—6·6″ howitzers, about 4′ 6″; *i.e.*, such a shell entering over an ordinary field magazine would penetrate to within 6″ of the overhead timbers.

The clay covering the magazine was comparatively dry and in good order for resisting penetration.

The 6·6″ howitzer shells, which struck the exterior slope of the magazine, went 13 feet straight in to point of burst.

The 8″ howitzer shells on bursting broke clean through into the magazine* and formed a huge hemispherical crater overhead right down to the beams.

The craters formed by the 6·6″ howitzer shells were also of a formidable nature, and it was observed that if such a shell took effect over the entrance passage, its explosion forced the overhead beams through the capsills, consequently they fell on the floor and blocked the passage; indeed it was unsafe to try to get in or out after this had happened.

This is a very important point, and one that may lead to a reconsideration of the present form of structure.

A few rounds of 8″ shell were fired at the blindage, which had 7′ of earth overlaying a layer of fir baulks 12′ × 10″ × 10″.

The few shells that took effect struck on the exterior crest or slope, and penetrated straight in from 13′ to 16′. One passed obliquely right through the earth overhead and exploded the other side; another right through the exterior slope, penetrated the sheeting and burst inside the blindage. The former went through 16′ and the latter through 13′ of earth.

These results show what a large amount of earth is required to keep out heavy shells, when the angle of descent at which they strike is sufficient to counteract the tendency to be deflected upwards, which exists at lower angles of impact, and also demonstrate the importance of firing shells with fuzes giving delay when the penetration of earthen overhead cover is the object in view.

Series 10 and 11.

Series 10 and 11, 1,200 *yards.*—These series were carried out to ascertain how far an effective fire of common and shrapnell shell respectively could be delivered against a battery concealed from view by a screen, or by an undulation of the ground, the information requisite to enable the laying to be corrected being obtained as follows:—

For line, from a post of observation in or near the battery or line of fire.

* The beams cut through by the explosion were of fir, 12′ × 10″ × 10″.

For range, from posts of observation thrown well forward and to a flank.

In this trial it must be noted that the exact range of the battery and the distance of the screen in front of it were known by the officer conducting the fire; and he had also the advantage of a pole set up in the gun portion fired at, which undoubtedly gave him a truer line than would have been afforded by the smoke of an enemy's guns. Furthermore, all the surroundings of the work fired at were of shingle, conquently if he saw earth fly he knew he was on the spot.

The conclusions drawn, at the termination of the practice, which was fairly effective, were as follows:—

1. It is not anticipated that much difficulty would ever be experienced as regards 'line'; the point of burst of one's own shells on impact would generally afford more or less indication, over the intervening screen or undulation, and the point of burst so observed, would be referred to the line given by a pivotted straight-edge (or some similar arrangement), which had been previously aligned on the smoke or flash of the gun attacked.

2. It was fairly apparent that the flanking parties,* if properly posted, would be enabled, by making use of a similar arrangement to that referred to in the preceding paragraph, to obtain a close approximation as to the distance 'under' or 'over' of each shot.

3. It appeared that the shrapnel had not the same trajectory as the common shell, but is very important that they should have, as the corrections for shrapnel fire are generally in large measure dependent on the observation of previous rounds fired with common shell.

4. As the 'effects produced' cannot be noted, it is obvious that a greater expenditure of ammunition will be requisite to achieve a given result, than would be the case when this advantage can be secured by the assailant.

MISCELLANEOUS.

Anchorages.—The anchorages, which were laid in clay by the R.E. all stood remarkably well.

Platforms.—The platforms exhibited as much stability as they could reasonably be expected to do under the continuous shock of heavy firing.

Wheel guides, trail planks, wheel plates.—The wheel guides, trail planks, and wheel plates stood well, and were in every respect satisfactory.

Telephones.—The Telephones worked admirably and without a hitch throughout the experiments.

* These parties must of course have the means of signalling or telephoning the result of their observations to the battery.

Decauville railway.—The Decauville railway, which had been sent from the S.M.E. Chatham, was highly approved of, and afforded great facilities for placing heavy pieces in position.

Reference has elsewhere* been made to the experimental pieces that were under trial, as well as to the means adopted for their mounting, which were tested at the same time.

Concluding remarks.—It is urged by some that it is unlikely that this country will ever again be engaged in an important siege. That may be so, but at the same time, so long as we consider it expedient to maintain a siege train for the R.A., and to instruct our R.E. in siege operations, it is surely essential that the instruction should, for both corps, be sound and thorough.

Theory is all very well, but nothing but extended practical experience can ever lead to really trustworthy conclusions, hence the special value of experiments, such as those we have had under consideration.

In conclusion, I feel it to be my duty to make some short reference to the very important part that has been played by the Royal Engineers in the experiments carried out at Dungeness and Lydd during the last four years.

Time does not admit of an enumeration of the many valuable services that they performed, but the following are amongst the most important, viz. :—

The survey of the ground.
Laying out the ranges.
Construction and repair of the lines of rail.
Batteries.—Target works and splinter proofs.
The laying the required anchorages and platforms.
The working the telephones.
The driving the engines.†
Photographing results of experiments.

I need hardly say that all they undertook was carried out with the zeal, energy, and ability which ever distinguishes that distinguished corps; and last, but not least, the genial social qualities of the officers shed such a warm ray of sunshine over that out of the way corner of the world, that I can safely say that all who had the pleasure of being associated with them at Lydd, will ever think of them with the kindliest feelings.

* Lecture on Modern Ordnance, &c.

† In the performance of this service several thousands of miles were traversed without accident of any kind.

PRÉCIS OF EXPERIMENTS CARRIED ON BY THE ORDNANCE COMMITTEE AT LYDD,

August and September, 1884.

OBJECT OF EXPERIMENTS.

THE main object of the experiments recently carried out at Lydd was to determine :—

1. The penetration into and effect on parallels and approaches of projectiles fired from 'quick firing' (Hotchkiss) and from field and medium B.L. guns.

2. The effect of the fire of machine guns on various forms of approaches.

3. The amount of overhead cover necessary to protect field magazines from high-angle common shell fire, when delay-fuses are used.

4. The amount of accuracy and effect obtainable in the curved or high angle common shell fire of medium B.L. guns, with *reduced* charges, against concealed revetments or earthworks.

5. The effect of gradual exterior slopes in deflecting projectiles on striking earthen parapets.

6. The relative value of bursting charges of different natures of powder when employed, in steel common shell, for the destruction of earthworks.

7 The number of rounds required (with various pieces of ordnance) to dismount a gun, on an overbank carriage, at a range of 2,400 yards, by frontal fire.

The experiments were divided into the following series :—

DETAIL OF SERIES.

Series	Ordnance	Target	Range (yards)	Projectiles	Fuze	No. of Rounds	Remarks
1st	6″ B.L. Gun . . . 5″ ,, ,, . . . 12-pr. B.L. Gun . .	1st parallel . . .	800	Common shell, filled	Percussion .	20 each piece.	
2nd	6-pr. Quick-firing B.L. Hotchkiss Gun . . 12-pr. B.L. Gun . . 5″ B.L. Gun . . .	2nd parallel . . .	400	Common shell, plugged	Nil . .	20 each piece.	
3rd	6-pr. Quick-firing B.L. Hotchkiss Gun . . 12-pr. B.L. Gun . . 5″ B.L. Gun . . .	2nd parallel . . .	400	Common shell, filled	Percussion .	20 each piece.	
4th	6-pr. Quick-firing B.L. Hotchkiss Gun . . 12-pr. B.L. Gun . .	Single sap . . .	300	Common shell, filled	Percussion .	20 each piece.	
5th	4th Series repeated at .	Double sap.					
6th	4th Series repeated at .	Blinded sap.					
7th	Nordenfelt 1″ Gun . Gatling Gun . . .	Single sap . . .	300	Service cartridges .	...	...	Machine Guns.

8th	7th Series repeated at .	Double sap . . .	...	...	...	...	Machine Guns.
9th	7th Series repeated at .	Blinded sap . . .	...	...	...	...	
10th	Not carried out . .	(Cancelled) . . .	...	...	...	...	
11th	8″ R.M.L. Howitzer .	Field magazine . .	2,400	Common shell, filled	Special delay-action	30	
12th	6″ B.L. Gun . . .	27′ × 18′ wood target and earthern parapet	1,600	Common shell .	Direct-action .	20	
13th	6″ B.L. Gun . . . 8″ R.M.L. Howitzer .	30′ earthern parapet, with gradual exterior slope	1,200	Common shell, filled	Direct-action percussion	20 each piece.	
14th	6″ B.L. Gun . . .	30′ earthern parapet .	1,200	Steel shell, filled with— 1. Shell L.G. 2. P. and pistol mixed	...	10 of each.	
15th	6″ B.L. Gun . . . 6.6″ R.M.L. Gun . . 5″ B.L. Gun . . . 8″ R.M.L. Howitzer .	Overbank gun mounted behind a 30′ earthern parapet, with screen in front	2,400	Common shell, filled	Percussion .	30 each piece.	

FIRST SERIES.

'Field and Medium Guns at Parallels.'

Conditions of Fire.

Ordnance	Charge	Angle of Descent ° ′	Striking Velocity f.s.	Fuze
6″ B.L. Gun, Mark II. .	34 lb. P^2	0 58	1,466	Large percussion.
5″ " " " I. .	16 " P.	0 53	1,520	Small "
12-pr. Gun . . .	4 " P.	1 5	1,320	" "

The object of this series was to ascertain the effect of the common shell fire of field and medium B.L. guns against a first parallel (as at present constructed) at a range of 800 yards. (Fig. 1, Plate VI.)

6″ B.L. Gun; Shell 100lb.; Bursting Charge, 6lb. 8oz.

The results obtained showed that the parapet was breached by every round fired from the 6-inch B.L. gun, which hit it even when the shell struck close to the ground line.

It did not appear that any of the shell broke up on impact, which is probably to be accounted for by the fact of the parallel being of comparatively slight profile and of loose material, viz., lumps of unrammed clay, and hence it is likely that the heavy (100lb.) shell started the whole mass in front of it on striking, and therefore never encountered sufficient resistance to cause the shell to break up. It may be as well here to observe that in previous experiments the majority of similar shell fired into solid 30′ parapets at ranges up to 1,200 yards have broken up; and, in some cases, *all* have done so.

5-inch B.L. Gun; Shell, 50lb.: Bursting Charge, 3lb. 8oz.

The fire of the 5-inch B.L. gun, with its lighter shell and bursting charge, was naturally considerably less effective than that of the 6-inch gun; nevertheless, it was found that one round sufficed to breach the parallel, unless it happened to strike very near the ground line, in which case a second round was required.

In order to ascertain whether these shells were liable to break up on impact when, as in this case, the striking velocity was 1,520 f.s., several shells were fired, plugged with their charges drowned, with the result that all that hit the parallel low down broke up, hence it is evident that the destruction of the work was due almost entirely to force of impact, for although the bursting charge was ignited, there was little or no force of burst.

12-Pr. B.L. Gun; Steel Shell: Bursting Charge, 1lb. 12oz. (P. and F.G. mixed).

This gun was fired at the parallel to arrive at the measure of its power in attacking earthworks, and gave very good results, about four rounds sufficing to breach the work, unless impinging very near the ground line, in which case about six rounds would be required.

SECOND SERIES.

Penetration Trials.

The object of this series was to ascertain the penetration of plugged projectiles fired into earthworks. The target was a short length of second parallel at a range of 400 yards. (Fig. 2, Plate VI.)

The conditions of fire were as follows:

Ordnance	Charge	Angle of Descent	Striking Velocity, f.s.
		° ′	
Hotchkiss 6-pr. Quick-firing Gun . .	1·95 lb.	0 25	1,600
12-pr. B.L. Gun, steel shells . . .	4 lb. P.	0 25	1,500
5″ B.L. Gun	16 lb. P.	0 22	1,655

Hotchkiss 6-pr. Cast-iron Shell.

The following results were obtained, 20 rounds being fired from each piece:—

Maximum penetration . . . . 12′
Mean ,, ... 10′

7 shells broke up on impact.

12-pr. B.L. Gun; Steel Shell.

Maximum penetration . . . 24′*
Mean ,, . . . 17′ through at ground line

1 shell buckled and split at side.

5-inch B.L. Gun; Cast-iron Shell.

Shell all broke up on impact.

* Sheil turned down under parallel.

THIRD SERIES.

Hotchkiss, Field, and 5″ B.L. Guns at Second Parallel.

In this series filled common shell were fired from the following pieces at a portion of second parallel, at a range of 400 yards :—

Conditions of Fire.

Ordnance	Charge	Angle of Descent	Striking Velocity, f.s.	Fuze
Hotchkiss 6-pr. Quick-firing Gun	1·95 lb.	0° 25′	1,600	Base percussion.
12-pr. B.L. Gun, common steel shell	4 lb. P.	0 25	1,500	Small "
5″ B.L. Gun, common shell . .	16 lb. P.	0 22	1,655	" "

Hotchkiss 6-pr.

The projectiles fired from this piece were cast-iron shell containing a 4-oz. bursting charge.

From the small weight of bursting charge the craters formed were but small; nevertheless, owing to the accuracy of the gun, and the high-striking velocity of its shell, the work was cut through in 15 rounds.

The effect of a piece of this nature is more marked when employed for the dispersion of small masses of earth, such as sap-heads, the 'first executed' portions of saps, &c., than when directed against such comparatively solid works as parallels, for the speedy demolition of which considerable shell-power, or momentum of projectile (or the two combined) is required.

12-pr. B.L. Gun.

The steel shell of this gun (containing 1 lb. 12 oz. of P. and F.G. powder mixed) made craters of considerable size. Round 1 struck the parallel 3′ above the ground line, penetrated 2′ to point of burst, and formed a crater 2′ in depth and 4′ in diameter.

Round 2 struck in the crater formed by the first round, deepening and enlarging it.

Round 3 struck about the same place, and breached the parallel, blowing away one gabion of the revetment.

5-inch B.L. Gun.

The results obtained appeared to indicate that one round taking effect about half way up the parapet was capable of breaching it effectually, and that a second, striking low down in the same line, would thoroughly open up the work nearly down to the ground line. It appeared that all of the shell broke up on impact.

General Remarks on Series 1, 2, and 3.

The question arises, under what circumstances the besieged would ever think it worth their while to open fire on parallels; having regard to their great length, the comparative ease with which any damage inflicted on them could be repaired, and the uncertainty of such fire proving destructive to the troops occupying the trenches. Now, although it may be conceded that 'to afford concealment from view' and strong musketry positions are the chief offices of parallels, yet instances may occur in which it would certainly be desirable that they should afford efficient protection to the troops manning them from the effects of such artillery fire as might reasonably be expected to be brought to bear on the works of the attack.

For instance, in the case of a sortie, the guard of the trenches would of necessity discover their position on opening fire, and if, under such circumstances, nearly every shell taking effect on the parallel cut right through it, sweeping away masses of the parapet, with the defenders in the rear, the effect could scarcely fail to prove disastrous.

This being the case, it becomes a question worth considering whether some modifications in the construction of such works could not with advantage be introduced, either by going deeper, or by procuring extra earth from a trench in front of the parallel, according to the circumstances of the case.

Certain portions of parallels might at any rate be strengthened by these, or by some other means, in those situations where the troops holding the trenches would be the most likely to be called upon to man the works and open fire for repelling sorties, or where the parallel covers an approach.

SERIES 4, 5 and 6.

Hotchkiss and Field Guns at Saps.

In these series a few rounds were fired from the Hotchkiss 6-pr. quick-firing gun, and from the 12-pr. B.L. gun, at a range of 300 yards at portions of:—

Single deep sap—Double sap—Blinded sap.

The results obtained showed that, even with the less powerful piece, (the 6-pr. Hotchkiss) very few rounds sufficed to effectually demolish the sap-heads, and also, in the case of the single sap, the 'earlier-executed' portion of the work. With regard to the blinded sap, the frame capsills, being exposed as soon as the sap head was demolished, were soon cut through, leading to the fall of the overhead cover.

From this it would appear that, in cases where it is considered advisable to blind certain portions of the approach, such blinded portions should be in rear of, and protected by, the parapets of one or more traverses formed in the usual manner by changing direction.

With the 12-pr. the effect was naturally far more rapidly destructive, and the only conclusion that could be drawn was that it would be impracticable to push forward sapping operations by day so long as fire, of the nature indicated, could be brought to bear on the approaches.

It is however, reasonable to suppose that the besiegers would keep a certain number of accurate rifled pieces advantageously posted, with the special object of silencing any fire of this nature which the besieged might bring to bear on the works of the near approach.

4TH SERIES (EXTRA.)

TARGET SHALLOW KNEELING SAP.

The practice in series 4 was in the original programme intended to be solely at a single deep sap; but a sap roller having been received from Chatham, it was decided to try the effect of a few rounds of common shell from the 12-pr. B.L. field gun and the 6-pr. Hotchkiss quick-firing gun at the sap-head of a shallow kneeling sap under the following conditions:—

Range, 300 yards.

Direction of sap, inclined to line of fire at 30°.

12-PR. B.L. GUN.

The steel common shell fired from this piece were found to burst about half way through the sap roller, cutting a large hole in the reverse side; the dummies in the head of the sap were struck by the splinters of shell.

The sap roller was not, however, displaced from its position.

6-PR. HOTCHKISS.

The cast-iron common shell of the Hotchkiss were found in like manner to burst in the sap roller without displacing it. The fragments of shell appeared to search the head of the sap thoroughly. One gabion which was struck was displaced.

FIFTH SERIES (Extra).

12-Pr. 'Ring' Shell Target. Sap Head of Double Sap.

A few rounds of 'ring' shell were fired at the sap-head of a double (deep) sap at 300 yards to try the effect of these projectiles which assimilate to the old pattern segment shells.

It was found that the shell burst in the sap head with destructive effect, cutting it down and sending numerous fragments and splinters into the trench.

Much the same effect would in all probability be produced by shrapnel shell with percussion fuses.

SEVENTH SERIES (Extra).

1″ Nordenfelt at Shallow Kneeling Sap.

A section of shallow kneeling sap was next fired at, at a range of 300 yards, with the 1-inch Nordenfelt machine gun.

A $\frac{3}{16}''$ inch steel shield (Knight's) was placed next the sap roller. The sap roller was pierced by the steel bullets, as were also those filled gabions which were not protected by earth in front, but the shield proved effective in deflecting a projectile which struck it after passing through a filled gabion.

·45″ Gatling; 1″ Nordenfelt. Target, Flying Trench Work.

A short length of flying trench work was fired at, at a range of 100 yards, with the ·45″-Gatling and 1″-Nordenfelt machine guns.

Gatling.

Half filled gabions, filled gabions, and $\frac{3}{16}''$ steel shields, unprotected by gabions, were fired at with the Gatling with the following results:

Half-filled gabions, some bullets through.
Filled gabions, none through.
Shields, indented but not perforated.

Nordenfelt.

Bullets through shield and filled gabions, except where the latter were protected by earth in front.

In these extra series considerable information was gained regarding the power and destructive effect produced by the projectiles employed; but there is no reason to doubt that the superiority, and power of concentration, of fire possessed by the attack would enable the besiegers to speedily quell any fire of the nature indicated which might be brought to bear on their works.

SERIES VII., VIII., AND IX.

MACHINE GUNS AT SAPS.

The object of these series was to ascertain the effect of the fire of machine guns on various approaches.

The machine guns employed were the ·45-inch Gatling and the 1-inch 4 barrelled Nordenfeldt at a range of 300 yards.

The penetrative power of the ·45-inch Gatling only exceeds, by very little, that of the Martini rifle, and the effect of its fire when directed against sap-heads was very slight, only quite the upper portion of the heap of sand bags being here and there penetrated.

The 1-inch Nordenfeldt was far more effective as regards penetration, but no doubt the amount of material in the sap-heads would always be regulated by the nature of the fire to which they were exposed, and having regard to the large amount of protection afforded by the deep sap (4′-6″) it is unlikely that the progress of such works would be arrested by the fire of machine guns. No doubt their fire would be annoying and more or less obstructive, dependent, in a measure, on the command over the approaches of the positions in which the pieces were worked; hence it would be incumbent on the besiegers to take effective steps for keeping down fire of this nature.

SERIES X.

Series 10 was not carried out.

SERIES XI.

Thickness of earthen overhead cover necessary to protect field magazines from the effect of high angle fire, with common shell having delay-action fuses.

Before entering upon an account of this experiment it will be instructive to glance briefly at the results obtained in the Ordnance Committee Experiments at Lydd in 1882 and 1883.

In 1882 the overhead cover of the magazine was of ordinary construction, as laid down in the School of Military Engineering text book, and the common shell were fired at it from the 6·6 inch and 8 inch howitzers with direct-action (quick) fuzes:

With a striking velocity somewhat under 500 f.s. the fuzes admitted of so little penetration to point of burst that the deepest craters were only 3 ft. 6 ins. in depth; consequently the magazine was uninjured, and it became evident that unless at least two shells fell in succession on precisely the same spot (an improbable contingency) the explosion of the magazine could not be secured.

In 1883, no delay-action fuzes being available, it was sought to imitate their action by employing unbored 30 seconds Wood time fuses with detonators and thin (·012″) suspending wires.

The experiment was fairly successful, and although some of the fuses were driven in on impact and burst the shell immediately, others gave long delay, and the conclusion arrived at was, that a field magazine, as ordinarily constructed, would require some additional protection to enable it to keep out shells with delay-action fuses.

In 1884 the Royal Laboratory undertook to provide two descriptions of delay-action fuzes, one kind intended for screwing into the nose, and the other for insertion in the base of the shell, both kinds so constructed as to be prepared to act with the small charges used with howitzers in high-angle fire.

The overhead cover of the field magazine first fired at consisted of one layer of fir baulks, 12 ft. 10 ins. by 10 ins., strengthened with two layers of light single-headed iron rails (36 lb. and a few 24 lb rails) arranged at right angles to the fir baulks, which were afforded additional support by baulks placed outside the frames, and the thickness of earth overhead was increased from 5 to 7 ft. (Fig. 1, Plate VII.)

8″ Howitzer; 70 cwt.

The conditions of fire were as follows:—

Range 2,400 yards.
Projectile, filled common shell, weight 180 lb.
Bursting charge, 14lb. (nearly) shell, L.G. powder.
Fuze, Experimental (Nose) Delay Percussion.
Charge, $4\frac{1}{2}$ lb. R.L.G^2.
Angle of descent, 33° 12′.
Striking velocity, 486 f.s.

Twenty-six rounds were fired, under very favourable atmospheric conditions, with the following result :—

Abnormal (error in charge)	1
Under	6
Over	7
Hits (not effective)	4
Hits (effective)	4
Short, but partially effective, as they moved a large amount of earth from the slope of the magazine	4
Total	26

Action of the Fuzes.

Not observed	1
*Blind	6
Burst without delay	1
Burst with delay	18
Total	26

The amount of delay which the fuzes gave appeared to be about half a second.

From this abstract it will be perceived that 8 shells fell on the earthern cover of the magazine, and four, which were just short, were enabled, by the delayed action of the fuzes, to get under the exterior slope and to blow away a large mass of earth.

Of the four hits classed as 'not effective,' one blind shell penetrated about 18′ of earth, and lodged near the overhead timbers; had this shell not been blind, it would in all probability have produced important results. Two grazed the top, and only displaced a little earth, and the other lodged in the exterior slope, blew away a good deal of earth, but did no serious damage.

The four effective rounds were Nos. 9, 20, 24, and 26.

No. 9 hit exterior slope high up near the left flank† of the magazine, penetrated about 13′, burst after delay, forming a crater 14′ in diameter, and about 7′ deep. The force of the explosion blew in the

* A slight alteration has been made in these fuzes, to guard against 'blinds' in future.

† The terms 'right' and 'left' refer to the line of fire from the battery to the magazine.

left end of the magazine (which was, it should be observed, 27′ long*) breaking several frames, and filling that end of the magazine with *débris*. It is hardly likely that this shell would have injured a magazine of the usual length (12′), but the round was instructive, as indicating the large results, in the way of earth displacement, secured by the employment of these powerful shells with delay-action fuzes.

Round 20 hit top of magazine, near exterior slope, penetrated 18′ to 20′ of earth, and burst as it passed through the sheeting into the magazine opposite the entrance passage, the splinters cut up the frames very greatly, and many fragments of the shell were buried more than their own depth in the overhead baulks. This round would certainly have blown up the magazine. (Pl. VII., Fig. 1.)

Round 24 struck top of magazine near exterior crest, penetrated about 18′ and burst, blowing a large mass of earth outwards, and the right end of the magazine inwards. Whether this round would have exploded the magazine is doubtful.

Round 26 struck top of magazine, penetrated about 12′, and burst on the rails of the overhead cover, broke a number of rails clean in two, also five of the overhead baulks; several of the other baulks were considerably injured. All the end of the magazine opposite the entrance was broken in overhead and filled with *débris*. Even if this round would not have blown up the magazine, it would have rendered it incapable of being used, as it could not be entered. (Pl. VII., Fig. 1.)

From the results, so far obtained, it appeared that the penetration of the shells into solid, well rammed, and fairly dry clay was from 15′ to 20′.

If was further evident that such penetration admitted not only of the shells reaching the overhead cover, but also of the front side of the magazine being penetrated by those passing just short of the overhead baulks. (Pl. VII., Fig. 1.)

In the former case the powerful bursting charge (being well tamped with 7′ of earth), sufficed to break the rails and baulks and to destroy the structure, and in the latter case the resistance offered by the frames and sheeting was of course so small that the projectile entered and burst inside the magazine with destructive effect.

Furthermore, that any shell lodging in the earth mass, with a line of least resistance in the direction of the magazine, would blow in the side, even if 6′ or 7′ of earth intervened between it and the sheeting.

Although it may fairly be urged that magazines would always be

* The magazine was constructed with an extra length of 15 feet, in order to give a larger area for testing the effect of shells on the overhead cover.

F 2

screened, and protected from the enemy's view, yet at the same time, if it be worth while to give overhead cover at all, such cover should certainly be capable of keeping out chance shell.

In order to afford further overhead protection, and to guard against the liability to be pierced *through the front side*, the magazine, when reconstructed under the supervision of Lieut.-Colonel Leach, R.E., was made with an extra layer of fir baulks 12′ by 10″ by 10″ with a double layer of iron rails over them, and this extra protection was so placed in the earthen overhead cover as to intercept any shell that might strike near the exterior crest and take a line towards the front side of the magazine. Fig. 2, Plate VII., shows the arrangement of the protecting layer of baulks and rails here referred to.

The magazine itself was covered with one layer of oak baulks 12′ by 12″ by 12″ and a double layer of 36 lb. rails with 7′ of earth above the ground line.

It may be as well to here observe that, unless checked in its course, a shell striking about the exterior crest would reach the sheeting after passing through about 20′ of earth.

When fire was opened at the reconstructed magazine 16 rounds of ammunition only were available, and they were of the following descriptions :—

	No. of Rounds	Description of Shell	Bursting Charge	
			lb.	oz.
'A'	3	Cast-iron common shell of service pattern; length. 3 calibres	13	10
'B'	10	Experimental cast-iron common shell; very sharp pointed, their heads being struck with a radius of 6 diameters; length, 3·62 calibres	11	5
'C'	3	Experimental steel common shell; heads similar to pattern 'B'; length, 4·08 calibres	21	11

The 'A' service pattern shells were fired with an experimental nose delay-action fuze as before, and patterns 'B' and 'C' with an experimental base delay-action fuze.

The other conditions of fire were the same as in the first part of the series. A fairly steady breeze prevailed during the practice, blowing nearly in the direction from the battery to the magazine.

The practice was unusually good, inclining one to the belief that the six-diameter headed shell were, notwithstanding their length, superior as regards stability in flight to the service common shells of three calibres. The spiral of rifling of the 8″ howitzer increases to one turn in 35 calibres at the muzzle, which is probably sufficient for a 4-calibre shell with its centre of gravity well placed, when fired with this charge ($4\frac{1}{2}$lb.):

RESULTS OF FIRE.

Under	4
Over	2
Hit	10
Total	16

N.B.—In the first practice only 8 hits were obtained out of the 26 rounds fired, and on a somewhat calmer day.

In order to save time, a detailed account is only given of those rounds in which the shell struck the earth mass covering the magazine, and produced more or less important results.

Round 2, pattern 'B' cast iron shell burst after delay under the left rear corner of the extra layer, broke seven rails, and displaced about ten cubic yards of earth; interior of magazine uninjured.

Round 5, pattern 'C' steel shell struck centre of berm in front of magazine, burst after delay, forming a very large crater.

Round 6, pattern 'C' steel shell struck 2′ above the berm on crater formed by the preceding round, burst after delay in the earth mass apparently some five or six feet from the front frames, blew in the whole of the front of the magazine, which was about one-third filled with earth and *débris;* the beam for affording additional support to the overhead baulks was also blown into the magazine, and the frames and sheeting broken up. (Figs. 2 and 3, Pl. VII.)

Hardly any earth was disturbed externally, but on a way being cleared through the *débris* to examine the crater (which somewhat hazardous operation was performed by a corporal of the Royal Engineers), it was found that an enormous crater had been formed in the earth mass in front of the sheeting, or rather in front of where the sheeting had been.

This crater which was 7′ deep, vertically, extended up to the baulks of the extra layer which roofed it in; its mean length was 10′ 6″, and its mean breadth 9′ 6″. In short, a fair sized chamber had been instantaneously formed in the heart of the earth mass by the powerful bursting charge of the steel shell (nearly 22lbs. of powder). It was not at first evident where all the earth had gone to, as the amount thrown into the magazine (about 100 cubic feet) constituted only about one sixth of the cubical contents of the crater, but a careful examination clearly showed that the clay had been compressed laterally, the sides being very dense and hard.

This shell had evidently passed under the front edge of the extra layer, and on exploding found a line of least resistance into the magazine, which it effectually destroyed. (Fig. 3, Pl. VII.)

Rounds 8 and 9, pattern "A" service cast iron shells, struck top earth mass and exploded on the extra layer where it had been deprived of support underneath by the effects of round 6. These shells broke clean through the rails and baulks, opening a way from the outside into the magazine.

34 rails and a large number of fir baulks were broken by these two rounds.

Rounds 13 and 15 hit the exterior crest and evidently penetrated to a great depth, as very little smoke came out of the tunnels they made.

They produced no effect that could be seen, but the whole mass of earth gave a perceptible heave upwards, when they burst after delay. They only contained 11lbs. 5ozs. of powder, being of "B" pattern, and hence, from being deeply buried, they acted as undercharged mines.

When the earth is removed the craters they doubtless formed by compressing the clay will probably be discovered.

Round 16, pattern "B" cast iron shell, penetrated on to the extra layer, when it was fully supported, broke clean through, and burst close underneath, forming a large crater.

This ended the experiment, in which the results obtained appeared to indicate that although the extra layer served to protect the overhead cover of the magazine, which apparently remained intact, it did not extend sufficiently far to the front to prevent a shell from penetrating to such a position in the earth mass that it had, on exploding, power to blow in the earth, in the line of least resistance which lay in the direction of the front side of the magazine.

The action of the delay fuzes was exceedingly good, only one shell seemed to be 'blind,' and in this case it is not unlikely that this sharp-pointed shell, having penetrated to great depth, the earth fell in behind it, and thus closed the tunnel and prevented the escape of any smoke.

Of the other 15 shells 12 burst after delay, and three on penetrating the extra layer of rails and baulks, without *appreciable* delay. It seems likely that the shock of striking the rails caused the slow-burning composition to crack up or fall in, and hence the usual delay did not take place.

Stowage of Powder in Traversed Recesses, below the Ground Level, with Covering Earth Mass in Front.

Plate VIII. Recent experiments having shown that unless an enormous amount of material (such as heavy baulks and rails) be employed to strengthen the overhead cover of Field Magazines, it is difficult, if not impossible, to guard their contents from explosion (which is, indeed, liable to be effected by even a single, well-placed, 8-inch Howitzer shell with delay-action fuze) this alternative method of stowing powder has been suggested, and would appear to have several points in its favour.

The system advocated consists of the distribution of the powder in a number of recesses, below the ground level, protected by a covering earth mass in front, and isolated one from the other by solid masses of undisturbed earth left between them. These excavations should naturally be as deep as circumstances would admit of, so as to obtain the maximum amount of cover, and it is obvious that, in any site where Mined Magazines could be employed, they could easily be made sufficiently so to secure ample protection for the powder.

It is not urged for this system that it would either be practicable or advisable to employ it under *all* conditions, or that it secures absolute immunity from explosion, nevertheless, when adopted on level sites (devoid of striking features of ground, capable of being taken advantage of for purposes of cover), it would appear to possess the following advantages over ordinary Field Magazines, other than mined. viz. :—

1. Ease and rapidity in construction.
2. Little or no material required.*
3. By confining the result of a chance explosion to the powder contained in *one* recess it is unlikely that any pieces would be put out of action, whereas when a whole Magazine goes up the results must be distinctly disastrous.
4. By keeping the covering earth mass *solid* it is probable that shells exploding in it would, for the most part, prove innocuous to the powder in rear, but when the earth mass is *hollow*, and the powder is stowed *inside it* (as in ordinary Field Magazines), shells exploding in the mass (being heavily tamped) are apt to find a line of least resistance in the direction of the Magazine and blow it in.

The amount of powder that it would be advisable to stow in each recess would in great measure be dependant on the depth of the excavation below the ground level. In the diagram this is only shown

* If the covering earth mass be made with a revetted interior slope gabions would be required for the purpose.

as 5′ 6″ (or the same depth below the ground line as the floor of an ordinary Field Magazine); but as a general rule the recesses should be sunk as much as is consistent with efficient drainage and fairly easy supply of powder to the Battery.

The powder being in M. L. cases (which are both air and water tight), it is hardly likely that the cartridges would run more, if as much, risk of deterioration from moisture as they would do in the damp and steamy interior of a Field Magazine.

Nothing but actual experiment can decide the amount of undisturbed earth necessary to secure effective isolation for the powder in the recesses, but it is well known that the explosive force of even large untamped charges of powder in the open is comparatively small.

The thickness of the traverses (which is merely tentative) is shown in the diagram as 20 feet at bottom.

SERIES XII.

6″ B.L. Gun 81 Cwt.

Effect of common shells fired with low charges from medium B.L. Guns at high angles of elevation in attacking concealed revetments or earth works—

The 6″ B.L. Mark II. on Naval Slide was the gun selected for this series, it being not unlikely that similar pieces might be disembarked from ships of war for use in the land attack of maritime fortresses, and that, under such circumstances, it might be desired to employ them for curved, or high-angle, as well as for direct fire. It was therefore sought in this experiment to determine the amount of accuracy obtainable in the curved fire of this piece under the following conditions:—

Range—1600 yards.

Targets—Wooden screen, 27′ long by 18′ high, for pattern on vertical target. Earthen parapet 30′ thick, with exterior slope at 8° for effect on earth works.

Projectile—Common shell, filled.

Bursting charge—6 lb. 8 oz. shell L.G. powder.

Fuze—Direct action (quick)

Charge—6 lb. R.L.G^2.

Striking velocity—580 f.s.

Angle of descent—about 14°.

The first 10 rounds were fired plugged at the vertical wooden target, for pattern; the wind was rather strong and variable in force.

The result was:—

Over	3
Under	5
Hit	2
Total	10

Three of the shells struck just short, and hit the lower part of the target 'en ricochet.'

The shells appeared to be nearly steady in flight, and the few that showed slight instability, on leaving the muzzle, soon steadied themselves.

It appeared that although the line was good, the vertical dispersion was considerable; this is probably to be accounted for by the 6 lb. cartridge only occupying one seventh part of the chamber, which was made to take a 42 lb. charge, and hence the air space was unduly large.

The next 10 rounds were fired at a 30′ parapet, with exterior slope at 8°. The first round was short, the next three over, and the remaining six hit the work.

Again it was noted that the line was good, but the vertical dispersion considerable.

The effect of the shells that entered the earthwork was decidedly small, for although none were deflected from their course, even when striking on the superior slope, the direct-action fuzes, at the low striking velocity, only allowed of such small penetration to point of burst that the mean size of the craters formed was only about 6′ long by 4′-6″ wide by 2′-3″ deep.

The $6\frac{1}{2}$ lb. bursting charge was capable of giving larger results had the penetration to point of burst been better.

From the small number of rounds fired it would be rash to attempt to draw any very definite conclusions, but, as far as could be seen, it appeared that fairly good results might reasonably be expected from the employment of these pieces under the conditions named.

SERIES XIII.

Effect of Gradual Exterior Slopes in Deflecting Projectiles on Striking Earthen Parapets.

In this series exterior slopes of 15° and of 8° were fired at, the former both with the 8-inch howitzer and the 6-inch B.L. gun, and the latter with the 6-inch gun only.

It appears reasonable to infer that the more gradual the exterior slope (or the more 'glacis-like' its form) the greater the expenditure of ammunition necessary to effectually open up the work, for the following reasons :—

1. The tendency of very gradual slopes, when unbroken, to deflect the projectiles from their course and cause them to rise in the air before bursting.

2. The comparatively small amount of earth over the shells which do enter the slope at the moment of bursting.

3. The greater horizontal distance required to be cut through to form a breach.

Experiments at Exterior Slope of 15°.

8″ R.M.L. Howitzer.

The section of the work fired at, in this case, is shewn in Fig. 1, Pl. IX. The parapet was of stiff clay, fairly dry and hard on the surface, and for some way in, but decidedly soft and plastic in the centre. The conditions of fire were as follows :—

Range, 1,200 yards.
Nature of fire, curved frontal.
Charge, maximum, 11½ lb. R.L.G².
Projectile, cast iron common shell, filled, weight, 180 lb.
Bursting charge, 14 lb. (nearly) shell, L.G. powder.
Fuze, direct action (quick fuze).
Angle of descent, 4°.
Striking velocity, 876 f.s.

Twenty rounds were fired with the following result :

Under	1
Over	2
Defective in line	4
Effective	13
Total	20

The effect of the 13 effective rounds was to breach and open up the work fairly well. The amount of earth moved was 53·75 cubic yards.

The quick action of the fuzes, and comparatively low s.v. of the shells, only admitted of a penetration of about five feet to point of burst, and it could not be perceived that they were, in that short distance, appreciably deflected upwards from their course.

In the earlier stage of the breaching the amount of earth moved by individual shells was small, compared with what would have been blown away by similar shell fired into a parapet with an exterior slope at 45°.

A reference to Fig. 3, Plate VI., will show the cause of this.

The outlines show sections through parapets having exterior slopes of 45° and 15° respectively. In the case of a shell hitting, say, two feet above the ground line, and penetrating five feet to point of burst; in the first instance, the shell entering at '*a*' bursts at '*b*,' and blows away the earth represented in section by the curve *a b c*; in the latter the shell only displaces the earth represented by the curve *a b d*, and this comparatively tardy destruction goes on until the main mass of the parapet under the superior slope is reached, after which the conditions are about the same in both cases. Thus we see that, in the earlier stages, the powerful bursting charges of the howitzer shells are, so to speak, in great measure thrown away, as the shells have never enough earth over them, at the moment of bursting, to enable them to do the work they are capable of, and hence there is a marked disproportion in the number of rounds required to breach the parapet in the two cases under consideration.

In previous experiments, the same piece, fired under like conditions, thoroughly breached similar parapets, with exterior slope at 45°, in from six to nine effective rounds; whereas with the 15° slope the work was not so completely opened up in 13 effective rounds.

6″ B.L. Gun.

The same parapet having been repaired, was next fired at by the 6″ B.L. gun, Mark II., under the following conditions :

Range, 1,200 yards.
Nature of fire, direct frontal.
Charge, 34 lb., P^2.
Projectile, cast iron common shell, filled, weight 100 lb.
Bursting charge, 6 lb. 8 oz. shell, L.G. powder.
Fuze, large percussion (quick).
Angle of descent, 1° 31′.
Striking velocity, 1375 f.s.

Ten rounds were fired with the following results :

Under	2	
Effective	8	of which 2 were blind
Total	10	

It may be as well here to explain the reason of the two blind shells being classed as effective. Owing to the high velocity, the striking energy is as high as 1,310 foot tons, consequently a considerable amount of earth was displaced even by the blind shells.

The effect of these 8 rounds was to breach and open up the work fairly well. The amount of material displaced was 31 cubic yards. (Fig 2, Plate IX.)

Notwithstanding the quick action of the fuzes, the high-striking velocity enabled the shell to attain to a penetration to point of burst of from 12′ to 18′, according as the clay was hard and undisturbed, or soft and loose.

The shell on striking was not appreciably deflected upwards, and, from the first, burst *in* the slope.

Thus, in round 2 (the first hit obtained) the shell penetrated 12′, burst, and formed a crater 15′ long ;* greatest breadth 6′, greatest depth 3′. (Fig. 3, Plate IX.)

EXPERIMENTS AT EXTERIOR SLOPE AT 8°.

6″ B.L. GUN.

We now pass on to consider the effect of a *very* gradual exterior slope, viz., one of 8°, in increasing the resisting powers of a parapet.

A reference to Fig. 4, Plate IX., will show the profile of the parapet fired at in this case ; all the other conditions were precisely the same as those which obtained when the 6″ gun was fired at the 15° slope. 23 rounds were fired.

The following is a *précis* of the results :

Under	1	
Over	0	
Burst prematurely at gun	1	
Scooped up and burst in air . . .	8†	hits, 21
Do-ricochetted blind	2	
Broke up on impact	2	
Effective	9	
Total	23	

* The length includes the 12-foot long scoop cut by the shell to point of burst.

† Of this number 2 were deflected upwards by the exterior slope before it was cut up, and 6 by the gradually sloping groove or crater ultimately cut through the parapet.

From this experiment it appeared that with so gradual a slope as 3°, and an angle of descent as low as 1° 31′, as long as the slope where the projectiles strike is hard and undisturbed, they will be deflected upwards (after cutting a scoop) before bursting; and, furthermore, from the fact of the general inclination of the groove, or crater, ultimately cut through the parapet being so gradual, a not inconsiderable proportion of the shell will be deflected upwards in like manner, and burst in the air during the process of forming the breach.

Thus, in this experiment, we see only 9 rounds are classed as effective, although it must be borne in mind that the 8 which scooped up and burst in the air, and the 2 blind cut away an appreciable amount of earth. For example, round 1 cut a scoop 12′ long, 2′ 6″ wide, and 2′ deep, and burst in the air; round 3, one 15′ long, 3′ wide, and 2′ deep, and burst in the air, and so on.

At the conclusion of the experiment the parapet was found to be fairly breached.

The amount of earth displaced was 45·5 cubic yards.

Précis of Previous Experiments.

The following are the results obtained in the Ordnance Committee experiments at Lydd in 1882 and 1883 with the same gun against a 30′ clay parapet with exterior slope at 45° at the same range (1,200 yards), the shells being fuzed with direct-action fuzes.

1882 Experiment.

Number of rounds fired			20
Result reported :—			
Under		3	
Over		1	
Hit	Blind, or broke up	12	16
	Burst	4	
Total		20	

Parapet not cut through by 8′. Amount of earth displaced, 26 cubic yards.

In this experiment the gun was fired with a 42 lb. charge, instead of with a 34 lb. charge of P^2, as in the 1883 and 1884 experiments, consequently the striking velocity was 1552 f.s. instead of 1375 f.s.

This high striking velocity in the 1882 experiment was doubtless the cause of so many of the shell breaking up on impact.

1883 Experiment.

Number of rounds fired		15
Result reported :—		
Under	1	
Over	1	
Effective	13	
Total	15	

The majority of the shell were noted as having broken up on impact, but some burst at good penetration, and formed large craters in the clay, which, in this experiment, was very wet and plastic; hence the parapet was cut through in the 15 rounds, and from 45 to 50 cubic yards of material were displaced.

From these two experiments it will be perceived how largely the results obtained are, in the case of clay parapets, affected by the state of the material, 20 rounds in one year's experiments doing far less than 15 in the next; at the same time it is right to bear in mind that the conditions of fire (as already pointed out) were not identical in the two experiments.

To sum up the results obtained in the three years' experiments (1882, 1883, 1884) it would appear, speaking generally, that howitzers are considerably less effective for breaching works with gradual slopes than they are for breaching works with steep slopes. The apparent causes for this have already been explained at pages 74 and 75.

Fire of High Velocity Guns at Gradual Slopes.

With high velocity guns, however, this does not appear to be the case, or at any rate, not in such a marked degree; to explain which we may, perhaps, not unreasonably, look to the following causes:—

1. The great accuracy of the gun enables shell after shell to be placed on the already cut-up portion of the slope, and hence to act with good effect.

2. The 'high velocity' cast-iron shell, ploughing along a gradual slope, lifts the earth over it as it goes, and consequently does not encounter such a measure of resistance as to lead to its breaking up; whereas, when fired into 45° slopes, the majority of these shells break up from the resistance encountered.

Thus, in the recent experiments, it was found that when the gradual slope was cut through, and the shells began to enter the heart of the parapet, a proportion of them broke up.

3. Again, when the shell power is comparatively small (as with the 6″ gun), those projectiles that enter a 45° slope low down, and do not break up, but burst properly, are unable to lift the superincumbent mass of earth unless the clay is very soft and yielding, and are consequently more or less smothered, whereas those that enter a gradual slope have never more earth over them than they are capable of blowing away.

Hence it would appear that with cast-iron projectiles there are absolutely fewer rounds comparatively ineffective in the earlier stages of breaching parapets with gradual slopes than is the case in attacking works with steep slopes. With howitzer shells these remarks do not hold good, for they are neither liable to break up on impact nor to be smothered on bursting.

Considering the few data we have at present to go upon, it would be rash to do more than thus indicate the various causes which probably tend to influence the case. To enable really trustworthy conclusions to be drawn as to the advantages possessed by the gradual slope over one at 45° it would be necessary to carry out extensive comparative trials under precisely similar conditions, not only as regards ammunition, angle of descent, and striking velocity, but also as regards the material of the parapet, its solidity, and (in the case of clay) wetness or dryness. The interior of clay parapets is apt to be very wet, and when this is the case very large craters are made, and an unduly high estimate of the power of the gun will probably be formed.

In the 1884 experiments, the recently introduced 'Large Percussion' fuze was used for the first time in shells employed for breaching earthworks, and whether it is quicker or slower between impact and burst than the D.A. percussion fuze used in 1882 and 1883 experiments has not as yet been definitely determined, and, as is well-known, the time the fuze takes to act exercises a very important influence on the results obtained.

It is more than probable that most common shell will shortly be made of *steel*, and will contain far heavier bursting charges than the present service cast-iron projectiles.

With such shells it is likely that for the reasons already given, there will be stronger cause than at present exists for modifying the usual form of exterior slopes.

SERIES XIV.

Comparative Effect of Steel Shell with Various Natures of Bursting Charges.

The object of this experiment was to obtain a direct comparison, under similar conditions, between the power of steel shells, filled with the ordinary bursting charge of shell L.G. powder, and similar projectiles filled with a mixture of pebble and pistol powder.

Reason of first Firing the Shells Plugged.

Had the shells been fired, fuzed, into an earthen parapet, and burst in the ordinary way, such a comparison could not have been instituted because it would have been a matter of uncertainty as to whether the projectiles were, at the moment of burst, equally tamped in each case.

If, on the other hand, the shells had merely been exploded electrically after being buried at a certain depth, but without having been previously fired, the results produced would have been erroneous, owing to the different extent to which "setting back" (on discharge) mealing, caking, and consequently loss of explosive power takes place with the different natures of bursting charges experimented with.

It was therefore decided to first fire the shells plugged into an earthwork at what might be considered a medium range (1,200 yards), so as not only to get the setting back effect on discharge, but also the (presumed) setting forward effect on impact; then dig out and explode electrically in earth, under given conditions.

In carrying out the experiment some difficulties presented themselves, viz.:—

1. The uncertainty as to whether the shells supplied, which were about four calibres in length, would, on account of their great length, be sufficiently stable in flight to secure accurate shooting.

2. The known tendency of unfuzed projectiles fired from high velocity guns, and striking at a small angle of descent, to scoop up out of the parapet and fall far beyond the work, in this case into the sea.

With respect to 1 (stability in flight).

In the 1883 experiments with steel shell some very accurate practice was made at 1,200 yards with the same gun with steel shell, four calibres in length, filled with discs of highly compressed powder, whereas in the series now under consideration the shooting was far from accurate, which may perhaps reasonably be accounted for as follows:—

Since the spiral of rifling (1 turn in 35 calibres) was found to impart stability in flight to 4-calibre shell on a previous occasion, the want of accuracy can hardly be attributed to insufficient rotation.

The position of the 'driving ring' is known to exercise an influence on the stability of a shell in flight, but it was in this case apparently of a similar kind, and at the same distance from the base of the shell, as the rings on the shells with which good practice was made last year; other causes have therefore to be sought for.

With regard to the position of the centre of gravity. It should, as far as is at present known, lie somewhat in front of the centre of the figure; as if in rear, a tendency to instability arises.

In this case the centre of gravity appeared to be well placed *before the shell were fired*, but it far from follows that it was so during flight for the following reasons:—

With a 4-calibre shell the long column of powder, which forms the bursting charge, is violently set back on discharge and highly compressed, especially in the case of shell L.G. powder, and this, it is urged, must cause an appreciable alteration in the position of the centre of gravity, in the direction of the base of the shell, for not only is the column of powder greatly decreased in length, but the densest portion lies at the base end.

With regard to the 4-calibre shells fired last year; from the fact of their being filled with powder, previously highly compressed under hydraulic pressure, it is improbable that any appreciable alteration in form, or distribution of the bursting charge took place on discharge, hence the position of their centre of gravity remained undisturbed.

With reference to 2, viz., the tendency of projectiles to be deflected upwards out of earth on striking at low angles of impact:—

It was sought to counteract this tendency, firstly, by firing at a portion of the parapet which had the exterior slope cut away till it was nearly vertical, and, secondly, to so lay the gun as to secure a point of impact close to the ground line, and thus obtain as much resistance as possible out of the earth mass.

The former expedient appeared to be in slight measure successful, but the latter could not, owing to want of accuracy in the shooting, be carried out.

It should be observed that the bursting charges of shell L.G. powder varied in weight from 8 to 9 lb., and those of P. and Pistol powder from 10 to $12\frac{1}{4}$ lb.; these varying weights doubtless further detracted from the accuracy of fire.

The conditions of fire were as follows :—

Range, 1,200 yards.

Target, 30 ft., earthen parapet.

Projectiles, cast steel shell filled with :—

1. Shell L.G. . . . } 10 of each nature.
2. P. and pistol mixed . }

Gun	Charge	Angle of		Velocity	
		Elevation	Descent	Muzzle, f.s.	Striking, f.s.
6″ B.L., Mark II., 81 cwt. .	34 lb. P².	1° 11′	1° 31′	1,660	1,375

The results of the firing were as follows :—

Under	2	One fell in sea, after graze. One broke up on impact on striking the work, en ricochet.
Over	2	fell in sea.
Hit lodged	3	(2 not found).
Hit rose and fell on shingle .	5	
Hit rose and went out to sea .	7	(1 recovered at low water).
Hit and burst	1	
Total . .	20	

From this abstract it is seen that only seven shells were recovered for burying in earth and exploding electrically.

EFFECTS OF SHELL WHEN EXPLODED ELECTRICALLY.

With regard to the effects produced by the shells when exploded electrically in earth, it was found that :—

The shells filled with shell L.G. powder (about 9 pounds) had not, with 6′ of earth over them, sufficient power to make a clean crater. Two fired under these conditions formed craters only 4′ and 2′ 6″ deep respectively, owing to the earth having fallen back. They displaced 4·68 and 2·93 cubic yards of earth respectively.

Three similar shells, buried 5 feet deep, formed clean craters 5 fee in depth, and displaced 10, 5, and 7 cubic yards respectively.

The shells filled with P. and Pistol powder (11 lbs. 10 ozs.) hadt ample power to form clean craters when buried 6 feet ; the two fired forming craters 6 feet in depth and displacing 13½ and 11½ cubic yards of earth.

From these results it would appear :—

1st. That similar shell take far larger bursting charges of P. and Pistol powder than of shell L.G. powder, and produce far larger results; which is believed to be due, not only to the larger bursting charge, but also to there being less loss of explosive power from the mealing and caking of the bursting charge with P. and Pistol than with shell L.G. powder.

2nd. That if shells which only contain about 9 lbs. of shell L.G. powder have more than 5 feet of earth over them at the moment of bursting, they are somewhat overmatched, and displace less earth than they do when acting at a smaller depth.

SERIES XV.

Number of rounds required to dismount a gun on an overbank carriage by frontal fire at 2,400 yards.

Effects of fire to be corrected by observations from firing battery and flanks only.

In this series the conditions of fire were as follows :—

Ordnance	Charge	Angle of Descent ° ′	Striking Velocity, f.s.	Fuze
6″ B.L. Gun, Mark II. .	34 lb. P.[2] .	3 50	1,150	D. A. and large percussion.
6·6″ R.M.L. Gun . .	25 lb. P. .	5 38	892	D. A.
5″ B.L. Gun . . .	16 lb. P. .	4 15	1,064	Small percussion.
8″ R.M.L. Howitzer .	11½ lb. R.L.G.[2]	9 12	809	D. A.

The projectiles used were common shell. The guns fired at were wooden dummies on wooden overbank carriages, which were placed in the two gun portions of a screened sunken siege battery of the ordinary type.

In the practice with the 6·6 inch R.M.L. gun, a pole showing over the screen indicated the position of the dummy gun, but as it was thought that this arrangement conferred undue advantage on the officer directing the fire, in the practice with the other three pieces the following plan was adopted :—

The officer on range duty held up (for a few seconds) from time to time a plank, or some such object, to afford such a transient indication to the firing battery as might reasonably be expected to be given by the smoke of one of the enemy's guns in a screened battery at the moment of firing.

The officers observing the effect of fire were stationed, one just to the windward flank of the firing battery, the other in a position about 1,000 yards in front and 700 yards to the flank of the same.

Each of these officers was furnished with a pivoted straight-edge fitted with sights, which he directed on to the aiming point when it was exhibited.

Correct *line* was thus obtained from the battery, the gun being laid approximately, in the first instance, on an auxiliary mark laid out in front, and the line being afterwards corrected by applying deflection, according as the point of impact was observed, by the officer looking over the sights of the straight-edge, to be to the right or left.

In like manner the officer observing (on the right flank) directed his sights on the temporally-shown aiming-point; then, as shell burst to the right or left of the fixed line thus obtained, he signalled over or under to the battery—

By this simple and easily applied expedient excellent results were obtained. Some such method of observing effects of fire is an absolute necessity when firing at an object concealed from view by an undulation of the ground or an artificial screen.

6″ B.L. Gun.

The results of the practice were as follows:—

Over	3
Under	8
Hit battery	12
Total	23

The gun in No. 1 gun portion was dismounted by a direct hit—the 12th round.

That in No. 2 gun portion by a shell bursting in the scoop—the 22nd round.

It is uncertain whether, under the latter circumstances, a real gun would have been dismounted or not.

Two of the shell were noisy in flight, and it was thought that the driving ring came off—both struck considerably short.

6.6-inch R.M.L. Gun—23 rounds.

This gun was mounted on a Moncrieff hydro-pneumatic carriage, with oil in the cylinder instead of glycerine and water, which was found to give rise to rapid corrosion.

The mixture of oil used in this trial consisted of two parts paraffin to one of olive oil.

The air pressures were the same as had been used with glycerine and water in the cylinder viz.:—gun down 700lb., and gun up 400lb., to the square inch.

The very permeating nature of paraffin oil caused it to be forced somewhat freely through the "U" leather at the neck of the cylinder, thereby occasioning a proportionate loss of air pressure.

A somewhat thicker and more viscid oil would probably be found to give better results—

The results of the fire were as follows:—

Under	8
Over	11
Hit	4
Total	23

Of the four shells that hit the battery, one, the 20th round, grazed on the superior slope, struck, and dismounted the dummy gun "en ricochet"

5″ B.L. Gun—25 rounds.

The results of the fire for dismounting purposes with this piece were as follows:—

Under	10
Over	4
Hit	11
Total	25

Of the 11 shells which hit the battery, round 17 dismounted No 1 dummy gun by a direct hit, and round 20 burst on the superior slope, a splinter of the shell knocking the left trunnion off dummy gun No 2. It is uncertain whether this shell would have dismounted a real gun.

8″ R.M.L. Howitzer—23 rounds.

Twenty three rounds were fired with the following results:—

Under	12
Over	1
Defective in line	1
Hits	9
Total	23

In this practice the observing officers were not in possession of proper straight-edges fitted with sights, consequently their observations were not always correct, which led to incorrect elevation being given in some instances. The dummy gun was dismounted by the 22nd round; the shell struck the superior slope 8 feet short and 3 feet right, the force of explosion blowing off the chase of the gun.

It is hardly likely that this round would have dismounted a real gun.

The results obtained in this series warrant the belief that, with an observing party properly posted (*i.e.*, well forward, well on the flank, and if possible in a somewhat elevated position) it is quite practicable to deliver an effective fire at an object concealed from view, provided the observing officers are furnished with suitable instruments, and that the smoke of the gun fired at can be seen when, or shortly after, it leaves the muzzle; of course if it has drifted some distance before it is seen, more or less uncertainty as to line and range must prevail, and tend to detract from the accuracy of fire.

Concluding Remarks.

In conclusion, it would perhaps be as well to call attention to the fact that the earthworks fired at in the experiments of 1882, 1883, and 1884 have *all* been made of the alluvial deposit found on the Holmstone range, and which may be termed a fairly stiff clay; hard when dry, and when thoroughly wet of the consistency of cheese. It is of course desirable to ascertain the effect of artillery fire on *all* natures of soils varying between pure sand and stiff clay, and it is to be hoped that in due course opportunity of so doing may be secured.

The heavy labour and expense of bringing sand or loam from other sites on to the Holmstone range, coupled with the fact of the ground having only this year become Government property, has hitherto intervened to prevent any steps being taken in the direction indicated.

Considering the many cases that might occur on service of works thrown up on alluvial sites, the various results obtained in these experiments necessarily possess considerable interest and value, and throw much light on the powers of resistance to artillery fire of the various works fired at when constructed of *clay*; which should, however, be recognised as the nature of soil least suited for the purpose, pure sand being taken as affording the *highest* powers of resistance, and light loam being probably a fair average between sand and clay.

APPENDIX.

Plate X. gives some sketches, not drawn to scale, of some of the fuzes used in the 1884 Experiments. The 'nose' fuzes are all of the 'General Service' Gauge.

Fig. 1 shows the Large Percussion Fuze intended for use with medium and heavy ordnance, and to act either on graze or impact at any angle of elevation. It may be described as follows:—

The heavy pellet, '*a*, *a*,' carries the cap, '*b*,' in its head, and is prevented from moving towards the needle, '*c*,' by the safety-pin, '*d*,' and the pea-ball, '*e*.'

When the safety-pin has been withdrawn the pea-ball alone prevents the forward movement of the pellet.

On firing, the guard, '*f*, *f*,' is set back and jams on the lower and larger portion of the pellet, *a*, *a*, and the pea-ball *e*, flies outwards from the action of centrifugal force, due to the spin of the shell, and remains clear of the pellet in the recess, *g*.

On graze or impact the pellet, *a a*, flies forward, and the cap, *b*, is fired by contact with the needle, '*c*,' ignites the powder in the magazine, *a*, and explodes the shell.

It will be observed that the guard, *f*, *f*, is higher on the side where the safety-pin passes through it, than on the other side where it holds the pea-ball ; it is prevented from revolving by the guide-pin, *k*, whose point lies in a groove on the guard.

The lead cylinder, *l*, sets back on firing and closes the hole left by the withdrawal of the safety-pin.

A thin shearing wire, *m*, guards against any tendency of the pellet to move before graze or impact.

Fig. 2 shows the Small Percussion Fuze intended for use with field guns, and to act on either graze or impact at any angle of elevation.

The pellet, '*a*,' carries the cap, '*b*,' in its head, and is prevented from moving towards the needle, '*c*,' by the pea-ball, '*e*,' and the safety plug, '*h*.' The pea-ball is kept in position by the hollow cylinder, '*d*,' which is, before firing, held fast by the safety pin, '*f*,' and the shearing wire, '*g*.'

After the safety pin is withdrawn the hollow cylinder, '*d*,' is free to be set back by the shock of firing on shearing the wire, '*g*,' leaving the pea-ball free to fly outwards, by centrifugal force, clear of the pellet.

The same centrifugal force also causes the safety plug, '*h*,' to fly outwards and compress its spiral spring, thereby leaving the pellet free to fly forward on graze or impact, and fire the cap by contact with the needle. The flash from the cap ignites the two powder-puffs, '*m*,' which fire the hollow columns of pressed powder on which they rest, and explode the shell.

'*n*, *n*' are small lead discs to prevent rebound.

Fig. 3. *Nose Delay Percussion Fuze.*

In this fuze the pellet, '*a a*,' which carries the cap, '*b*,' in its head, is, before firing, prevented from moving by the plug, '*e*,' which is retained in position by the two small safety plugs, '*f f*,' which are themselves kept in their place by the spiral springs by which they are pressed forward, and by the safety-pins, '*d d*,' passing through them.

The safety-pins having being previously withdrawn, the following is the action of the fuze:—

On firing, the small safety-plugs, '*f f*,' fly outwards by centrifugal force, compressing their spiral springs, and liberating the plug, '*e*,' (which carries the needle, '*c*') which also flies outwards in the direction of its heavier end by the action of the centrifugal force due to the spin of the shell, and by so doing frees the pellet, '*a*,' and brings the needle '*c*,' opposite the cap '*b*.'

The needle is kept true, *i.e.*, at right angles to the surface of the cap by a guide-pin, '*l*,' whose point lies in a groove on the under surface of the plug, '*e*.'

As soon as the plug, '*e*,' has thus flown outwards, it is securely kept there by the small plug, '*g*,' being forced in front of it by the action of its spiral spring.

On impact the pellet, '*a*,' flies forwards, the cap is exploded and fires the column of 'delay,' or fuze composition, '*h*,' which, when it has burned out, fires the magazine of F.G. powder '*k*,' which ignites the bursting charge of the shell.

The amount of delay, which was estimated at about half a second, appears sufficient to enable the shells to attain to their maximum penetration.

Fig. 4. *Base Delay Percussion Cap.*

This fuze is, as its name implies, screwed into the *base* of shells which have especially sharp points.

Its action is as follows:—

The pellet, '*a*,' which carries the cap, '*b*,' in its head is, before firing, retained in position by the three small safety-plugs, '*e*, *e*, *e*,' which are kept in their place by their spiral springs, and also by safety-pins '*d*,' which latter are withdrawn before ramming home.

On firing the three small safety-plugs fly outwards, by the action of centrifugal force, due to the spin of the shell, and in so doing compress their spiral springs.

As soon as this takes place, the pellet, '*a*,' is forced a *little* forward by the action of the spiral spring underneath it; this forward movement prevents the small safety-plugs from resuming their former position holding the pellet.

On impact, the pellet flies forward, the cap is exploded by contact with the needle, '*c*,' and its flash ignites the delay or fuze composition '*ff*,' which, when it has burnt out, fires the F.G. powder in the magazine, '*g g*,' and the shell is exploded.

The amount of delay which was estimated at about half a second, appeared sufficient to enable the shells to attain to maximum penetration.

STUDIES

IN

FORTRESS WARFARE

PART I.

THE DEFENCE

TRANSLATED BY CAPT. G. S. CLARKE, R.E.

PART II.

THE ATTACK

TRANSLATED BY LIEUT. M. NATHAN, R.E.

Printed by

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TRANSLATOR'S PREFACE.

THE following papers—termed by von Brünner 'schätzenswerthe Brochüre'—were published anonymously in Berlin in 1880. They created a considerable impression, and reference is made to them in numerous subsequent writings. Their scope is limited to what may be called the higher principles of siege-warfare, and they do not deal with the details of works of attack or defence. Such details are of relatively less importance, do not form subjects of debate, and are fully dealt with in the text books of all countries. The right conduct of a siege, or of a defence, will always exercise a determining influence on the result, and no amount of technical skill in sapping and earth works will serve to counteract the effects of a wrong conception of those general principles which form the basis of what may be termed the strategy of siege-warfare.

Much of the subject-matter following will be readily accepted; some portions of it may fairly be questioned; other portions will perhaps be pronounced mere truisms. Allowance should, however, be made for the peculiarities of the German habit of mind, the tendency to over-systematise, the slightly professorial tone. To the German, the careful subdivision of his subject is essential; nor does he shrink from platitude or repetition in establishing what he accounts as the logical completeness of his position. So much we must pardon him. These things notwithstanding, the 'Studies' will, it is believed, be found to be not only suggestive, but invested with a certain freshness of thought as well as a freedom from that pedantry of the past, that thraldom to terms and forms of expression now changed or dead, which is occasionally visible in military writings. Our literature on this special subject is not too copious, and it is possible that these Papers may have a certain use. With this hope, the translations are offered to the Corps.

G. S. C.

London, October 1884.

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STUDIES IN FORTRESS WARFARE.

Part I.

THE DEFENCE.

Introduction.

In no department of military science do we meet with so many conflicting views as in that of fortress warfare. Notwithstanding that the Franco-German war of 1870–71 and the Russo-Turkish campaign of 1877–78 were rich in sieges, the standing questions relating to fortress warfare have not been practically set at rest. The resources of fortress warfare, and particularly those of the defence, have been essentially changed and improved since the former of these campaigns, while the fortresses which came into play during the course of the latter were neither storm-free nor ready for defence. It is, therefore, left to theoretical investigation to clear up our views regarding fortress warfare. Meanwhile, the experiences of past wars ought still to be made use of in spite of the changes in the objects aimed at and the means employed, since these changes are only in the direction of extension. (Sphere of operations, general effectiveness of weapons, style of fortifications and of siege works.) Numerical conditions and the relative efficiency of the means at the disposal of antagonists in future warfare have not altered with the time, while the attack and defence meet under the same general strategical and tactical conditions to-day as formerly. Hence it is not the principles of fortress warfare which have varied with changes in means and ends, but the tactical forms.

In the following studies, suggestions for clearing up the subject of fortress warfare have been sought for in theoretical considerations based on military history.

The factors with which fortress warfare has to deal are :—

1. The resources available :—
   (*a*) Personnel;
   (*b*) Matériel.
2. The nature of the objective.
3. The end sought to be attained by the combatants.
4. The general strategical and tactical positions of the combatants.

Considering the above factors comparatively in the case of both combatants, we arrive at the following general results :

1. Resources.

(*a*) *Personnel.*—The besieger must be numerically superior to the besieged in order that a siege may be, generally speaking, conceivable. Moreover, the moral superiority of personnel will, in consequence of the general situation, be on the side of the besieger. In the most heroic defences such as those of Danzig and Colberg in 1807, and Sebastopol in 1854–5, military history shows, by the complaints of the defenders of numerous desertions, by the conduct of the commanders, by the offensive operations they undertook and the judgments since passed upon them, that the feeling of moral inferiority was present in the minds of the leaders as well as in those of the troops, and that energetic leaders may set limits to this feeling but can never altogether suppress it.

(*b*) *Matériel.*—In matériel—by which is meant guns and munitions of war, since the rifle is more bound up with the personnel than the artillery weapon, and does not come under this head—the defender is numerically superior at the beginning of the siege. The organisation of European armies, and the development of fortress systems at the present day, will allow no besieger to establish an initial numerical superiority in ordnance against the great fortresses of the latest type, which in future wars will dispose of 1,000 to 1,500 guns. The besieger must win his superiority by fighting. Here the disadvantage of the besieger comes into play, since he must bring his heavy matériel to the scene of operations over great distances. The development of railway systems more or less facilitates this transport of matériel to the siege-objective. On the carrying capacity of the railway it will mainly depend whether the conditions as to matériel soon change to the advantage of the besieger. This change must eventually arrive on account of the inexhaustibility of the resources of the besieger. It is nevertheless certain that the defender of a well-armed and provisioned fortress will be initially superior. There is probably no instance in military history where the besiegers were superior to the besieged in armament and resources at the beginning of a siege if the fortress was ready for hostilities. The siege of unprepared fortresses, such as Ardahan in the Russo-Turkish war, are not taken into present consideration.

It is otherwise with the relative *efficiency* of the material fighting resources. In this respect the besieger will usually have the advantage, since economical considerations have hitherto made it impossible for any State to keep pace with the development of weapons in the armament of its fortresses. The defender will be obliged to employ a number of antiquated guns, since the requirements of the fortresses will be taken into consideration after those of the field army.

In future wars, a few fortresses may possibly be so fortunate as to be able to meet the attack with fighting matériel of equal value. Such cases, however, will, according to past experience, be exceptional. (Sebastopol.) It may, therefore, be assumed that the defender is at the beginning of a siege numerically superior to the attacker in matériel, but inferior as regards the relative efficiency of his armament.

2. Nature of the Objective.

The objectives of the besieger are storm-free, closed positions, provided with bomb-proofs, against which the besieger must move pace by pace, covering himself till he is close, and to take which he must employ artificial means, such as descents and breaches. If, on the one hand, the taking of these positions by Infantry has become difficult for the besieger, since their construction renders them hard to surprise; on the other hand, they offer a favourable target to the artillery of the attack. Beside these storm-free positions, the besieger has to take advanced positions of a field type. These positions, consisting of slight earthworks with obstacles, are more or less hard to attack, and mostly difficult to shell with good effect by siege artillery.

The objectives of the defender are not rendered storm-free. The besieger can make his first positions, with their slight, inconspicuous earth-cover and obstacles, almost unassailable. (Investment lines of Metz and Paris.) He cannot, however, as he advances, provide his positions near to the fortress with strong obstacles, since both time and labour fail. The work must be carried out under the effective fire of the fortress, and, moreover, such obstacles would hinder his own movements. The objectives of the defender, therefore, are not storm-free, but they are bad targets to shoot at.

3. End sought to be attained.

The besieger has in view the permanent possession of his objective; the besieged, on the other hand, wishes to retain the position occupied.

4. General Strategic and Tactical Position.

The strategic and tactical position of the combatants is entirely dissimilar. The defender is surrounded, shut off from the outside world, and thus tied down to limited resources. The besieger, on the other hand, envelopes the position and his fighting resources can be brought up without limit. These differences in the conditions of the combatants bring about the inevitable result, that the defender cannot indefinitely replace his expenditure of matériel, and must finally succumb. Nevertheless, favourable opportunities offer themselves to the defender, since he has tactically the great advantage of the surprise and of a storm-free position. If the defender bases his line of action on these advantages, holding fast to the object he has in view, and having due regard to his resources, he is able to dictate to the besieger the form of advance, and can thus successfully accomplish his task.

In the following remarks, a fortress of the most recent type, with detached forts, is to be understood.

THE DEFENCE OF A FORTRESS.

THE commander of a defence must always bear in mind that the retention of the fortress is the problem to be solved, that all measures which do not further this object retard its accomplishment, and that the defender, on account of his inferior strength, can only fight advantageously within the range of the guns of the fortress. The defence appears to be too willing to forget these principles, which military history bears out in all respects. It demands from Infantry the accomplishment of tasks which involve the employment of this arm beyond the protecting fire of the fortress guns, and which do not afford the slightest prospect of a successful result. With regard to the employment of movable armaments also, the defence adopts unsound views. With the object of obtaining a steady development of artillery fire, it is proposed to bring guns into action by driblets under the enemy's fire, and in positions not storm-free. While the Infantry is to be handled offensively, the Artillery is to play a waiting game. The mutual support and concert of the two arms is thus lost. Such an employment of force appears questionable, both theoretically and also from the experiences of past wars.

I.—MEASURES TO BE TAKEN WHEN A FORTRESS IS THREATENED.

The general organisation of the defence must be laid down beforehand in peace-time. Whatever may be the nature and extent of the previous preparations (which are not dealt with here) a fortress cannot in peace-time be kept always ready for defence. If, therefore, it is threatened, two tasks present themselves to the defenders :—

a. The observation of the enemy.

b. The placing of the works in a state of defence.

Both tasks require for their accomplishment forces which must be employed in ways which preclude mutual action, since troops employed in observation are lost as far as technical preparations are concerned.

a. The Observation of the Enemy.—Considering that it is a question only of observing the enemy, and not of securing the fortress in face of the enemy, it is clear that the force to be employed for the purpose must be sought in that arm which is best suited for observing—the Cavalry. Infantry should be used only in default of Cavalry, or in a very close country. In the strategic position of the defender, Infantry is entirely unsuited for the service; since this arm, by its slow movement in face of an enemy advancing concentrically on a broad front and in superior force, will be compelled to draw in towards the fortress in order to avoid being rolled up by the mass of the enemy's forces, or cut off from the fortress. Moreover, by thus employing Infantry, valuable forces are withdrawn from the work of interior preparation.

Good observation is the first condition of success against the advancing enemy, and this cannot be secured by Cavalry alone, since the defence will be relatively weak in this arm. Hence, for every fortress an organised system of obtaining information is desirable, which, established in front of the observing Cavalry, will support them in their task. In order to carry on the observing with certainty, the several detachments must be in close communication with each other and with the fortress. Bearing in mind the weakness of the defence in personnel, this requires that the observing line should be no further from the fortress than the first object of observation—security against surprise—demands.

Having regard to the extent of the latest fortresses and the marching powers of troops, it will be sufficient for the defence if the observing is carried out at a distance of a day's march from the fortress. Surprise is then precluded, and sufficient time is given for action on the advance of the enemy, since the defender with his numerical weakness should limit himself to an offensive within the range of his guns, unless he desires to fight under unfavourable conditions—that is, without sufficient support from his Artillery. Military history supports these conclusions by numerous examples.

At the defence of Danzig (1807), Infantry were detached, when the fortress was threatened, to distances varying from 16 to 56 miles—to Stolpe, Stargard, Dirschau, and the Werder—without any system, partly in order to keep up communication with fortresses not occupied by the enemy, partly to hold certain points as a check to the enemy's marauding parties.

This employment of the Infantry was very detrimental to the later defence, since it led to the destruction of detachments at Stolpe and Dirschau. The forces of the defender were thus enfeebled by fighting, which had nothing to do with the maintenance of the fortress itself; and, further, the Infantry was withdrawn from work on the defences—a far more necessary service. As far as observation and reconnaissance were concerned, all these detachments effected nothing.

The defenders of Belfort were obliged, for want of Cavalry, to push out Infantry in observation on all sides—eastwards as far as St. Morice, Thann (Plate 2), and Dammerkirch, weaker detachments towards Soulz and Mülhausen. These detachments neither checked the enemy nor aided in observation. The parties pushed out about 20 miles towards Soulz and Mülhausen, by their frequent retirements in consequence of disquieting rumours, spread terror among the people and increased the demoralisation of the troops.* These forces would have been better employed on the defensive works.

It is otherwise when Cavalry is employed. This arm, for example at Danzig in 1807, carried out valuable reconnaissances, even as far as Bromberg, 80 miles from the fortress. Here the Cavalry correctly ascertained the approach of the enemy's forces on the south, and thus unfortunately occasioned the useless occupation of Preussich-Stargard, and later of Dirschau.

Similar results were obtained by Cavalry at the defence of Sebastopol. Here, by a service of Cossack patrols and visual signalling, information was received in a few hours at Sebastopol of the anchoring of the enemy's fleet at Eupatoria (80 kilometres from the fortress) and of the landing.

These experiences indicate that the defence should only employ a minimum of troops—Cavalry if possible—in observation, and that the mass of the troops should be retained within the effective range of the fortress guns.

In Plate 4, a scheme for guarding a fortress threatened from the east is given, having regard to the roads only and not to the topographical features :—

(1) When Cavalry is employed.

(2) When Infantry only is available.

(1) In the first case, the observing squadrons have only pushed out sections to the cross roads, and the rest of the regiment is retained within effective range of the fortress guns as a general support. From this main body, parties are taken for special reconnaissances. The advanced sections, which are to be relieved daily, send out weak patrols day and night toscour the country from 4 to 6 miles to the front. The advanced detachments and the main body communicate by telegraph with the fortress. With such dispositions and communications, the

* The 'demoralisation' of the defenders of Belfort was not, however, particularly apparent.—*Trans.*

main body can remain dismounted in alarm-quarters, since it will be certain to receive warning in good time. Moreover, the commandant of the fortress will have ample time to take his measures against the advancing enemy, while the latter is still two miles distant. The conditions will be all the more favourable if there are agents in the villages A and B (Plate 4), assisting the Cavalry reconnaissances by supplying information. No Infantry support is given to the observing Cavalry, since the troops who are at work on the threatened front of the fortress can be got together in an hour, and a portion of these troops will be available to support the Cavalry.

(2) In the second case, on account of the less mobility of Infantry; and since Infantry patrols cannot cover as much ground as Cavalry, the observing parties are pushed further forward. In the example sketched out (Plate 4), the observing is carried out in three sections.

For the Infantry of the defence, far-ranging reconnaissances are not recommended. It appears necessary also in this case to make the detachments guarding individual roads stronger, and to apportion a main body to each, in order to be able to delay the advance of the enemy. These measures will render a daily relief of the observing detachments unnecessary; since, on account of the strength of these detachments, they will be able to relieve their patrols and outposts at sufficiently short intervals. A weekly relief from the fortress of the observing detachments is, however, desirable, so as not to tire out a particular portion of the Infantry before the siege begins, and also in order always to have fresh and capable troops employed on this important service. In Plate 4 the disposition of the Infantry is shown. The advanced pickets from which the patrols are sent out are not indicated.

It appears unadvisable to allot Artillery to the observing detachments, since the latter are intended to watch, and not to fight. If the co-operation of Artillery in special distant reconnaissances appears desirable, it can be taken from the fortress.

b. The placing of the Works in a state of Defence.—This concerns the completion of the organisation, and the application and maintenance of the means of defence. It will be more or less facilitated by any special preparations which have been made in peace-time.

The measures to be taken for the organisation of the defences will depend not only on the condition of the fortress to be defended, but also on the method of defence adopted.

It is most advantageous to the defence to employ all its resources from the beginning of the struggle in first line, since at this time the morale of the troops has not yet been weakened. This principle will all the more carry conviction if it is clearly recognised that the strength of the defence lies in the employment of weapons from advantageous positions, and that success is to be sought only in an offensive based on the best possible employment of the weapons available. This offensive is, as history teaches, possible only by the calling into operation of every kind of means. Moreover, the success of this offensive demands careful previous preparation.

Disposition of Armaments.—If the defence recognises these conditions, the first question asked will be: 'How are the several arms to be disposed so as to fulfil the above object?'

The strength of the defence lies in the employment of arms from secure positions, consequently in Artillery. The lie of the ground prescribes for this arm strong positions, if it is to be used to advantage. Hence the Infantry and Engineers must subordinate themselves to the Artillery.

In Artillery circles, opinion is divided as to where the guns are to be placed for fighting, whether in the forts or in wing and intermediate batteries. It cannot be denied that gun emplacements, in forts visible far and wide, offer favourable marks to siege Artillery. On the other hand, it appears to be a questionable policy to fight the most important arm of the defence in positions which are not storm-free, and in which, moreover, the supply of ammunition, under the convergent fire of the attack, will be very difficult. Wing batteries do not possess such important advantages as has been usually ascribed to them. Aided by the visibility of the forts, it will not be difficult for the besiegers to fire into such artillery positions. And is not the artillery of the defence, in a wing battery of 12 or 14 guns with storm-freedom abandoned, crowded together to an undesirable extent and exposed to convergent fire?

I hold that the fort is always the natural position for the Artillery of the defence, which against the close attack is altogether helpless. And this view finds adoption in the design and arrangement of the latest forts. The Engineer has, in the latter, done his utmost to add to the enduring power of the guns of the defence in the Artillery duel. Possibly the Engineer might have effected more in this direction if he would give up high relief and cover his forts better by the ground. Why should not forts be placed behind the brows of hill ridges, so as not to be looked into from heights in front? If the space between the brow of the hill and the fort forms a counter-sloping glacis in the form of a mask, and is under effective infantry fire, the fort would be as difficult to hit as siege batteries which are well covered by the ground. That the terrain of such a fort would not be swept by its direct fire, seems to be no disadvantage. The direct defence of this ground will be better secured by the fire of the collateral fort, and particularly by the advanced Infantry.

The forts of to-day are exposed and disadvantageous for the Artillery defence. It must be decided whether to fight in them or in protected intermediate positions. The latter have great advantages in action, if only the ammunition supply can be rendered secure. If there is any great difficulty in conveying heavy ammunition to the intermediate batteries under the enveloping and convergent fire of the attack, this will tell against the energy of the Artillery fight. It is otherwise in the case of the forts, where the most careful provision has been made for the supply of ammunition to the guns. For this reason it will probably be decided to carry on the Artillery fight with heavy guns in the forts, or at any rate in wing batteries which have been rendered difficult to assault by obstacles.

In disposing the Infantry of the defence, we must look closer into the effective scope of the Infantry and Artillery weapon, if the main principle of the defence—the full utilisation of the arms—is to be carried into effect. The full scope of the arms can be turned to account only when Artillery and Infantry fire supplement each other. Why should the Infantry of the defence remain inactive in the advanced posts? Whatever may be the range of individual guns, the possibility of observing the effects of fire, together with a reasonable certainty of hitting and obtaining satisfactory results against completed siege works, begins at 2,500 metres. At 1,200 metres—beyond the effective range of Infantry fire, but within the range of the rifle—the mass of the guns of the defence can carry on the Artillery fight.

The maximum range of the rifle does not exceed 3,000 metres. In almost all countries it is sighted up to about 1,500 metres. At 200* metres, the Infantry weapon gives the best destructive effect over the whole ground swept at the level of the height of a man. Under these circumstances the Infantry must be pushed out about 1,000 metres beyond the line of forts.

The most effective range of both weapons will then coincide at that zone of ground on which the attacker must carry on his Artillery fight—a circumstance which will compel him first to operate against the advanced positions, and to throw up his earlier siege works at a greater distance, since the ground between the distances of 1,200 metres and 2,500† metres from the fort will be under a mutually

* About 500 metres with the new rifle.—*Trans.*

† Hardly so much, since rarely or never would it be possible for the artillery of the fort to fire at an enemy 200 metres beyond the heads of infantry, the latter being 1,000 metres distant.—*Trans.*

supporting and very effective fire of both Infantry and Artillery. Moreover, these advanced Infantry posts favour the offensive against the positions of the besieger, and are so near them that the construction of batteries at decisive distances is rendered impossible until the advanced posts have been captured.

It will not be advantageous to push forward the Infantry beyond 1,000 metres, since at this distance the co-operation of Infantry and Artillery will be secured under the most favourable conditions. Infantry posts far in advance of the line of forts are, moreover, more difficult to support by reserves from the fortress. They require, therefore, very strong garrisons, which the defence, on account of its relative weakness in personnel, will not be able to dispose of.

The Execution of the Works of Defence.—The following work has to be carried out:—

1. The entrenchment and preparation of Infantry posts about 1,000 metres in advance of the gun positions, with a view both to giving scope to the arm and also as aids to the offensive.

2. The mounting of guns, together with the provisions necessary for the safe supply of ammunition.

3. The clearing of the field of fire for both arms.

4. The establishment of communication between the two arms which have to fight far apart.

1. *The Infantry Posts.*—The advanced Infantry posts are intended for carrying on an Infantry fight, and also as points of departure for the offensive. In action, the Infantry will also find many opportunities of usefulness in firing at the observing stations of the besieger's Artillery, or at any gun detachments which may be visible, and where their position is a commanding one, in directing an oblique or flanking fire at long range against the siege batteries themselves; since at 1,000 metres the angle of descent of the bullet is about 5°, and at 1,500 metres about 10°.

The positions selected should be limited to those points which have the greatest tactical importance, and which can be held by the least number of men. Houses, farmsteads, small plantations, are well suited for the purpose if they happen to be parallel to the front of the forts. If such positions are not available, field works must be thrown up.

The weak garrisons of these positions necessitate obstacles in front, réduits, and communications to the rear. All these provisions must be of a field nature, since only a short time can be allowed for carrying them out. In the réduit, there should be a store containing rifle ammunition, provisions, and water, so that after the loss of the position the réduit can be held until a counter-attack from the fortress can be made.

The communications to the rear should be so arranged that reserves can be thrown into the position in as short a time, and with as much safety as possible.

To connect individual posts by shelter trenches appears unnecessary, since by day-time patrolling is superfluous over ground which can be seen, while at night the patrols will be covered by the darkness. Thus the defence will not create too many positions capable of being subsequently utilised against the fort.

To forego altogether the construction of these advanced Infantry posts and their communications with the rear, because they can afterwards be utilised for the purpose of the attack, is unwise. The preponderance of advantage in the use of such positions for increasing the fire-effect and for facilitating the offensive is undeniable. Military history affords instances of the creation of such positions even under the enemy's fire, and of their successful employment.

2. *The Gun Positions.*—Guns employed for the purpose of the active defence have to fulfil the following tasks :—

(1) To compel the besieger to keep as far away from the forts as possible.

(2) To fire at any siege works begun within range, and to render their completion impossible.

(3) To prevent the bringing up of the siege Artillery.

(4) To resist all attacks on those advanced Infantry posts, the special object of which is to keep the attack at a distance.

(5) To prepare the way for counter-attacks against the completed works of the besieger.

The Artillery must recognise its principal sphere of usefulness in the last-named of the above tasks. It appears impossible to hinder for long the execution of the siege works and batteries. To keep down the fire of the batteries when completed is also an undertaking the success of which is doubtful. Even if the Artillery of the defence disables individual guns of the attack, no decisive results in this direction can be obtained, since the guns of the defender have to fight under less favourable conditions than those of the attack, and must be more sparing of ammunition. The Artillery of the defence can only prepare the way to success, the Infantry must achieve it.

The flank defence, which is committed to the Artillery with a view of economising Infantry, is of minor importance during the earlier stages of a siege. Flank defence will come into play only against assaults and during the later stages of a formal attack.

The scope of the Artillery of the defence is thus many-sided and of the highest importance, beginning with the appearance of the enemy within range of the guns of the fortress. It appears necessary, therefore, in order that this Artillery should be ready for action at the first approach of the besieger that all the arrangements relating to the guns should be completed.

There is no reason that the mass of the Artillery of the defence should wait for what the besieger may do and where he may attack.

The positions of the siege batteries are in general prescribed by the ground.

The disposition of the Artillery of the defender is dictated by considerations relating to the lie of the ground and the possible enfilading of the defender's lines by the besieger's Artillery. For this reason, before the enemy appears in front of the fortress, every gun which can be laid hold of should be mounted in the forts in such a way as best to accomplish the tasks above stated, and, if the forts are too small, in that wing battery which is best able to meet the possible development of the attacking batteries.

Should objects for fire present themselves in unexpected positions; then, if a powerful armament is available, it will always be possible to find a few guns to take them in hand. It is no disadvantage that there should be guns standing ready for action on the ramparts of fronts not attacked. In case of need, these guns can be moved to the front besieged as easily as from the bomb-proofs. In any case, it will be advantageous to the defence to be able to begin the fight on the front attacked with a superiority of metal, instead of being obliged to mount guns by day and night. It appears unnecessary to keep back guns as a general reserve. In case of necessity, guns can be obtained from the forts which are not attacked. Only the mass of the light rifled guns and mortars should be retained as a general reserve, to be employed in the intervals between the works in support of the heavier guns. The former are selected for the reserve, since their ammunition is more easily transported, and they are more easily mounted.

The way in which these guns will be used is undetermined. They will find their proper employment as soon as the Artillery attack begins. It is, therefore, an important condition of the mounting of these guns, that they should be ready for action in a short time. Hence, the defender must make communications to all suitable positions between the forts, so as to be able to bring these guns into action rapidly. No considerable effect can be obtained by their fire unless the ammunition supply is assured. Tramways might be made to the positions, and expense magazines constructed as near as possible to them, in order to be able to seize favourable opportunities for bringing up ammunition.

3. *Clearing the Field of Fire.*—The clearing of the field of fire must correspond to the sphere of action of the arms. With the present weapons the ground on the level should be cleared to a distance of 3,000 metres. To go beyond this appears unnecessary, since the defender, on account of his numerical inferiority, cannot prevent the attack from occupying more distant ground, while his fire cannot be advantageously employed beyond 2,500 metres against the siege works and batteries without incurring a waste of ammunition. The defender must, above everything, guard against the latter, since his means are limited. Hence, the harassing of the besieger by the employment of unaimed fire directed on roads in order to make them difficult to traverse, is not included among the duties of the Artillery. Costly Artillery ammunition can be expended to better purpose. Such an employment of Artillery must be resorted to only when there is special indication or information that the enemy's troops in great masses are moving on a particular road.

Where the ground is much accentuated, it will be advisable to make a clearance of wood only on areas turned towards the fortress and seen from it. To clear slopes which cannot be seen from the fortress or brought under direct fire, and which can be used by the enemy as sites for his batteries, appears disadvantageous, since the construction of the latter will thereby be facilitated. Buildings and woods which cannot be seen from a fortress need be removed only where they would impede a counter-attack on the siege works.

4. *Communications between Positions.*—The defence can only aim at success by the co-operation of Artillery and Infantry. Both arms fight in positions far apart. In order to obtain intimate co-operation, communication appears absolutely necessary. This communication is all the more required, since the Artillery must make use of the advanced Infantry positions as observing stations if its fire is to be effective and the waste of ammunition prevented. The advanced Infantry positions must be connected by telegraph with the forts and with the stations of the reserves in order that the condition of complete co-operation may be fulfilled. Communication by patrols is insufficient.

Examples.—An employment of the means of defence and an arrangements of defensive positions similar to that above indicated was adopted at Danzig in 1807. At Sebastopol, the same principles were first realised after the beginning of the siege and under the enemy's fire. At Belfort and Paris in 1870-71, similar ideas were apparent.

The defenders of Danzig formed an advanced Infantry position in the covered way, which was palisaded and provided with réduits, and they utilised this position with partial success for the offensive. At important tactical points, they constructed flanking works. On the west front they intended to create posts of blockhouse form at 800 to 1,000 paces to the front. This plan had, however, to be given up for want of time and labour. The defenders had all their guns mounted except twelve, so that they were able at the beginning of the siege to fight with energy. Covered communications linked the advanced positions with the enceinte.

Sebastopol was not storm-free at the time of the landing of the besiegers. The armament of the land fronts was so weak that the fire of three guns at most could be concentrated on a given point of the terrain. When the besieger threatened the south front, the energetic defenders immediately made rifle pits and abattis in front of their Artillery position, which had meanwhile been considerably strengthened. The construction of advanced Infantry posts took place during the siege.

At Belfort (Plate 3) the Infantry of the defence was pushed far forward without the necessary intrenchments. The fortress guns could not afford an Artillery support to these positions.

At Paris, the ground in front of the forts was held on the south front only, although this was intended to be done on all the fronts. The occupation and strengthening of this ground was first commenced during the siege. The influence which these positions exerted on the defence will be noticed later.

Completion of the Organisation of the Means of Defence.—All the forces and resources of the surrounding country, which can be utilised for the defence, must be swept into the fortress.

The mode of employment of the arms which has been set forth above demands the following special organisations:—

1. Teams for enabling the guns of the general reserve to be employed in varied positions between the forts and for horsing two-wheeled ammunition carts for the service of these guns.

2. Railway detachments.

3. Telegraph detachments with portable stations.

Further, it is necessary to organise on a military basis all mechanics and artisans who can be rendered available for purposes of the defence.

Measures for keeping up the Supply of necessary Means of Defence.—In order to increase the means of the defence, it is necessary to make numerous requisitions, particularly in the neighbourhood of the fortress—the latter being specially advantageous, since they deprive the besieger of resources. The advanced posts and their reserve positions, which have to await the enemy's fire in first line, require particular attention in these respects. Provision for an assured food and ammunition supply ought to have been made in peace-time. If this has been neglected, the necessary arrangements for the purpose must be taken in hand first.

In practice, much has always been left undone, both in the perfecting of the organisation and in the measures taken to increase the means of defence, since these points have not been sufficiently thought out, and the carrying out of the necessary measures has not been sufficiently advanced. The time available for placing a fortress in a state of defence is generally brief. The work, therefore, demands well-considered arrangements, and the utilisation of all the resources of the surrounding country.

The men employed on the works can, if it is not desired to retain them within the fortress, be sent away on the approach of the enemy.

II.—Measures to be taken on the Advance of the Enemy.

The besieger advances to the attack in numerical superiority and concentrically. The defence should not, therefore, expect to be able to arrest the enemy beyond the effective range of the guns of the fortress. If a portion of the garrison is pushed beyond this limit in order to hinder the advance of the enemy, the latter, moving on a broad front, can easily plant a detachment in rear of such a force and cut it off. Reconnaissances alone should, therefore, be undertaken—a task which belongs to the Cavalry, aided by Artillery.

How far the Cavalry should move out to perform this duty will depend on the available information, and on the measure of intelligence which it can itself obtain. Hence the Cavalry should always be in communication with the fortress by a chain of forts, or by telegraph. If this condition is fulfilled, the Cavalry may be several days distant from the fortress, in order to ascertain the truth of such information as is forthcoming. If the reconnaissances determine the approach of the enemy, the positions within range of the guns of the fortress, and in which the garrisons can scarcely await events, should be occupied. The general reserve should be drawn together on the front threatened, in order to be ready to act against the investment. But on no account should there be an advance beyond the effective range of the fortress guns. Military history, in the sieges of Danzig, Sebastopol, Belfort, and Soissons, has shown us the fate of advanced detachments.

Examples.—At Danzig, the defender pushed out a force 15 miles to Dirschau, providing it, moreover, with a support. The detachment was surrounded and destroyed. The demoralising result was the drawing in of all the detachments to within 4 miles of the fortress.

At Sebastopol, an army of 33,600 men was employed to arrest the besiegers, 62,000 strong, at the Alma, 30 kilometres from the fortress. The defenders were defeated with a loss of about 5,700 men.

The defenders of Belfort intended to resist the enemy advancing, 20,500 strong, at Gros-Magny and Roppe (Plate 2). The Gros-Magny detachment was driven back into Belfort. Roppe had to be abandoned in the night, without having really hindered the advance of the besiegers.

Finally, at Soissons, the defenders attempted a useless resistance west of Venizel.

The miscarriage of undertakings of this kind is the result of numerical inferiority, and of the general position of the defence. Where the detachments of the garrisons have not recognised these conditions and retired, a catastrophe, which must have been detrimental to the morale of the troops, has occurred. As far as the defence of a fortress is concerned, such undertakings are useless.

III.—Measures to be taken against the Investment.

Although the defence cannot obtain any satisfactory results against the advance of the enemy, there will nevertheless be favourable opportunities for successful action against the investment.

In order to cut off the fortress from the outside world, the besieger must divide and execute a flank march round the position. This march can, it is true, be carried out beyond the range of the guns of the fortress; but in *accidenté* and wooded ground, and particularly in the cases of fortresses *à cheval* of a great river, it can be met and checked without danger to the defender's force. The operations of the latter should be directed against the heads of the enemy's columns of march, and especially against the passage of rivers or streams. To act against the flanks of the enemy's columns will clearly be useless, since, in making such an attempt, a force would risk being surrounded by the besieger's troops arriving from all sides.

To carry out such operations successfully, the defender must be able to count on good Cavalry observation and numerous bridges in order that the proper moment may be recognised. While the mobile portion of the defender's force on the threatened front stands ready for the offensive within effective range of the fortress guns, the Cavalry must watch the flanks of the enemy. In the case of fortresses on great rivers, Cavalry observation is particularly necessary on that side of the river which is not yet threatened. The defender will thus obtain information as to preparations for crossing the river, and be able, in the event of any error on the part of the besieger, to carry out a successful offensive beyond the range of his guns.*

At the siege of Paris there was an example of such an operation in the sortie from Chatillon on the 19th September. The operation failed, since there had been no observation of the movements of the besieger, and the reconnaissances were insufficient, so that the attempt was made against the flank of the investing column, and not against the head, nor against the passage of a river.

Briefly the proceedings were as follows:—General Ducrot, with the 14th Corps, stationed between and behind the forts on the south of Paris, wished to attack the flank of the columns of march of besieger which had appeared before Paris on the 17th September, and which he knew were moving round the fortress, intending by an advance from Chatillon to drive them back to the Seine. Bernis' Cavalry brigade had made a previous reconnaissance on the 18th September towards Bièvre, and was repulsed by Infantry fire at Bois de Verrières. On the 19th, Ducrot ordered a sortie against the line Villacoubley—Bois de Verrières, and intended to advance his right wing to Vélizy. This sortie, made with the object which Ducrot proposed, had no prospect of success. Undertaken with a numerical and moral inferiority of force, without sufficient information as to the enemy's movements, and in a direction which was also that of the enemy's march, the operation was sure to be nipped in the bud. The attack, begun at 6 A.M., only attained the development shown in Plate 5, although there was hot fighting till 1 P.M. By about this time there were two German Army Corps ready to drive back the defender's force, individual portions of which soon began to take to flight. The result of the retreat was the abandonment of the ground occupied in advance of the south front, and a closing in of all the troops on Paris. The intervals between the forts, as well as the terrain of the south front, were not reoccupied till the 22nd September.

The defender should undertake such a distant attack only if the advance of the besiegers has been thoroughly observed, if the movements of the latter are known with certainty, or if errors in their dispositions have been discovered. Under the conditions which

* It is a drawback to a fortress to be very weak in Cavalry. In this case the latter will find it difficult to carry out the tasks above described, and thus the defence may be obliged to forego such undertakings.

obtained before Paris, a sortie on the south side was only possible on the 17th September from Villejuif and Vitry against the bridging operations of the Vth Corps at Villeneuve St. Georges. But in order to have been able to recognise the opportunity, a well-organised system of observation was necessary. The moments which favour operations of the defenders beyond the range of their guns are of brief duration.

How far the effective range of the fortress guns extends, depends entirely on the ground. A tactical study of the latter can alone enable it to be decided how far to advance without danger. If, according to the above views, an offensive beyond the range of their guns is rarely advisable for the defenders, the question arises as to where, within range, the first resistance should be offered, and with what object. The most favourable line at which to fight appears to be that of the positions from which the besieger can shell the forts. The object of the resistance to be offered here is to ascertain the strength and intentions of the besieger.

IV.—Measures to be taken against the Occupation of the First Positions of the Attack.

The sites of the besieger's first batteries are within effective range of the guns of the fortress; since, assuming equal ranging powers, the positions from which the fortress can be shelled can themselves be shelled from the fortress. The form of the ground determines the positions on every front which the besieger must occupy. Whether the occupation of these positions takes place simultaneously on all the fronts, whether they are occupied one after the other, or whether they are conquered section after section before the investment, depends on the strength of the defence. In any case, these positions should not be abandoned without fighting; since, during such fighting, an opportunity of learning the strength of the besieger is obtained. If the latter proceeds to drive in the defenders before the investment, it will be a sign that he is weak, and that the sites for the first batteries should not be given up without serious fighting. If the besieger is so strong that he begins to drive in the defenders simultaneously on all the fronts, it will scarcely be possible to make a long and energetic stand. If several of the positions occupied are taken by the besieger, the defence will abandon the rest for fear of being surrounded.

After the loss of the sites of the first batteries, the defence ought to make no sorties for the purpose of retaking them; since such operations are costly, and as a longer retention of individual positions will be impossible, the result will not be worth the sacrifice. An offensive is advisable only if individual positions, the regaining of which affords a prospect of maintaining command of the more distant terrain for a longer time, are lost; sorties directed against these lost positions are first necessary when there are signs that the batteries are being built, and should be undertaken for the purpose of destroying the batteries. In such a case, the sorties have a definite object, the accomplishment of which will have a sensible effect on the course of the siege.

Examples.—The defence of Danzig (Plate 1) affords an example of the effect of the retention of the more distant terrain in hindering the taking up of the first position by the attack. The besiegers, 18,000 strong, at first invested the fortress only on the left bank of the Weichsel. The defenders maintained themselves at about 1,000 metres in front of the ramparts, and thus prevented the besieger from taking the heights which he required in order to open his Artillery fire. From the 12th to the 26th March, the defender held these positions, notwithstanding that they lay beyond the support of the fortress guns of that day; but this successful resistance was only rendered possible by the fact that the garrison was tolerably strong (about 15,000 men).

During the period stated, the besiegers here and there succeeded in surprising and taking individual posts, but were compelled by counter-attacks on the part of the defence to abandon them again. These successes appear, unfortunately, to have led the defenders on to more extended operations with a view to drive back the investing force. On the 21st March, they made a sortie to Wonneberg, about 2 miles from Danzig. This sortie was repelled with great loss. The great sortie of the 26th March met with the same fate. The result of this latter failure was the loss of the advanced posts. We thus learn from the siege of Danzig how dangerous it is for the defender to venture too far in his sorties. The shattering of the troops in these fights was the cause of the rapid loss of positions which had previously been successfully held, and of the later unfortunate course of the defence, since meanwhile more necessary tasks were neglected. The defenders of Danzig were right in making counter-attacks in order to reconquer the lost posts of the distant terrain, since only individual posts had been lost, and their reoccupation afforded a prospect of successfully holding on to the distant terrain for a longer period. Although, in this instance, the terrain *beyond* the effective range of the fortress guns was held for fourteen days, this fact must not be considered as normal, since the defence is seldom so relatively strong in Infantry as was here the case during the first period of the siege. A resistance offered at the first positions of the attack would have been easier, and would have secured the same results.

The defenders of Belfort also at first—from the 3rd to the 22nd November—held the distant terrain, which included the first artillery position of the besieger. In the fighting from the 22nd to the 28th November, this position fell into the hands of the latter. The fortress Artillery could not support the advanced posts. Attempts to retake them failed. Offemont only was reoccupied, since here the Artillery fire of the fortress compelled the besiegers to abandon the place.

The sortie of the 24th November, undertaken with the object of recapturing Essert, "the Mount," and Cravanche (Plate 3), clearly shows the difficulty and purposelessness of sorties for retaking the positions of the first batteries, if the besieger has occupied the whole front. If this ground is once lost, it is not worth while to expend force on retaking it; since a long-continued occupation of all positions is impossible by reason of the defender's weakness in personnel. If the positions have not been retained on the defensive, it is improbable that they will be reconquered with the means available.

V.—Employment of Troops.

In accordance with the principles above laid down, the defence should not attempt any extended offensive. A gradual retirement within effective range of the fortress guns, combined with good observing of the enemy, appears to be the best policy. The first stand should be made at the positions which the besieger requires for his first batteries.

a. Infantry.—The defender must consequently garrison the forts and enceinte very sparingly with Infantry in order to be able to dispose of sufficient forces for the above purpose. So long as the terrain is held, it appears unnecessary to keep an Infantry garrison in the forts; on the other hand, the latter must be strongly garrisoned with Artillery, which will furnish the guards of the works. These conditions need not be changed so long as entrenched positions, 1,000 metres in front of the forts, are held, and the Artillery fight has not begun.

If an enterprising besieger makes a successful dash through the Infantry positions and attempts to escalade, the artillerymen not required for the service of the flank guns will suffice to check the operation with their small arms till reinforcements come up from the rear.

The abandonment of the idea of a far-ranging offensive leads to strong independent garrisons for the several sections of the defence and the setting apart of only a small general reserve.

The commandant of a besieged fortress cannot personally direct all the minor operations over such a wide field of action. If he busies himself with details on the front attacked, he will readily lose the general supervision and clear view over the whole; he will be apt to neglect the remaining fronts, and as in the case of Danzig, the besieger will suddenly surprise him at an unexpected point.

Independent section-commanders acting at the probable points of attack, disposing of strong section reserves, including Cavalry and Field Artillery, and at the same time directing the Artillery defence, can alone order the successive stages of the drawing in on the fortress. The commandant has only to preserve unity of action on the part of the sectional commanders, and to give them general directions in accordance with such information as he may receive.

The small general reserve which the commandant holds at his own disposal must be under the orders of an officer junior to the section commanders on the fronts attacked, in order that this reserve may be placed at the disposal of any section without upsetting the commands.

The harmony of action of all the arms can only be secured when the section commanders are in constant communication with the Artillery in the forts. They direct and give the orders for every operation which is carried on in their sections.

It is necessary for the independent section commanders to have large staffs, since they stand in the same relation to the commandant of the fortress as the divisional commanders in a field army to the corps commanders.

The desirability of strengthening the troops symmetrically as far as possible is another argument against the setting apart of a large general reserve. The advanced portions of the section garrisons require reliefs, and the more frequently these reliefs can be carried out the fresher the troops will be.

The following detail should be followed as long as possible:—

No. of Day	Time	Duty.
1	From afternoon to afternoon.	Guard.
2	Afternoon to morning.	Rest.
3	Morning.	Work.
	Afternoon to afternoon.	Next for duty.
4	Afternoon to morning.	Rest.
5	Early morning to evening.	Work.
	Evening to early morning.	Rest.
6	Morning.	Work.
7	Afternoon to morning, as on 1st day.	Guard.

According to this detail, every man coming on guard has had two previous nights' rest. Men next for duty have had one previous night's rest. Men neither on guard nor next for duty have complete rest at night. They are kept behind the forts and turned out only under special circumstances.

b. Cavalry.—Up to the completion of the investment of a fortress, Cavalry is the most important arm of the defence. During this period the defender cannot have too much Cavalry. It is recommended, therefore, that a Cavalry Corps should be given to a fortress during the earlier operations. This Corps would operate in full communication with the fortress, and act against the flanks of the enemy's columns during the investing movements. If, however, the commandant has no strong Cavalry force at his disposal, he should keep his Cavalry together as much as possible, and use it independently, in order to obtain information as to the enemy's movements. The besieger will outnumber the defenders and possess a numerous Cavalry. The Cavalry of the defence must, therefore, up to the completion of the investment be handled as an independent portion of the general reserve, which is detached on the threatened front. After the completion of the investment, the horses can be distributed among the several sections and used for draught purposes.

c. Garrison Artillery.—Artillery alone should form the garrisons of the forts. When the siege batteries first open, the Artillery of the defence replies vigorously with every available gun, and carries on a duel which may perhaps last weeks and months.

The Artillery combat can only be carried on advantageously by day. If proper observations are wanting, no effect can be relied upon. To shoot without observing is to waste ammunition, and this the defence must carefully guard against. Hence, night firing must be reduced to a minimum. Night firing must not, however, be altogether given up, especially by a defender weak in Infantry, who will find it absolutely necessary to prepare the way for sorties. Assuming that, for night firing, only $\frac{1}{4}$ to $\frac{1}{5}$ of the guns mounted are told off for particular objects, and that the Artillery fight is carried on with every available gun for twelve hours by day, it appears that, having regard to the sparing of the troops and to the work required in connection with ammunition supply, the gunners should only serve their guns on every third day. This requires twenty men for each gun engaged, reckoning eight men for the gun detachment.

The following table gives a detail of the duties of the gun detachments of four guns, if all the guns are in action by day and only one at night. The eighty men required are divided into ten detachments.

<table>
<tr><th rowspan="2">No. of Day</th><th rowspan="2">Time</th><th colspan="10">No. of the Detachment</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th></tr>
<tr><td rowspan="2">1</td><td>Day</td><td colspan="4">Battery</td><td>Rest</td><td colspan="5">Work</td></tr>
<tr><td>Night</td><td colspan="4">Rest</td><td>Battery</td><td colspan="5">Rest</td></tr>
<tr><td rowspan="3">2</td><td rowspan="2">Day</td><td colspan="4" rowspan="2">Work</td><td>Morn., rest</td><td colspan="4" rowspan="2">Battery</td><td>Morn., work</td></tr>
<tr><td>After., work</td><td>After., rest</td></tr>
<tr><td>Night</td><td colspan="9">Rest</td><td>Battery</td></tr>
<tr><td rowspan="3">3</td><td rowspan="2">Day</td><td>Morn., work</td><td colspan="4" rowspan="2">Battery</td><td colspan="4" rowspan="2">Work</td><td>Morn., rest</td></tr>
<tr><td>After., rest</td><td>After., work</td></tr>
<tr><td>Night</td><td>Battery</td><td colspan="9">Rest</td></tr>
</table>

Under this system, a company at war strength can serve about ten guns.

No special detachments need be provided for the flank guns, since the latter only come into action when the guns of the fronts have been silenced. This applies also to the light rifled guns, which during the Artillery combat are kept under cover.

Artillerymen not required for service in the forts form part of the general reserve, and are employed in preparations for the construction of emplacements between the forts.

If the above demands are fulfilled, the available Artillery force will be insufficient. Hence the defenders will always allot a portion of the Infantry to Artillery duties.

d. Field Artillery and Pioneers.—A portion of the Field Artillery and Pioneers are detailed to the several sections. The greater part of the former, however, is posted to the general reserve, in order to be able to act powerfully in any direction against an assault.

So long as the strnggle is still carried on in front of the works, the forts are not the place for the Pioneers.

VI.—Operations of the Defence after the Loss of the First Position required by the Attack up to the Opening of the Bombardment.

After the loss of the site of the besieger's first Artillery position, the defender must make every possible effort to prevent and hinder the construction of the siege batteries. This can only be effected by reconnaissances with a strength not exceeding one company, directed against the positions where it is supposed the batteries are being built. These operations should be of the nature of surprises under cover of darkness, and should be made in numerous directions. It is therefore impossible to prepare the way for them by means of Artillery fire. On the other hand, after such reconnaissances are over, the Artillery will immediately find an opportunity to fire on the besieger's forces which have been brought together to repel them. In order that the Artillery may be able to carry out this task without endangering their own people, telegraphic communications to the rear and optical signals are necessary, so that the Artillery may know the positions of the reconnoitring parties. The officer who directs the Artillery fire should be with the leader of the reconnaissance.

If these reconnaissances discover strong forces massed, or battery construction going on, the Artillery must fire accordingly, while the section reserve is placed in readiness for a sortie in force, in order to destroy the works. Preparation by Artillery fire is particularly necessary, if the besieger employs a strong covering force for his works. In this case the Artillery must, during the sortie, fire at greater range in all directions which do not touch that of the sortie, so as not, by the cessation of fire, to give the enemy warning. Moreover, by firing over the heads of the reconnoitring party, the enemy may be deceived. Thus optical signals are specially necessary, which, by showing a light to the rear, serve to indicate the position of the reconnoitring party to the forts. It is desirable to provide two-wheeled carts to transport these signals, or a telegraph line. Such carts would follow the party, take up assigned positions in front of the outpost line of the fortress, and thence direct the cessation and re-opening of the fire of the forts.

Cavalry should not be employed in these operations; nor can Field Artillery be advantageously used in such night sorties. The duty of supporting the sorties must be left to the Garrison Artillery. In the case of sorties delivered in the early morning, the Field Artillery must be held in readiness for employment in covering the retreat.

Examples.—The defenders of Danzig, in this period of the siege, effected nothing of importance. They endeavoured, by combined Artillery and Infantry fire, to stop the advance of the besiegers. The force of the Infantry was expended too soon, by fighting in the further terrain of the fortress, so that great sorties for the purpose of destroying siege works could not be undertaken. On the right flank only, the Infantry made an indirect advance against the works of the attack. On the 4th April they recovered a small entrenchment (Plate 1) which had been lost, and from thence endeavoured to hinder the attack by flank fire. The attempt was without result. By the 11th April, the besiegers had gained possession of positions for the 2nd parallel in spite of heavy front and flank fire.

The defenders of Sebastopol allowed the positions for the first siege batteries to be occupied without fighting. From the 3rd October, they directed a heavy Artillery fire on all the supposed battery sites on the fronts threatened. When, early on the 10th October, the French siege works were discovered, they were fired at day and night from the fortress; small bodies of volunteers were sent out to reconnoitre the batteries. Marksmen, posted in front of the fortress, fired at the enemy's works; but no sorties were made for the purpose of destroying them, and the effect of the fire was not turned to account.

The defenders of Belfort, after they had been driven from the positions required for the first batteries of the attack, directed their Artillery fire on the supposed battery sites. Every gun thus employed was supposed to fire one shot an hour. The Infantry attempted sorties in order to recover the lost positions, but did not make reconnaissances to see what was going on. The small sorties directed against the villages occupied by the enemy were without result.

The defenders of Paris made many sorties in force after the surrender of the siege battery positions. These were partly of the nature of reconnaissances, and partly attempts to break through the investing line.

Future defenders of fortresses can learn much from these sorties, and will recognise that such operations should not be carried on beyond the range of the fortress guns; that they should be of the nature of surprises, and that they need advanced Infantry positions. The defenders of Paris, in October, after they had recognised the importance of such positions, developed a system of counter-approaches, which, in some places, extended to 2,000 metres in front of the forts. Such works should be thrown up as far as possible before the arrival of the besieger, so that during this period of the attack no unnecessary labour may have to be expended on them.

One reconnaissance-sortie made by the defenders of Paris—that of Chatillon on the 13th October—may be mentioned here as showing the object and the advantage of sorties at this period of the siege. At 9 A.M., a reconnaissance of about 25,000 men and 80 guns, operating from the counter-approaches (or, which is the same thing, from advanced Infantry positions) was undertaken from the south front. Clamart and Bagneux completely, and Chatillon partially, fell into the hands of the defenders. The force maintained itself till 2.30 P.M. in the investment line, and obliged the besiegers to deploy the whole IInd Bavarian Corps. The loss on both sides was nearly equal—about 400 men. This sortie, undertaken by day on a front of 3,500 metres, penetrated to the line of investment and the vicinity of the recently created Artillery position.

VII.—The Opening of the Besieger's Batteries and the Artillery Combat.

The besieger may open fire with his first batteries at 2,500 metres, or further, from the forts; the latter must immediately take up the action with all their heavy guns. The moment of opening fire is most important to the defence. It places the latter at a disadvantage in all engagements in the terrain of the fortress.

The Artillery of the defence also, although numerically superior, fights at a disadvantage, since the siege guns converge upon it. Hence the defence must do all in its power to hinder the construction of the siege batteries. This function cannot be accomplished by the Artillery of the defence alone. The latter can only prepare the way for the destruction of the works of attack; the Infantry must effect it.

The Artillery of the defence has, therefore, during this period two tasks:—

1. To keep down the fire of the siege batteries.
2. To prepare the way for sorties.

Both tasks can be simultaneously accomplished, if, to keep down the fire of the attack, shell and shrapnel fire are judiciously combined—that is, if the defence does not employ front fire alone, but also oblique fire from different sides. Thus the heavy guns in the forts will not suffice by themselves. The field batteries must come into action as well. Further, it appears desirable that a great part of the light guns of the general reserve should be rendered available for employment as movable batteries immediately on the opening of the enemy's fire. Both the Field Artillery and such guns of the general reserve as can be provided with teams must move out as far as possible in front of the forts, under cover of the advanced Infantry posts, and fire obliquely and with shrapnel against the siege batteries. In many places it will be necessary to cover these guns by Infantry, in order to keep the enemy's riflemen as far as possible from them.

If the Artillery of the defence is thus handled, the ground in the neighbourhood of the siege batteries will be under such a fire that the enemy cannot keep strong reserves near his batteries, and thus the way for sorties will indirectly be prepared. Only when the positions of the reserves covering the siege batteries is known should special guns be told off to shell it. To shell the ground indiscriminately appears a waste of ammunition in view of the limited resources of the fortress. On the other hand, if the siege batteries are protected against sorties by works, the latter must be shelled by the heaviest guns in order to render a sortie possible.

On ground which is much intersected by valleys, where the employment of Field Artillery and a movable armament is not possible, light rifled mortars, possessing a range of about 2,000 metres, and provided with two-wheeled ammunition carts, are recommended. Such mortars can also be suitably employed even in the advanced Infantry positions. Field magazines for them should, therefore, be constructed in these positions, and replenished under cover of darkness.

From the beginning of the Artillery combat, the Artillery is fully occupied. The Infantry must, therefore, take over the duty of guarding the forts. For this purpose it will be best to bring up Infantry from fronts which are not threatened, and detail them as garrisons for the forts. The full garrisoning of the forts with Infantry is not at present necessary, since the advanced positions are still held.

The Artillery combat must be carried on day and night. The activity of the Artillery of the defence must be seconded by sorties delivered for the purpose of destroying the siege batteries. The sorties should be directed against those Artillery positions by which the fortress is most endangered. When the sorties are delivered, the fire of the fortress guns must be directed by the commanders of the sorties. Surprise of the besieger, rapidity of movement, and the deployment of superior forces, are the conditions of success.

Whether such operations should be undertaken by night, during thick weather, or at daybreak, depends on the special conditions on both sides. A defender strong in Infantry, with well-developed advanced Infantry positions, will be able, if the ground is favourable, to make sorties by day. If the defender is weak, the cover of darkness will be necessary. Such a defender will be obliged to attach more value to night fire, since his sorties will need Artillery preparation. The sorties must advance against their objectives in several columns, reserves and working parties following in second line. Individual columns should be as strong as possible, so as to be numerically superior to the enemy's force posted in first line and covering the objective.

Examples.—The besiegers of Danzig opened fire against the west front with 72 guns forty-five days after the investment was completed. The defenders replied vigorously. They had 145 guns (including flanking guns) on the fronts attacked, and their fire was directed first against the enemy's batteries, and later against his approaches. From the day after the opening of fire, the defender's Infantry made small sorties daily between nine and ten in the evening, at first employing one column, later several columns about 300 strong, with a working party of 150 to 250 men to destroy the siege works. These sorties failed, since the sudden cessation of fire of the defender's guns placed the enemy on the alert, and enabled him to bring up his reserves at the right moment. In spite of the heavy fire of the defence, the attack daily gained ground under cover of the fire of the siege batteries. The defender's Artillery only effected one success. A redoubt on the enemy's right was silenced by concentrating all available guns upon it.

We see, therefore, that the defenders of Danzig attempted a co-operation of the arms. The attempt did not succeed, because the Infantry had expended itself in the earlier fighting, which it had carried on alone, and because the sorties were revealed too soon by the cessation of fire. The distance to the batteries was too far; the covering troops were nearer to the latter than the positions from which the defenders delivered their sorties.

The defenders of Sebastopol, when the besiegers opened fire, had 341 guns on the fronts attacked. They replied most vigorously to the 120 guns of the attack, and dismounted several. Nevertheless, it was only want of ammunition which brought about the silencing of the besieger's batteries, and gave the Artillery of the defence an opportunity to develop an activity almost without parallel in military history. The Infantry of the defence at first did nothing to second the partial successes of the Artillery. They established a chain of posts in front of the works, and watched the enemy. The Artillery fire was directed by the information thus obtained. This system led to the supply of very false intelligence, and required a large force to garrison the long line. Hence, later on, pickets of twenty-five men each were posted by day at selected points. With these pickets were listening posts, and men told off to watch the effect of the fire. If a picket discovered the enemy's works, it retired, and the Artillery then fired with shell for a quarter of an hour in the direction indicated. These tactics had no result. The besieger constantly approached. The defender consequently constructed Infantry positions disadvantageously advanced, termed counter-approaches, and later made sorties from them against the works of the attack.

At Sebastopol, we at first find the Artillery and Infantry not acting together to obtain their objects. The Artillery was expected to destroy the siege batteries by itself. Moreover, we note an enormous waste of artillery ammunition. Thus—to give only one instance—on the first day of the bombardment, 20,000 shots were fired against the siege batteries without any possibility of observing the results.

The defenders of Belfort replied with 60 to 80 guns to the besiegers, who opened fire with 27 guns. The Artillery of the defence shelled the enemy's batteries, the roads, as well as the expected site for the construction of batteries, and any visible bodies of troops. The Infantry, driven in on the line of forts on the western front of attack, carried out fruitless sorties. The Infantry positions of the defenders of Belfort lay too far from the forts. The Artillery of the fortress could not lend support to these positions. The Infantry garrison was too weak to offer serious resistance in the distant terrain. The Infantry posts were, therefore, easily lost, and, at the moment when their rôle should have begun, were in the hands of the enemy. This early loss of the posts in the terrain of the fortress was favoured by the arrangement of the commands. All the independent posts were directly under the orders of the commandant, a circumstance which rendered all mutual support and unity of action difficult.

Thus, at Belfort, the Artillery engaged the siege batteries without Infantry support, although the intention to support it by Infantry is apparent. The action of the defenders' Artillery was rendered all the more difficult, since it was carried on in two lines. The weak first line in the forts was soon overpowered by the convergent fire of the attack. The second line in the fortress had to act at too great a range, so that results against the siege batteries could hardly be expected. That the defence of Belfort was so prolonged is to be ascribed more to the extremely unfavourable conditions of weather under which the attack had to operate, and which rendered works and transport difficult, than to the measures taken by the defence.

The preparation of Paris for defence was incomplete when the besiegers opened fire. According to Ducrot, the guard armament of the forts should have consisted of 658 guns. For the war armament, 650 fortress and 192 field guns additional were required.

It is doubtful, however, if this matériel was in Paris, since a part of it was first brought up from the provinces when the fortress was threatened. When the besiegers began the bombardment on the east front, the forts could not reply, since no heavy long-range guns had been mounted. By the 6th January, the defenders had mounted forty long-range naval guns, in the forts and intermediate works of the east front, which inflicted little damage on the attack. The Infantry on the east front only made reconnaissances, and carried out no great operations against the enemy's batteries. On the south side, when the fire was opened on the 5th January, the forts replied vigorously. Their Artillery held out bravely, in spite of the harassing fire of the besiegers. Thus, after the Artillery fight had lasted ten days, there were still 20 guns in action in Fort Montrouge. Here the Infantry made little sorties, which did not succeed in surprising the besieger, and were therefore without result. Only one sortie, undertaken by 300 Marines, according to Ducrot, reached a siege battery which had been begun at Clamart, and caused some destruction. On the south front, emplacements for Field Artillery were thrown up between the forts as a support to them. During the Artillery fight on the northern side, similar measures were taken.

The defenders of Soissons replied to the first opening of the siege batteries with a lively Artillery fire. The besieger had 44 guns in action in enveloping positions. When the fortress was given up, the defenders had still 94 serviceable guns on the ramparts. Here it may have appeared a difficult operation for the Infantry of the defence to attack the siege batteries constructed on the steep slopes. Nevertheless, with a garrison 4,800 strong, it might well have answered to make an attack against the enemy's batteries, with from 1,500 to 2,000 men, instead of allowing them to be uselessly killed behind the ramparts. If the Infantry had occupied the terrain of the fortress, such an operation would not have been too difficult.

VIII.—The General Conduct of the Artillery Fire of the Defence.

Only general directions as to the firing should be given by superior authority. For the latter to lay down special tasks for individual guns appears a questionable proceeding. The special employment of guns must be left to the discretion of the officer commanding a work, who should fight his guns at his own discretion, in accordance with the general directions he has received. The determination of individual objects to fire at must be left to the officer in command of the Artillery of a face of the work. If, in the broad directions given to each work, the general tasks to be performed by each face or group the guns of which are to act in concert, are laid down, and if the commanders of these groups detail to their subordinates the directions received, having regard to the tactical conditions, there will be a sufficient guarantee for unity of action.

The directions should include the general management of the Artillery positions, the objects to be attained by each individual Artillery line, the expenditure of ammunition. Every officer must know what he has to do.

The fire of an 'Artillery line'—*i.e.*, of several guns mounted in one line, but laid on different marks—must be directed in detail, in order that individual shots may be properly observed. The observation can best be conducted from the nearest advanced Infantry position, thus necessitating telegraphic communication; but should be carried on from the gun itself as well.

The commander of an Artillery line usually occupies a position where an observing station has been made for him. He communicates by telephone with the most convenient advanced post, gives out the mark, the rapidity and the order of firing, and corrects the direction of the fire of individual groups.

In order to support sorties, it is recommended that the officer directing the fire should be in the advanced Infantry position from which the sortie is delivered, in order to be able from thence to direct the fire.

Groups of guns—*i.e.*, several guns, usually of similar class, told off to fire at a single object—should be commanded by subalterns. The commanders of these groups direct the fire in accordance with their own observations made from the position of the guns. They should know the tasks which their groups can accomplish, and should make all necessary arrangements, so as to be able rapidly to change the object aimed at, on the order of the officer in general charge of the firing.

IX.—Conduct of the Defence after the Loss of the Advanced Infantry Positions.

The besieger need not by any means disclose his direction of attack on opening fire. If his first Artillery position is an extended one, if it envelopes half or a third of the fortress, the special objective will still be unknown. And the besieger must take this course if he wishes to keep his objective secret, if he intends a surprise. The fire from the first Artillery position of the besieger, which, on account of the advanced Infantry positions, must be at least 2,500 metres from the forts, cannot bring the contest with the defender's Artillery to a close. It will only be able to keep down the fire of the forts, and to prepare the way for the capture of the advanced Infantry positions, failing the possession of which the besieger's Artillery cannot be brought up to decisive range.

The operations for the capture of the advanced Infantry positions must be undertaken over a far more extended front than the attack itself requires, in order not to disclose prematurely the direction of the latter, and so as not to leave in the hands of the defenders important *points d'appui* from whence flanking counter-attacks can be delivered.

So long as the Infantry and Artillery of the defence are not shaken by a cross-fire of heavy siege guns, the assault on these well-entrenched advanced positions, which should be defended with all available resources, appears to be impossible. If single positions are lost, every effort must be made by the defenders to retake them; since it is only by holding these positions that the fighting capabilities of the forts can be maintained.

The besieger, however, with the inexhaustible resources at his command, will ultimately take the advanced positions. After their loss, the Infantry of the defence must still carry on the fight on the glacis and in the intervals between the forts, so long as the Artillery, supported by light guns from the general reserve, can maintain itself in face of the near approach of the siege batteries. At the same time, the defenders must make every effort to bring up heavy guns from the fronts not attacked, and mount them in rear, and especially on the flanks of the front attacked.

If the guns of the forts are placed *hors de combat*, the Infantry must occupy these storm-free defences, and keep up a fire on the enemy's approaches, while other bodies seek to take advantage of this fire, and of that of the Artillery in rear and on the flanks of the forts, by making sorties from the intervals. In order to be able to utilise the forts for the close defence by Infantry, it appears specially desirable to provide a glacis at effective Infantry range, and that this glacis should be countersloping, as has been stated above.

The Artillery fire of the defence will be delivered from two positions: first, from the forts themselves, and, secondly, from the rear positions.

In the forts, in provisionally protected positions at the foot of the *chemin des rondes*, light and heavy, smooth-bore and rifled mortars can be kept in action. They will shell the enemy's approaches and batteries, and render it difficult for him to mass troops.

The extent of the field of the near attack is limited, and it can easily be kept under a constant fire without waste of ammunition.

Light movable guns can also be employed in rear and on the flanks of the forts.

The effect of the fire of the guns in the rear positions can be well observed. These guns should regard the keeping down of the fire of the siege batteries as their main object, and must have their observing stations in the line of the forts.

The defenders should give special attention to those batteries, which are seeking to form breaches and to destroy the flank defences of the ditch. It is specially important to keep down the fire of these batteries; since, so long as no breaches can be made and the flank defences remain intact, a fort properly provided with ammunition and provisions cannot be taken.

History proves the particular advantages of curved fire. In the present day, we unfortunately attach too much value to flat trajectories, which, in field warfare, have unquestionably produced great results, but which, in fortress warfare against well-covered objects, can be less effectively used. If the accuracy of vertical fire is relatively small, the moral effect is, nevertheless, very great, and by direct fire sapping cannot be prevented.

Thus the besieger should be compelled to advance step by step towards his objective, and must ultimately resort to mining.

Infantry, Artillery, and Pioneers in greater numbers, then form the garrisons of the works attacked. The Engineers begin offensive operations with countermines, and are supported by the fire of the Artillery and by Infantry sorties.

After the approaches have arrived close to the works, after the fort has been laid open at one point, and the flank defence of the ditches destroyed—tasks which the miner must accomplish—the next object is the defence of the breach. For this purpose sorties from the rear positions, combined with Artillery fire, delivered more especially from the flank positions, are necessary.

Thus, defending the ground yard by yard, and utilising the effect of their fire by means of sorties, the defenders will be able to offer a successful resistance until their resources are exhausted.

If one or several forts have fallen, the struggle must be carried on in the way already described between the forts and the enceinte. In the case of a defender whose resources are weakened, the collateral forts enter in as a species of reinforcement. The defender will begin to reap the advantages of an enveloping position, if the besieger does not proceed to take some of these collateral forts. The fortress combat, however, presents no new features.

Examples.—In spite of the energetic resistance offered by the defenders of Danzig, both with Artillery and Infantry fire, the besieger advanced rapidly, and four days after the opening of the bombardment had completed the 3rd parallel against the Hagelsberg. (Plate 1.)

The Infantry, which had previously expended its strength, did not carry out the sorties intended. Nevertheless, sharpshooters posted in the covered way prevented the approaches from being pushed on by day, until the besieger had by the 7th May constructed a trench-cavalier, which dominated the covered way. Sharpshooters posted in this trench-cavalier drove the defenders from the latter. Only the réduits of the covered way were still occupied.

While the defender energetically held his own on the western side, but had, nevertheless, committed the error of engaging his Infantry in unequal combats at the beginning of the siege and thus weakening it, he had entirely neglected the other fronts of the fortress. The Danziger Nehrung up to the Frischen Haff—a total extent of 5½ miles—was occupied at the beginning of the siege by 1,448 men, and should have been held in order to keep up communications with Pillau. The Nehrung was lost on the 20th March at the first attack of the French. Attempts to recover it failed. Connection with the lake was cut off by the besieger occupying both flanks of the line of communication. On the night of the 6th May, the Holminsel, the occupation of which allowed communication to be carried on at least by night between the fortress and the mouth of the Weichsel, was lost. By reason of this loss, an attempt to relieve the fortress by sea and land from Pillau failed.

At the beginning of May, the approaches of the besieger from the 3rd parallel against the Hagelsberg could not be checked by the fire of the fortress guns. Soon the latter became unable to hit the works of the besieger, and mortars were employed with good effect, while the infantry in the réduits held the covered way. These circumstances compelled the besieger at the beginning of May to take to mining, since the obstacles in front—the palisades and the réduits of the covered way—served to render an assault impossible, in spite of the known weakness of the defender's Infantry.

At this period the successful sorties of the defence began. The success of these sorties is explained by the facts that the way for them was well prepared by Artillery fire, that they were undertaken in several strong columns, and that the latter were nearer to their objectives than the reserves of the besieger. Two sorties in particular—those of the 17th and the 20th May—may be noticed. The first was directed in three columns against the works crowning the glacis, and destroyed much of them. The second was delivered against the descents into the ditches, and burned them.

Thus, for three weeks after the opening of the 3rd parallel at a distance of 100 to 150 metres, the defenders held the besiegers in check by mortar fire and sorties, until negociations for surrender were begun on account of want of powder and provisions. After a resistance of 76 days the fortress was given up to the enemy. There were still 210 guns standing on the ramparts. The besieger had worked at the trenches for 55 days.

If the defenders had not undertaken impossible tasks at the beginning of the siege, if they had limited themselves to the maintenance of their communications with the sea, and if they had begun their struggle with the besiegers on the heights on which the first siege batteries were built, the defence might have lasted much longer.

The siege of Antwerp in 1832 may also be instanced as an example of a good Artillery defence. The fortress guns bravely kept up the fight for nineteen days against great odds. Good results were obtained by vertical fire from covered positions, by which one siege battery was even silenced. By direct fire, on the other hand, the fortress guns effected nothing, though they were well served. The Infantry defence of Antwerp was bad. The covered way was not occupied, and observation was indifferently carried out. The Infantry sorties against the siege batteries were inadequate. They were undertaken with a force of from 9 to at most 40 men. No measures were taken for the defence of the breaches.

The defenders of Sebastopol, after the first bombardment, extended the chequered rifle-pits on the front of attack so as to form Infantry trenches. Even the bastions were strengthened by obstacles and flanking arrangements, while their armament was increased. The Russian army, posted outside the fortress at Mackenzie's Farm, attempted at the end of October to operate against the rear communications of the besieger at Balacklava, but without the support of the fortress garrison. Early in November, the Russian army, supported by two large sorties from the fortress, made a fruitless advance against the right wing of the besiegers. Only one of these sorties—that of the 5th November along the Quarantine ravine, made by about 8,000 men and one battery under Timofejeff—although not prepared by the fortress Artillery, reached the French batteries and spiked several guns.

Towards the end of November the Infantry positions between the harbour and the Woronzoff ravine, 1,000 paces in advance of the works, were lost. At the end of December, the trenches in front of the central bastions suffered the same fate. These Infantry positions had neither obstacles nor réduits. In spite of this, the besiegers did not think of reaching their goal at this point, since they were aware that the defenders knew their direction of attack, had strengthened their defences, and resorted to mining. Hence, in February, the direction of the attack was altered to the Malakoff. This determination was further strengthened by the fact that the Artillery attack on the left flank had not prospered. Since January 1855, the Russians employed convergent mortar fire against the siege batteries, by which those of the French, which were crowded together on the left flank, suffered severely. When the defenders became aware of the change in the direction of attack, they immediately built several detached works for Infantry on the fronts threatened, one of which was 1,500 paces in front of the Artillery position. From the works on the left flank it was proposed to advance further by means of counter-approaches. Moreover, the Infantry here made little sorties by night against the siege works without success. Once only, in the night of the 22nd March, a more serious attempt was made against the French approaches in front of the Kamschatka redoubt. In this attack 8,000 men were employed. Demonstrations were to be made to draw off the watchfulness of the besiegers. The attack failed, since the fortress Artillery, from want of ammunition, had not sufficiently prepared the way for it, and the prearranged demonstrations came too late. One of these false attacks, however, succeeded in reaching the 3rd parallel of the English attack, and spiked a few guns.

The Russian Infantry needed advanced positions. They were obliged, during the siege, to work in order to render the fortress defensible, rather than to fight in order to follow up the results obtained by the Artillery. While the Russian Infantry were more active with the spade than the musket, and produced astonishing results with the former, the Artillery developed unexampled energy. Although at many points kept down by the enveloping fire of the siege batteries, it nevertheless lasted out six bombardments, and always brought a numerical superiority of guns into action. In the first bombardment there were 341 guns mounted on the south front; in the last, 1,259. The besieger in this last bombardment had 700 guns in position.

This energetic Artillery defence, and the fact that the Artillery positions of the defenders were meanwhile rendered storm-free, compelled the besiegers to resort to mining. In the latter, the Engineers rendered more support to the Artillery of the defence than had hitherto been afforded by the Infantry. The Engineers, with their systems of counter-mines, which lay below those of the attack, had been the principal cause of the change in the direction of the attack. The fortress finally fell by assault, which was possible only because the works lacked the degree of storm-freedom possessed by permanent forts. Sebastopol held out 305 days from the date of the appearance of the besiegers on the front of attack. The advantages of this long delay were not, however, on the side of the defender alone. The besiegers also benefited by the lapse of time, since they at first employed insufficient resources against the fortress.

At the defence of Belfort also, the Artillery and Infantry did not go hand in hand. The Artillery was in action day and night till the 13th February, without any support from Infantry sorties. The siege batteries soon obtained the upper hand, in consequence of their greater number of guns.

Only the guns of the defence in covered emplacements, and those which employed indirect fire at long range, held out. The guns of Fort Bellevue had to be withdrawn on account of an error in the armament, since it was impossible for such light guns to cope with the siege batteries.

The Infantry restricted its action to the defence of the posts occupied. In the further course of the siege, two unfortunate sorties were made—one to recover the wood of Bavilliers, the other to retake Danjoutin. Besides this, the Infantry reconnoitred and demonstrated on the days of the fighting on the Lisaine. None of these operations succeeded in driving in the investment line.

The defenders of Belfort had resisted for 103 days, when they were obliged by the orders of their Government to give up the fortress. This successful resistance was rendered possible by the unfavourable weather and the weakness of the besieger's resources.

The fortress warfare carried on during the Russo-Turkish campaign was not fertile in lessons, although it affords some hints. The improvised fortress of Plevna shows the importance of the storm-freedom of positions. In the assault of the 11th of September the Russians penetrated into the defensive line, because it was not storm-free. The captured works, except the Grivitza redoubt, were certainly retaken; but only by strong Turkish counter-attacks from the rear lines, for the purpose of which attacks there were reserves of a strength which has never been available in the case of the defence of a fortress.

The defences of Kars and Ardahan, even more than that of Plevna, bear testimony to the importance of storm-freedom, and give rise to reflections as to the carrying on of the Artillery fight in intermediate positions liable to capture by assault.

X.—Conclusions.

The following are, briefly, the conclusions to be derived from the examples cited :—

1. The observation of an enemy threatening a fortress can best be carried on by Cavalry. *Danzig; Sebastopol.*

Infantry detachments pushed far to the front effect nothing in the way of observation. They merely hinder the progress of the works of defence. *Danzig; Belfort.*

2. It is impossible to stop the advance of the besieger outside the effective range of the fortress guns. All such attempts end disadvantageously for the morale of the defenders—in defeat or even disaster. *Danzig; Sebastopol; Belfort; Soissons.*

3. The closing in of the besiegers round the fortress beyond the effective range of the fortress guns, was not hindered in any one of the instances mentioned. Nevertheless, to hinder it appears theoretically possible in special cases.

4. The taking up of the positions of attack can be successfully delayed by holding on to these positions. *Danzig.*

By holding them, the defender obtains the best opportunity of reconnoitring the strength of the besieger. If these positions are lost, offensive operations with a view to retake them are not to be recommended, since such operations do not promise success and are costly. *Belfort.*

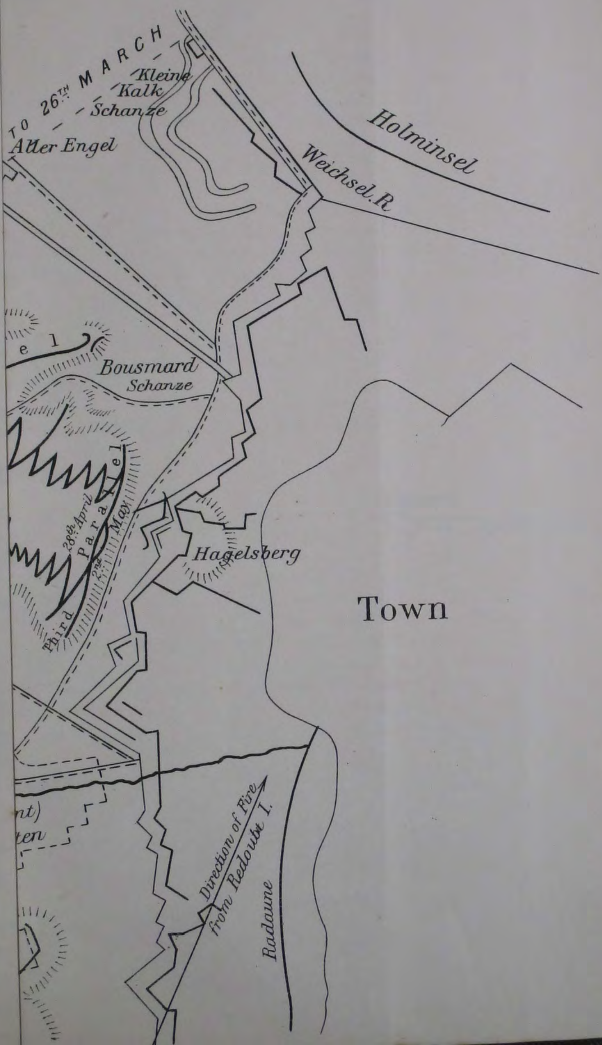
Only when individual posts are lost, is an attempt to recapture them advisable. *Danzig.*

5. The time for an energetic offensive on the part of the defenders arrives with the commencement of the siege works and batteries. This offensive must be supported by a powerful Artillery, and it will then successfully hinder the progress of the attack.

A powerful Artillery alone will not check the course of the attack. *Danzig; Antwerp; Sebastopol.*

The effect produced by the Artillery must be followed up by strong sorties based on the principle of the surprise.

For the purpose of such sorties, advanced Infantry positions must be previously constructed; otherwise the sorties will be unsuccessful. *Danzig; Sebastopol; Paris.*


TO 26TH MARCH
Kleine Kalk Schanze
Alter Engel
Holminsel
Weichsel R
Bousmard Schanze
28th April
Third Parallel
2nd May
Hagelsberg
Town
Direction of Fire from Redoubt I.
Radaune

Part II.

THE ATTACK.

The attack, as compared with the defence, has the advantages of a numerically and morally superior personnel: of better though fewer guns: and of practically inexhaustible supplies. Supposing the choice of the front of attack to be open, there is the further advantage of being able to strike at the most susceptible part of the defence, or to surprise and defeat it tactically.

But, on the other hand, the details of the fortress, the approaches to it, the formation of the ground and the methods of defence, exert a most important influence on the attack.

The method of defence appears to be one of the principal elements that the attack has to take into account. However pronounced may be the superiority of the attack, on this depends its nature; supposing always that the fortress possesses the necessary strength for the proposed method of defence.

Sebastopol, Danzig, and Belfort are examples of the dependence of the attack on the method of defence.

Before Sebastopol, where the defence at first only relied on the ramparts and their armament, the attack, though deficient in means, succeeded in establishing the first parallel without great loss, at a distance of 950 to 1,200 metres from the place, and in constructing siege batteries in this parallel.

Before Danzig and Belfort, where the defence held possession of the ground in front of the place, sanguinary Infantry engagements for the possession of this terrain preceded the construction of the attacking batteries. That these fights before Danzig did not allow the attacking Artillery to be brought up, was due to the sites of the defender's Infantry positions, which had been chosen beyond the effective range of the fortress Artillery. On the other hand, in the case of the south-east attack on Belfort, the capture of Danjoutin and of the copse and village of Pérouse, forced the attack to construct a battery at Andelnans and a second one east of Bavilliers against Danjoutin, to maintain two batteries (Nos. 13 and 14) at the northern end of Bosmont wood, about 2,200 metres from the Hautes Perches, and later on to turn two other batteries (18 and 20) against the above-mentioned advanced Infantry posts. In the western attack on Belfort, after the Infantry had been driven from the insufficiently fortified advanced positions, the construction of the batteries at a distance of 1,500 to 1,800 metres became possible.

The engagements round Ardahan and Kars, in 1877, also demonstrate the dependence of the attack on the method of defence. While, in front of Ardahan, the Russians, acting against a passive defence, were able to construct batteries without any other preparation at distances of from 2,000 to 2,500 metres; at Kars, they were forced by sorties and Artillery fire to place the first batteries at a distance of 4,800 to 5,000 metres from the place.

These examples show that the nature of the attack is far more dependent on that of the defence than is generally assumed to be the case. For this reason it appeared advisable to discuss first the principles of defence. These principles, as laid down in Part I. of these studies, should therefore be taken into consideration in connection with the following pages.

I.—The Preparation for the Attack.

A study of the history of fortress warfare shows how insufficent and incomplete preparations for the siege of fortresses have been in the past. An investment with weak forces follows the isolation of the object of attack and the attempts made to stop the defensive preparations. By degrees the attacking force is reinforced till it becomes a Siege Corps; the Artillery matériel comes up slowly, until it appears that such measures are insufficient to cope with the energy of the defence.

This experience is dearly bought. It is only necessary to read the losses at the bombardment of Sebastopol (Weigelt, p. 305) to learn what waste of power as well as of time and what failures result from an attack commenced with insufficient means.

It must be acknowledged that in many cases, at the commencement of a siege, the general conditions of the war will not permit of the adoption of those measures which are necessary for its prosecution. But, under these conditions, it has to be decided whether the attack should be commenced at all.

If a fortress is to be attacked, and if it is intended that it should fall quickly, the necessary means for the conduct of the siege must be on the spot. Operations conducted quickly and without waste of time are essential for a strong attack, for the defender utilises every day for strengthening his position and preparing for the struggle.

The investment of a fortress, with a view to hindering further provisioning, and to disturb the defensive preparations, can only be a makeshift in those cases where the necessary forces to attack, and to make certain the result of the attack, are not at hand.

(*a*) *Necessary Personnel.*—The new text-books lay down that to be strategically safe the besieger should, as a general rule, be three times as strong as the defender. This does not appear to be sufficient for all cases. The strength of the besieger's forces is determined by the size of the fortress to be attacked, and by the strength of its garrison. As the difficulty of mutual support in the attack increases with the size of the fortress, the besieger's superiority must necessarily be increased in proportion to this size. The experiences of the campaign of 1870–71 before Metz and Paris with regard to the force required for the maintenance of the investment, cannot be taken as applying to regular sieges, in which the troops have to operate within the effective range of the Artillery of the fortress.

The fortresses of the newest type, with the exception of Paris, have a circumference of from 15 to 30 miles measured along the line of the forts. If we consider as adequate such a garrison as would allow for three reliefs, counting the men absolutely necessary for guards and for fatigue duties, we arrive at the conclusion that half the strength of the garrison would be available for sorties on important occasions.

If the besieger wishes to be secure against any reverse, he must also be able to meet everywhere, with an equal force, any such exceptional undertakings on the part of the defence.

Under the above conditions, the besieger would have a front of from 25 to 40 miles under the Artillery fire of the fortress. He can be attacked at any point by half the garrison. Taking into account the possibility of mutual support and the relief of the troops, it appears that the strength of the besieging corps for every 6 miles of the investment line should be double that of the greatest sortie-strength of the garrison, so as to allow for two reliefs. Further, a force equal to that of the garrison is required to cover the works on that side from which the approaches are to be made. The investing troops already counted for this front would be available, in sufficient numbers, for working parties.

For fortresses of the type above mentioned, the strength of the Siege Corps comes to from four to five times that of the garrison.

It is assumed in this calculation that the value of the troops on the two sides is not as unequal as in the sieges of the 1870–71 campaign.

(*b*) *Necessary Matériel.*—The besieger may give up the idea of having a greater number of guns than the defender. It appears more advantageous to keep uninterruptedly in action a few good guns, well and effectively served, than a great number, which might from time to time have to cease firing from want of ammunition.

As a rule, by utilising the advantages of the attack, thirty-two heavy guns will be sufficient to keep down the fire of the largest fort; and if this fort is the special object of attack, and its capture necessary for the success of the siege; then, even if it is supported by intermediate batteries, ninety guns will be enough unless the fort have shielded emplacements or turrets, in which case four more heavy guns would have to be brought up for each shielded emplacement.

The calibre and nature of guns will be determined by the style of the fort. In recent forts, built in the form of lunettes, an attempt is made to render them secure against enfilade. When the faces cannot be thrown back, so as to be secure from enfilade fire, each individual gun is protected by traverses, about 6½ feet higher than the gun, which they entirely cover from fire in any position, up to an angle of descent of about 20°. In forts situated on commanding points, the guns are placed out of sight behind strong earthworks. Under these conditions, only pieces with very curved trajectories can be used with advantage against the Artillery of the fortress.

On account of the abnormal conditions of the fortress warfare in 1870–71, it has been forgotten that the experiences of former sieges had already clearly demonstrated the advantages of guns with curved trajectories.

This was notably the case at the siege of Sebastopol, where, although the building of the fortress was not completed, and the protection of the defender's Artillery by means of traverses cannot be compared with that provided in the latest forts, the want of mortars was very much felt by the attack. Shortly before the final storming of the Malakoff, it had been decided to increase the Artillery of the attack by 400 mortars.

Even Vauban, in whose time the defender's Artillery was more exposed than at present, required for a siege park a proportion of about ⅓ mortars. Rustöw held that half the Artillery of a siege park should be mortars. For the later forts, the proper proportion for a siege train appears to be 61% howitzers, 12% guns, and 27% mortars; and 21 cm. seems to be the maximum calibre admissible, when the difficulties of working the guns and of transporting ammunition are considered.

A moderate number of good guns is sufficient for keeping up an uninterrupted bombardment. Three reliefs are required for their service, and there must be a plentiful supply of ammunition. Judging from former sieges, 100 rounds per day must be allowed for each gun in order to make certain of silencing the defender's Artillery, and of reventing it from reopening fire. In order to guard against the ossibility of losing advantages already gained, by having to cease fire rom want of ammunition, it appears necessary to have five days' upply before commencing the bombardment, with the certainty of eing able to renew this supply. The importance of this was repeatedly hown in the sieges of 1870–71. Where the latter lasted any time, an nsufficient ammunition-supply prevented a systematic uninterrupted ombardment. The difficulties of sending up ammunition to the front vere always very great, and chiefly due to the want of a proper system f transport.

The supply of ammunition to the front requires per day for each gun of from—

21 to 22 cm. calibre,	$8\frac{1}{4}$	wagons	of 1 ton capacity.
of 15 cm. ,,	$4\frac{1}{2}$	,,	
of 12 cm. ,,	$2\frac{1}{4}$	,,	

The Engineer park, and the troops belonging to it, must also be ready at the commencement of the siege; although they only come up after the transport of the Artillery park has been completed and the besieger has succeeded in establishing his superiority.

The investment line can be strengthened by the troops and field Pioneers, with their own intrenching tools.

For the actual attack, Engineers are specially detailed for working in front of the Infantry and for mining duties. In the attack of one fort, three companies of Pioneers, working in four reliefs, are sufficient for the sapping and mining work.

The equipment of the Engineer park should be calculated so as to allow the construction of a parallel, 2,000 metres long, to go on at one time. Similarly the park should contain mining and sapping appliances, to allow of three approaches proceeding simultaneously against each fort attacked.

It is interesting to compare the relative strength in men and guns of the attack and defence with the duration of the operation in different sieges. Though no positive conclusion concerning the necessary strength for the attack can be drawn from the following figures, yet they show that a greater superiority on the side of the besieger is necessary against well-defended fortresses free from the danger of assault, than was the case in the examples quoted.

Siege	Besieger's Strength		Duration of the Siege in days from appearance of the besiegers before the fortress	Remarks
	Proportion of Personnel to that of Defence	Proportion of Guns to those of Defence		
Danzig, 1807	In March, 1·26 In April, 2·3 In May, about 3	In the middle of April, 0·3* Later on, more	76	* Including field guns.
Antwerp, 1832	13	1*	25	* Including field guns.
Sebastopol, 1854–55	September, 1854, 1* January, 1855, 2–3	November, 1854, $\frac{1}{20}$ † At the end of the Siege, $\frac{1}{3}$	318	* Including the Russian army and the ships' crews. † Exclusive of the field Artillery as well as of the ships' guns of the Allies, but inclusive of the Russian ships' guns.
Belfort, 1870–71	9th November, 1870, 1 At the end of December, 2	December, $\frac{1}{10}$ Later, $\frac{1}{5}$	105	
Soissons, 1870	1·4	$\frac{1}{3}$	22	
Ardahan, 1877	About 1·5–2	1·6*	4	* Including field guns.
Kars, 1877	1·2	—	32	Second siege.
Plevna, 1877	31st August, 0·9 10th December, 2	10th December, 5*	143	* Including field guns.

Unfortunately, the quantity of ammunition ready to hand at the commencement of the siege cannot be accurately determined. The total quantity of ammunition varied very much.

The average daily consumption per gun, as far as can be ascertained from the imperfect information available, was about as follows :

Danzig, 25 rounds.
Antwerp, 40 rounds.
Sebastopol, 80 to 100 rounds, during the days of heavy firing, and from 5 to 10 rounds at other times.
Belfort, 25 rounds.
Paris (south attack), 25 rounds approximately.

A regular bombardment, without such pauses in the firing as would allow of the defenders repairing some of the damage done, has nowhere taken place.

The following figures may be quoted with reference to the force required for actual siege operations.

At Danzig, 11 companies of Pioneers were available for the Engineer attack.

Before Sebastopol, after the reorganisation of their army at the beginning of the year 1855, the French had for the service of 260 siege guns—

11 fortress companies.
12 field batteries.
1 mountain battery.
2 companies of Marine Artillery, and 800 sailors, as well as 1,000 extra hands from the ships.

Before Belfort, there were present at the end of December, for the service of 90 guns, 24 companies of siege Artillery—that is, 4,800 men ; and for the Engineer attack, 6 Pioneer companies. 100 military carts and 200 country wagons were employed in the parks.

Before Paris, for the service of the 254 guns forming the Villacoubley Artillery park, there were 35½ fortress Artillery companies. The Artillery park had 400 horses for 350 two-wheeled and 140 four-wheeled wagons, 66 other carts, and 100 French ammunition wagons. Later on, three more transport columns were formed. Six to seven hundred men were daily employed at work in the park.

The technical troops present were 7 field and 1 fortress Pioneer companies, and 1 photographic detachment.

The Engineer park contained 13,500 shovels and 8,800 picks, in addition to the special tools for sapping, mining, and other Engineer work.

II.—The Advance on the Fortress.

(*a*) *Conduct of the Operations.*—The besieger during the advance has two things to take into consideration—his own safety and the investment of the fortress.

The very fact of a siege being undertaken assumes the absence of a hostile army, or its retreat. Nevertheless, in both cases there will be hostile troops to deal with, who will keep up communication with the fortress, or will serve to cover the retreating field army, and carry out its reconnaissances. The one exception to this is when the fortress concerned lies to the rear of the attacker's own victorious army, and in the absence of sufficient troops can, at the time, only be masked.

Covering a siege is part of the field operations. As it can only be done by sending troops in threatened directions, the task, which lies outside the proper sphere of the besieging corps, should be entrusted to an independent force.

The Siege Corps and the covering troops advance simultaneously, and therefore in such strength that they can move on a broad front without incurring any risk. In this manner, not only is the march made more convenient and the supply simplified, but the besieger is also preparing for his operations against any offensive undertaking on the part of the defence, and for the investment of the fortress, in the the most advantageous way. This method of proceeding has only one weak side; viz., the difficulty of supporting the flanks. For this reason it is best to concentrate in two bodies towards the flank, as soon as touch is obtained of the fortress.

On his front the besieger has nothing to fear from the weak garrison of the fortress. The garrison and the troops outside can, however, operate successfully against the flanks. The flanks of the advancing force should therefore always be prepared to resist an attack, and they should be covered by a good Cavalry screen, so as to make it impossible for the enemy to reconnoitre them.

(*b*) *Examples.*—The march on Paris in 1870 will serve as a model for the fortress warfare of the future.

In this case, about 150,000 men with 620 field guns appeared on the 16th September, between Beaumont-sur-Oise and Moissi-Cramayel—that is, on a front of about 40 miles—at a distance of 15 miles from the fortress. Cavalry covered the flanks.

In less than two days, the besieging army approached in two bodies from the N.E. and S. of Paris (Plate 1), to just beyond the reach of sorties, but so as to have touch of the fortress. These bodies kept up only a slight connection with each other, but their flanks were secured by masses of Cavalry. If the defenders had wished to reconnoitre the flanks of the approaching besieger, with a view to operate against the investment with the two Corps standing between the intervals of the forts (given by Ducrot as 50,000 men), the reconnaissance on the 16th September would have had to extend over 20 miles.

In the march on Belfort, the conditions were different. In this case, the attack had only 8,000 men and 24 field guns, and it occupied, at a distance of 8 miles from the fortress, the line of Rougement—La Chapelle-sous-Rougement, a length of $2\frac{1}{2}$ miles; the Cavalry was mostly in front. There were 17,000 men at the disposal of the defence. With such relative strength, the attack is exposed to considerable danger at the hands of an energetic and active defender; since, in the nearer approach, a division of forces must occur in such proximity to the fortress that the weak points of the besieger could hardly fail to attract notice. Suppose that Denfert, who received, on the 1st of November, intelligence of the advance on Belfort, instead of occupying the position shown in Plate 2 (Part I.), had kept all his troops concentrated under the supporting fire of the fortress Artillery, in Pérouse and in the suburb on the road to Epinal. Then, taking into account that as well as the above-mentioned favourable conditions, there was a good Cavalry outpost service supported by the population, the weak points of the besieger at La Chapelle and Bessencourt might easily have been detected, and one of these points attacked with a successful result.

The possibility of such extensive offensive action on the part of the defence will only occur very exceptionally.

If such an offensive promises good results; if there is any prospect of keeping up the connection between the fortress and the sources of assistance from the rear, and so of materially increasing the strength of the defence, an active defender, as soon as he *clearly* perceives these conditions, will adopt such offensive action with all his forces. If he cannot make certain of the existence of these conditions, such an offensive had better be left alone.

III.—The Investment and Preparations for the Attack.

(*a*) *Conduct of the Operations.*—The investment should cut all communication between the fortress and the surrounding country while securing a base for future operations.

The knowledge of the fortress to be attacked will generally be incomplete at this period, and a plan of attack cannot be definitely laid down. The positions of the investing troops should therefore be chosen with a view to carrying out reconnaissances of the fortress and of the ground in front of it without unnecessary loss, so that a plan of attack may be got out, the positions for the batteries decided upon, and preparations made for further operations.

The reconnaissances can be well carried out with good eyes and field-glasses up to distances of 3,000 metres. The investment line can, therefore, be chosen beyond the range of high-angle fire and of shrapnel, at 4,500 to 4,800 metres from the works, according to the nature of the ground. If pickets and outposts are pushed 1,000 metres to the front from these positions, and, in order to cover the reconnoitring parties, approach another 500 to 1,000 metres nearer the fortress in the daytime, the positions next to be occupied, as well as the works themselves, may be sufficiently reconnoitred without incurring unnecessary loss. We say sufficiently reconnoitred, for it does not seem necessary that the besieger should make up his mind at this stage as to the direction of attack. He will at first only choose the front of attack (that is one of the sections into which the ground is divided by rivers, and which thus forms one unit of the defence), and subsequently an objective in it. The choice of the direction of the attack can be left to a later period, when he is nearer to this objective.

The occupation of the investment line will take place by a gradua deployment from the two bodies which have approached the fortress in the manner described above. It is while the besieging force is crossing rivers that suitable occasions for assuming the offensive will present themselves to the defender.

The distribution of the besieging troops should be so arranged that the strategical units occupy sections, and the larger tactical units the ground between roads. This is the only way that a satisfactory distribution of troops from front to rear can be obtained, and one which allows of the intimate tactical connection being maintained when fighting is going on. The smaller tactical units are distributed in the outpost line in deep formations, and in accordance with their positions.

The choice of a front of attack is determined from a consideration of what decisive point would by its capture ensure the fall of the fortress. To occupy works which are easily captured, but whose fall does not involve that of the fortress, nor prevent an energetic defender continuing his resistance, is useless. By the decisive point is understood that commanding work which so dominates the defender's centre of supply that from it the supplies may be destroyed. The loss of this point will materially affect the defensive power of the other works. This definition does not preclude the existence of several such points.

Which of these decisive points is to be chosen will depend on the besieger's line of supplies. An Artillery siege train requires such a large amount of transport that the attack should start as near as possible to the line of supplies unless this line can be extended.

An Artillery siege train of 200 guns, with 1,000 rounds per gun, and all necessary personnel and matériel, is estimated to require about 32 railway trains each of 100 axles. A 22 cm. gun with 1,000 rounds requires for its transport 900 wagons, each carrying a ton.

These facts force the besieger to keep to the railways in the attack of great fortresses, and prevent tactical and other considerations having any great weight in the choice of the front of attack.

As soon as this front has been chosen, it becomes necessary to draw up a general plan of operations.

In doing this, it must not be forgotten that the defender's numerous heavy guns are ready for action in strong, secure emplacements, while his Infantry is lying under cover of the guns in intrenched positions in front of the fortress, waiting for an opportunity for effectual offensive action.

The capture of these intrenched positions, covered by heavy guns, presents difficulties. A successful bombardment by field Artillery at decisive ranges appears impossible on account of the Artillery of the fortress. It is only when guns of equal power have been brought to bear on this Artillery that the capture of the advanced intrenched positions will be feasible.

It will not be possible to effect the capture of the defender's line all round the fortress, although such capture would serve to conceal the front of attack. The capture of the advanced Infantry position before one or two fronts will suffice to conceal the actual objective and direction of the attack, considering the extent of the fortifications and the room for choice in the selection of this objective and direction.

The first Artillery position must, however, extend over as great an arc as does that part of the Infantry position which it is necessary for the besieger to capture in order to conceal his intentions and secure the flanks of the near attack.

The extent of the first Artillery position involves a decentralisation of the gun park. On the other hand, the ammunition park, with the powder and unfilled shells, should remain centralised for the sake of facilitating laboratory work and the general ammunition supply, while the expense magazines for made-up ammunition should be distributed so as to suit the Artillery attack. This decentralisation of the parks will facilitate the establishment of the batteries and their ammunition supply.

When the direction and extent of the attack have been decided on, the parks are established in several groups corresponding to the general plan. They are strengthened by works and placed under the protection of the investment line, and out of reach of the shrapnel fire of the fortress.

A railway is absolutely necessary for the transport of the siege parks, and for the ammunition supply, if a regular attack is to be energetically carried out and brought to a speedy close. Even if there is a railway up to the selected front, and it has been put in a state of repair, at least nine days must elapse before the attack can be commenced.

After the occupation of the investment line, at least one day will be taken up in reconnoitring the fortress, two days in arranging the unloading places, and five more in establishing the parks and in bringing up and organising a supply of 500 rounds per gun; since it seems impossible, even with the best arrangements, to unload more than four trains daily. Moreover, the advance of the besieging corps will not allow of more trains being used for artillery purposes.

The foot Artillery will employ the last eight of these days in preparing brushwood for the construction of the batteries. This work will be done as near as possible to the position of the batteries, in order to lessen the difficulties of transport for the day on which the batteries are constructed. The tactical reserves can now also be employed, without danger to the safety of the investment line, in preparing brushwood for the Engineer attack. The nearer the place of preparation of the brushwood is to that of its use, the easier does this use become.

The manufacture of revetting materials in the cantonments in rear increases to too great an extent the already considerable transport requirements of a large Siege Corps; moreover, it deprives the troops in rear of the time for rest; on the other hand, by preparing revetting material in the investment line, a portion of the reserves can be suitably employed in the daytime, without detriment to the execution of their regular duties.

(*b*) *Examples.*—In practice the investment has generally been otherwise conducted, owing to its being undertaken with insufficient resources.

At Danzig (Plate 4) the besiegers at first only carried out the investment on the left bank of the Vistula, in a position about a mile distant from the fortress. The troops appear to have been concentrated in three divisions of about 4,000 to 6,000 men before the south-west front; one battalion observed the east side. The Cavalry was divided between the divisions. The latter were in cantonments, and had sent forward one or two battalions, with some troopers and guns as outposts, against the localities occupied by the defenders. Three days after the investment on the left bank of the Vistula, the besieger's outposts west of the fortress began to intrench themselves at five points between the posts occupied by the defence. Attempts to push the outposts further to the front failed. Five days afterwards the investment was completed on the right bank of the Vistula.

It appears strange that the throwing up of field-works so very near to the points occupied by the defenders could have been carried out without any serious interruption; while at the same time the defenders had several times been successful in advancing to the west.

Altogether the conditions of the siege of Danzig show what waste of time and what reverses accompany a siege commenced with insufficient resources. For 14 days the besieger was fighting for the site of the investment line.

The investment of Belfort (Plate 2), with 1 line and 10 landwehr battalions, $5\frac{1}{4}$ squadrons and 4 batteries, was a very venturesome undertaking, justified, however, by the result. In two days the investment was completed on a line 25 miles long. The troops were disposed in eight groups, and were weaker than the defenders. The latter had barricaded the roads, interrupted communication by rail and telegraph, occupied fortified pickets 300 metres from the place, and posts 200 metres further to the front. Under these conditions it was impossible to interrupt the communication of the fortress with the surrounding country; and an energetic offensive on the part of the defenders appeared probable, since such an offensive promised the possibility of keeping the communications open for some time, of receiving further reinforcements, and so increasing the resisting power of the fortress.

The operations at Belfort, apart from the general result, show the effect of too close an investment without the protection of sufficient Artillery; for, on the 17th November, the garrison of Bessancourt had to be withdrawn to Phaffans on account of the fire of the fortress, and for the same reason the village of Offemont had to be abandoned on the 23rd November.

In this case, also, 15 days elapsed before the besiegers could isolate the fortress.

At Belfort, and also at Danzig, no preparations for the attack could be made during this period, on account of the weakness of the besiegers. This circumstance much delayed the progress of the attack.

The investment of Paris, and the preparations for the south attack, give a fair model for future sieges. The investment line beyond the effective range of the Artillery of the fortress was chosen with a view to defence, and rested principally on fortified villages and woods. From this line the outposts were pushed forward, so as to have a good view to the front. The reserves moved into the line itself. Where there were no defensible localities, redoubts were constructed to hold a company of Infantry. The Artillery emplacements were in rear on the flanks.

The line lay through Croisy, St. Cloud, Sèvres, the Park of Meudon, l'Hay, Choisy-le-Roi, Chelles, Montfermeil, Clichy, Livry, Sevran, Aulnay, le Blanc Mesnil, Garges, Arnouville, Sarcelles, Montmagny, Deuil, Argenteuil.

254 guns, with 1,000 rounds per gun, were conveyed to Nauteuil on 3,100 railway axles for the proposed Artillery attack on the south front; 35½ companies of fortress Artillery were detailed for the service of the guns.

The transport of the guns from Nauteuil to the Park of Villacoublay lasted nearly a month, and required 1,248 teams of field Artillery horses.

The ammunition was mostly brought from Nauteuil to Villacoublay on requisitioned two-horsed carts of from 7 to 10 cwt. carrying capacity. By the end of December, 3,700 such cartloads of ammunition had been carried.

From the 1st January to the 4th February, after the changes in the organisation, 3,500 more wagon-loads (four horsed), of 16 to 20 cwt., were transported.

The preparation of the brushwood was left to the Army Corps. It was stored in depôts at Meudon, Chatillon, and Petit-Bicêtre.

Notwithstanding that the Artillery attack extended over twelve kilometres from Sèvres to Chevilly, the parks were concentrated at Villacoublay; on the other hand, the materials for the batteries and the intrenching tools were stored in depôts, and the made-up ammunition was distributed in five bomb-proof magazines.

The preparations for the siege of Soissons were covered by an investment line at a distance of from 3,000 to 6,000 paces from the works.

Forty-eight pieces, with 470 rounds per rifled gun, were forwarded from Toul to Reims on 230 railway axles. The park was taken from Reims by about 800 carts, and the gun park was divided into two sections, corresponding to the proposed extent of the attack, whilst the ammunition park remained concentrated further to the rear.

Before Sebastopol, the English had a similar arrangement of the siege park, which is supposed to have answered well.

IV.—The Preliminary Operations of the Attack.

(*a*) *Conduct of the Operations.*—When the establishment of the park is sufficiently advanced, and the preparations for throwing up the batteries are completed, the besieger's Infantry will push forward as near as possible to the fortress, so as to enable the construction of the proposed batteries to be proceeded with.

This forward movement must take place all round the fortress, so as not to disclose the front of attack, and also so as to facilitate the investment of the fortress and to strengthen it. The whole movement must also be carried out at the same time to make it more difficult for the defender to resist in his advanced positions. This advance of the Infantry will generally take place at dawn, in order to enable the troops to find their positions, unless it involves the occupation of points very much exposed to the fire of the fortress, from which fire the Infantry must first obtain cover by intrenching.

It will not always be possible to occupy the line of investment without a serious engagement. The defender's Infantry, collected on the flanks in small groups and deep formations, in positions well commanded by his Artillery, will watch the investment line with a view to making it more difficult for the besieger to establish himself there. The besieger will only in exceptional cases have to deal with the defender's intrenchments in these positions; as, for instance, when the fortress has an exceptionally strong Infantry garrison. But, even then, the defender will be very cautious about using intrenchments here, because they are very easily surrounded, difficult to defend, and may perhaps later on become prejudicial to the offensive action of the defence.

This new position of the Infantry, which may be called the investment line (*Einschliessungsstellung*), to distinguish it from the blockading position (*Abschliessungsstellung*), will be decided on by the lie of the ground and the position of the advanced Infantry posts of the defence. It will be from about 2,000 to 3,000 metres from the fortress. Patrols and outposts will be pushed forward from it 500 metres towards the position of the defence.

The besieger will fortify the investment position as much as possible, and, above all, throw up emplacements for field guns to sweep the ground where sorties are possible. The field Artillery will answer best for sweeping the ground beyond the effective range of Infantry fire from the fortress.

When the taking up of the investment line, previously well reconnoitred from the blockade position, has been successfully accomplished at dawn, the construction of the batteries can, if the preparations have been sufficient, be commenced the following night.

The material for building the batteries is prepared at different points in the blockade position, about 2,000 metres behind the positions they are to occupy. The decentralised Artillery parks and the bomb-proof magazines are probably about 2,000 metres behind the blockade position.* If the ground is favourable for the construction of the batteries, the preliminary ones can open fire on the morning after the taking up of the investment line. On the other hand, if the ground is unfavourable, the Infantry must hold out for two or three days before they can be supported by the besieger's Artillery.

The preliminary batteries will extend round a third, or perhaps a half, of the fortress, in order that the direction of attack may be concealed, and the safety of the close attack secured against enfilade fire and flank attacks. They must breach the advanced positions of the defence, demoralise their garrisons, and keep down the Artillery fire of the forts during and after the storming of the advanced positions.

The direct support of the Infantry, during the storming of the advanced position of the defence, is the task of the field Artillery, which can also, under favourable conditions, undertake the breaking of the advanced positions of the defence. When, however, substantial buildings and earthworks have to be taken, the preparations for storming the work, if they are to be made quickly, require Siege Artillery.

The most important work of the Siege Artillery is to keep down the Artillery of the defence which can be approached to within a distance of 3,000–4,000 metres, and, in favourable cases, of 2,500 metres; but then the attacking batteries are much exposed to the offensive action of the defence. The Artillery of the defence is covered from fire from the flank up to an angle of descent of 20°, and only offers a small mark to frontal fire. The Artillery engagement will therefore partake more of the character of a bombardment.

Under these circumstances, there is a temptation to lay out the batteries so as to be as much hidden by the undulations of the ground as the elevation with which the guns are to fire will allow. But the advantage of safety against the fire of the enemy, which is obtained by so placing the batteries, seems to be outweighed by the disadvantages of such positions for the direction of the fire. Effect is more important than cover. The former is impossible without good observation and direction of the fire. Therefore each battery must be

* This seems very far to the rear.—*Trans.*

so planned that there is a direct view of the target from it, and that its fire may be directed by word of command. To place batteries in depressions, directing their fire by means of speaking apparatus, is at best an uncertain method. If the signalling arrangements are rendered useless at critical moments by the enemy's fire, the whole action of the battery is endangered.*

Dispersing the batteries within the groups, and arranging small groups of not more than four batteries, seems a better way of diminishing the effect of the enemy's fire, than to retire the batteries behind covering ridges.

An endeavour should be made to place the batteries, when the ground allows it, in front of the intervals between the forts.

The sketch shows how advantageously batteries in front of the intervals are placed for bombarding forts of modern construction.

Generally speaking, eight batteries of four guns each must be allowed for a fort; and pieces for curved fire, which have an angle of descent of 20 degrees or more, at 3,000 metres must be chosen, on account of the protection given to the artillery of defence.

If the besieger has a hundred rounds per gun to expend daily, three batteries will suffice against the largest fort armed with as many as 100 guns, because the guns of the attacking batteries are better covered than those of the fortress, the effect of the enemy's fire can be weakened by dispersing the batteries in the groups, and the batteries of the attack can be arranged to give enveloping fire.

The duties of the attacking Artillery are more difficult if the defence has turrets or armoured emplacements. With armoured emplacements, heavy guns of precision, in small batteries, must accomplish the task by firing at the fort from two directions; but, in the case of turrets, the foundations and revolving arrangements must be destroyed by means of indirect fire from a distance.

Whilst the fire of four or five forts, occupying a considerable arc and mounting 160 to 200 heavy howitzers, mortars, and guns of precision, is being kept under, and the attack on the defender's advanced position is being prepared, it is advisable after the opening of fire to retire the investment line somewhat before the fronts not to be attacked, so as not to expose the troops to unnecessary losses. The pickets will be established in the investment line itself, with their posts and patrols sufficiently to the front; the supports of the outposts must, however, take up a position 500 metres or more further back. Finally, the field Artillery will

* This paragraph is directly opposed to the principles laid down in Part II. *Milit. Engineering*. The practical German view of 'covered batteries' is worth consideration.—*Trans.*

construct batteries at a distance of about 2,500 metres, to bombard, from positions beyond the range of the shrapnel fire of the fortress, those forts not attacked by the Siege Artillery, as soon as the disarmament and transport of the pieces to the front attacked commences.

It is in this period that the opportunity of the defenders appears to lie. If they succeed in hindering the construction of batteries at several points by Artillery fire and sorties, they will gain more time than by postponing the decisive point of the operations to the close attack and the defence of the breach, at a period when most of their Artillery will have been disabled.

(*b*) *Examples.*—The following examples show that the operations preceding attack may vary greatly. At Danzig, the besieger was unable to occupy the investment line until fourteen days after his appearance before the fortress, and then only after serious fighting, without, however, making use of Siege Artillery. If the defenders had not held the whole extent of the country round the fortress, but had established works to the east of Neufähr and had restricted themselves to warding off attacks and hindering the construction of works within the lines of defence, the besiegers would still have required a considerable time, together with reinforcements and the assistance of Artillery, to enable them to occupy the positions of attack. The besiegers began to construct a parallel on the heights north-west of the fortress, after having been for six days in possession of the villages which the defenders had occupied in front of the fortress, beyond the range of their Artillery. Eleven days later, the redoubts thrown up in the captured first line of defence were armed with heavy field pieces, intended to batter the walls and to annoy the town and the shipping in the Vistula. The *matériel* for the Artillery attack was then brought up, and twelve days later, during which time the approaches had advanced about 300 metres towards the fortress, fire was opened with the Siege Artillery.

Supposing here that, instead of the works commenced at too late a period on the heights of the attack, systematically constructed defences like those shown in Plate 1 (Part I.) under the name of 'Bousmard' defences, had been planned on the whole of the front, the besieger would scarcely have been able thus to push forward the works of attack without Artillery support. As these defences were only built during the attack, they proved useless, and could not prevent the besieger from gaining 500 metres of ground in ten days without Artillery support.

The positions for the bombardment of Belfort were occupied twenty days after the besieger's appearance before the fortress, and four days after the arrival of the first instalment of the siege park. Only in the north and west of the fortress was this occupation effected without difficulty within seven days. Five days later, fire was opened. The guns of the fortress fired on the positions occupied by the besieger, without causing any considerable loss to the garrisons, or to their advanced and intrenched outposts.

The establishment of the park only began three days after the preliminary fighting, but the construction of the batteries was begun three days after the occupation of the last points required for the attacking position, and was completed in one night. The advanced parties of the covering troops were from 700 to 900 metres in front of the battery sites.

An introduction to the attack with very weak forces, such as succeeded at Belfort, is only possible against a fortress occupied by troops as unprepared, badly armed, and untrained as they were in this case. Fort Bellevue, an unfinished earthen redoubt, distant about 1,500 metres from the battery sites, was only armed with two siege guns; Fort 'des Barres,' distant 1,900 metres from the position of attack, had a bad view, owing to the salient spur of the 'Hauteur du Mont.' The distant Artillery fire on the field of attack came from the Château, 3,000 metres distant, and, moreover, the Infantry was concentrated in two groups in shallow formations, pushed forward as far as and even beyond the first position of attack, so that on the besieger's attack they could not be supported by the Artillery of the fortress.

The conditions were but little better on the 'Perches' front. Nevertheless, the slightly better arrangement of the guns obliged the besieger to have recourse to another method of procedure. The advanced parties of the troops in the investing position were forced to keep 1,800 metres away from the fort. Twenty-five days elapsed before the occupation of the village of Danjoutin, between 300 and 600 metres from the positions of the most important batteries. If the Infantry of the defence had been distributed more deeply, if their morale had been kept up by daily reliefs, and if patrolling had been diligently carried on at night, a sudden attack on Danjoutin would hardly have succeeded.

Danjoutin was an exceptionally favourable base for offensive action against the batteries numbered 15 to 18 in Castentolz's work. This village could have afforded peculiarly effectual support to a sortie on the right bank of the river, directed against battery groups 21 to 25.

At the siege of Soissons, on the 9th October—the day on which the last instalment of the siege train arrived—the besieger's line of outposts was pushed to the front, without any fighting, to within 750 metres of the glacis of the fortress, after weak sorties of the garrison had been driven back on previous days. Two days later, the building of the batteries on a front of 6,000 metres, at a distance of from 1,130 to 2,330 metres from the place, was effected in one night.

At Sebastopol, the positions of attack fell into the hands of the besiegers without fighting. The attack, extending over about 6,000 paces, was opened with the construction of a parallel; in spite of this, the direction of attack was insufficiently concealed. In the parallel, batteries in three groups were thrown up in from two to six days. The work was carried on by day with weak parties and without excessive loss.

The position of attack was from 950 to 1,200 metres distant from the ramparts of the fortress. The positions of the batteries in the parallels, especially on the French left flank, were disadvantageously crowded together. Moreover, these positions did not sufficiently conform to the trace of the lines of defence, nor were they adapted for bringing an enfilade fire to bear on the lines. The French batteries, which were obliged to carry on an Artillery engagement on a front of 950 metres, were, for the reasons given, easily silenced on the day of opening fire. These five batteries had two guns dismounted and two carriages disabled in a few hours.

In the southern attack on Paris, the first Artillery position had ultimately a front of about 8,000 metres, and was developed out of posts which had already been occupied for some time. The battery sites were distant from 1,800 to 2,600 metres from the forts. Later on, two more batteries were added on the right flank against Fort Bicètre and against the advanced defensive positions, thus increasing the extent of front to about 12,000 metres. In this case, it was not the concealment of the direction of the attack, but rather its protection against the advanced Infantry positions of Cachon Redoubt and Hautes Bruyères on the right flank, and against the neighbouring fort, that imperatively demanded an extension of front.

Five batteries were constructed against one of the forts attacked. The number and nature of guns here employed is no guide for the future, because new forts provide more cover.

V.—The Bombardment and the Capture of the Advanced Infantry Positions.

(*a*) *Conduct of the Operations.*—The object of the bombardment is to prepare the way for the capture of the advanced Infantry positions.

The bombardment will commence simultaneously from all the batteries. A plentiful supply of ammunition—at least 100 rounds per gun per diem—will be necessary so as to obviate the possibility of an interruption of fire.

The field Artillery will also be able to take part in the bombardment of the forts, first of all at considerable distances; but later on, when the fire of the forts is somewhat silenced, at short distances and at shrapnel ranges. It would be rash to attempt to lay down the course of a siege from the moment of the bombardment.

The character of the commanders of both parties, the quality of the troops, any successful offensive action on the part of the defender, and the caprices of fortune, will vary greatly the progress of the attack.

An energetic and well-prepared defender will place his general reserve of movable guns, and also his field batteries, into emplacements thrown up between the forts. He will combine the fire of the forts and of the mobile batteries, so that every group of the enemy's batteries receives fire from three or more directions. The Infantry of the defence in the advanced forts will attempt to fire on the posts of observation of the Artillery of the attack, and, if possible, also on the siege batteries.

Light mortars will take part in the fight from the interior of suitable advanced Infantry positions. When a sortie is to be undertaken with a view to destroy the batteries, it must be attempted energetically, and with all available forces.

The advantages of an enveloping position, and of greater frontal development for his Artillery, remain, however, to the defender. He will bombard the fort from several directions, from groups of batteries not too close to one another, and he will employ single guns in the advanced infantry positions for breaching. The field Artillery will be engaged wherever its employment promises a successful result. Besides the direct observation of the fire from each battery, a central observing station for each group will have to be established in the outpost line, so that the fire of the batteries may be directed from a point nearer the place.

Such direction of the fire necessitates telegraphic communication between the groups and the central observing stations.

After the bombardment, this method of directing the fire will be discontinued, and the fire controlled only from the batteries. Against good fortress Artillery, the besieger will very frequently, where the ground is commanded, have to proceed by saps against the advanced Infantry positions.

If the Artillery of the forts is kept sufficiently engaged, if breaches are made in the advanced Infantry positions; then the field Artillery will be brought up, and the attack undertaken simultaneously on all the defensive posts, during which the forts should be heavily bombarded. Attacks on fortified points no longer secure from assault have been in practice successfully undertaken at all times of the day, when the attacker was so near the object as to make surprise possible. For the attack on the advanced Infantry positions, the day is generally to be recommended, because it is easier by day to reconnoitre and to direct the attack in columns and to support them by Artillery. It must also not be overlooked that the defender will have mounted for night work light pieces at places unknown to the attack, which will sweep the flanks of the Infantry positions.

(*b*) *Examples.*—Sebastopol and Belfort give important lessons with regard to the attack on advanced Infantry positions.

Sebastopol.—On the night of the 23rd February, the French made an attack with five battalions on the unfinished redoubt of Selenginsk which had been constructed in front of the Malakoff towards the end of February, and was situated 900 metres in front of the Artillery line; this attack was repulsed with great loss. A systematic advance, as well as an increase of the batteries against the detached Infantry posts, successively erected here, had to be decided upon. Even the severe bombardment of the 9th April, in which 514 guns with 80–100 rounds per gun, fired at the detached works, failed to drive the defender from these positions.

These redoubts were only taken at 6.30 P.M. on the 6th June, after a day's preparatory bombardment with 604 guns and 150 rounds per gun, and after the approaches had been brought close up to the works.

The churchyard before the west front of Sebastopol, 360 metres from the Artillery line, was also held by the defence up to the 23rd May. It was taken on the night of the 23rd by ten battalions after heavy firing, and after the attack had been prepared by two days' Artillery fire, with an expenditure of 10,000 rounds.

Belfort.—On the 7th January, 1871, six new batteries (9, 15, 16, 17, 18, and 20)* opened fire, the Artillery attack of the Perches front having been commenced on the 18th December, 1870, with one battery (8*a*)*, and reinforced on the 25th December by two batteries (13, 14)*.

It appears doubtful whether such an attack as was carried out at Danjoutin would in all cases be possible against an able and energetic defender.

This attack, which was intended to keep under the Artillery of the fort and prepare the capture of Danjoutin, was a brilliant success.

* The numbers of the batteries are those given in 'The Siege of Belfort in the Year 1870–71,' by A. Castenholz.

Danjoutin was destroyed on the 7th January by a battery (8*a*)* of 80 incendiary and 20 ordinary 12 cm. shells, and by a battery (9)* with 80 27 cm. shells. One battery (18)* at a range of 600 metres directed one 12 cm. gun by day and four by night against this village. This bombardment, however, did not contribute to the capture of Danjoutin. Unfortunately, no mention is made in the works of either Thiers or Laurencie of the losses incurred by the garrison of about 800 men. That this village was taken suddenly by a night surprise was due not only to the want of vigilance of the garrison, but also to the defective dispositions for the support of this important post, and for the maintenance of its communications with the fortress.

With a proper distribution of the Infantry garrison, having regard to support from the rear, as at Sebastopol, Danjoutin would have undoubtedly made a better resistance.

VI.—The Engineer Attack and its Preparation by the Artillery.

(*a*) *Conduct of the Operations.*—After the loss of the advanced Infantry posts, the defender will still be in doubt as to the direction of the attack, since the latter has been commenced on a front of 12 to 20 kilometres, and so has a wide field of possible action.

The repulsed Infantry of the defence will only in very rare cases, and under favourable conditions of ground, be able to intrench itself again in front of the forts; generally, it will be driven back as far as the covered way and the interval between the forts, because the ground near the forts will not afford it a covered position. The fortress Artillery will still remain in action—mortars in the forts and heavy Artillery in rear.

Under these conditions, the close attack will commence at a distance of 1,000 metres from the captured positions.

It does not appear possible to carry out the close attack without powerful Artillery support, for as soon as a parallel is constructed against the special object of attack, the defenders will immediately make use of all available means behind the front, so as to be able to bring a powerful and uninterrupted fire to bear on the confined area of the close attack, and, moreover, they will make sallies under cover of this fire.

The siege Artillery must, therefore, approach as near as possible, so as to completely silence the fire of the special objective, and also to command all the rear positions of the defence bearing on the close

* The numbers of the batteries are those given in 'The Siege of Belfort in the Year 1870–71,' by A. Castenholz.

attack. The Engineer will thus be able to commence his works as near as possible to the place, and so shorten the operations.

The captured Infantry positions, fortified, strongly garrisoned, and supported by the bombarding batteries in rear, will sufficiently cover the construction of batteries at decisive distances of from 1,200 to 2,000 metres. This assumes that strong reserves are held in readiness on the flanks of the groups of the second Artillery position, ready to advance against any offensive movement of the defence.

The further functions of the Artillery against the special objective are as follows:

1. The silencing of any of the defender's Artillery that can open fire from between or behind the forts against the Engineer attack.

2. Breaching.

3. The destruction of the ditch flanking defences.

4. The annihilation of the Infantry posts which may have been established in block-houses in the covered way, or between the forts.

5. The destruction of the communications in the fort, so as to make their defence against the storming party more difficult.

It appears superfluous to make action against the communications of the forts to the rear a special task of the siege Artillery. The long-range guns will cross their fire behind the fort and on its communications to the rear, in such a manner that to detail special guns for this work would be unnecessary. Moreover, it appears to be a waste of ammunition to fire on concealed roads.

Where the roads are visible, it will be the duty of the light overbank field pieces to fire on them as soon as there is something to fire at. Unseen roads will only be fired on when, during an action, movements of troops are supposed to be taking place along them.

The destruction of food and provision stores can be made a special task, when their positions are known to the attack. The attack must endeavour, when constructing the second batteries, to gain a superiority in number of pieces.

The batteries of the second position must, if possible, be placed in front of the intervals of the first position, so as not to hinder the latter in bombarding the forts, for the fire of the first batteries must continue uninterruptedly until the second position has commenced firing with good effect.

When this has been done, the first Artillery position will be moved forward in the direction of attack so as to be able to engage with more effect the batteries behind the forts.

Taking into consideration the construction of the forts, the destruction of the Artillery defence will be the work of mortars and howitzers of medium and light calibres. A battery of light guns of precision should be charged with the work of silencing any guns that may be temporarily mounted to oppose the Engineer attack.

For breaching the main walls and for destroying the ditch flanking defence, heavy and medium howitzers must be employed. Possibly, mortar fire can be advantageously brought to bear on revetment walls, so that the walls on which masses of earth are exerting a great pressure may be brought down by means of projectiles striking in front and behind the cordon.

The demolition of block-houses on the covered way should be effected by howitzers of medium calibre.

Finally, for destroying the communications in the fort, high-angle fire is required. For this purpose the mortar batteries of the first Artillery position should be brought forward.

The sketch (Plate 3) shows the grouping of the batteries, and the nature and calibre of the pieces for a typical attack.

In future about 90 pieces in 15 batteries must be allowed for each fort attacked, including the batteries on the flanks and those thrown up in rear of the intervals between the forts.

These 15 batteries for action against the special objective must be thrown up, armed, and furnished with ammunition in one night. To secure these batteries against sorties, obstacles must be placed in front of them, and the front trenches between the batteries so arranged that they can be occupied by a portion of the covering troops moving up from the rear; whilst positions must be found for the main body of these troops on the flanks.

These measures would secure the safety of the batteries, which would also be under the protection of the captured positions of the defence, 200 to 500 metres to the front. The engineer attack will only be commenced some days after the opening of fire from the second Artillery position.

The preparations for it, however, will have been going on since the opening of fire from the first Artillery position, and as soon as the direction of attack has been decided on.

The depôts for the preparation of the brushwood material, and for the tools, will be placed under cover and at different points, as near as possible to the attack so as to economise transport.

The equipment of the parks with tools can be calculated by assuming that for attacking a fort of from 200 to 300 metres of front, an Engineer attack on a front of from 1,500 to 2,000 metres will be required. Greater extent and connecting parallels seem to be unnecessary for a simultaneous attack on several forts.

The object of the Engineer attack is to enable the storming columns to assemble under cover in the approaches and parallels, and penetrate to the objective.

The extent of the parallel as given above seems sufficient to enable the necessary troops for storming to assemble in the first and second parallels. According to this estimate, 2,000 spades and 1,800 picks will be sufficient, while sappers and miners' tools will be required for the advance on three lines. To these must be added the tools for such number of workmen, principally carpenters, as are needed for the construction of bomb-proof cover. Tools for preparing brushwood will be obtainable in sufficient numbers from the troops. The telegraph detachments and their *matériel* are not included here, as these are required, not for the Engineer attack alone, but also in connection with the administration of the troops, and with the battery groups; they should, therefore, be directly under the commander-in-chief, and must come up quite at the commencement of the siege, before the arrival of the siege train.

Finally, for each fort to be attacked, three fortress Pioneer companies will be required, so as to make it possible to proceed simultaneously against the objective on three lines. Every endeavour must be made to commence the engineer attack as near the fort as possible. The points of departure for the attack will be the captured advanced position of the defence. From them, on the opening of fire of the second Artillery position, the outposts will be pushed considerably to the front to intrench themselves. It will depend on the ground, and on the energy of the defence, whether it is possible to advance from 200 to 300 metres, or more. It will perhaps be possible, in special cases, to push forward the posts to within 500 metres of the front. On the following nights, with the aid of such a number of workmen as the fire of the fortress allows, the trenches of the advanced posts will be widened and ultimately joined up, to form a continuous parallel, which will be thrown up at night by the Infantry, under the direction of the Engineers, and will be provided with communications to the rear.

This parallel should be continuous only in front of the fort attacked. If two adjacent forts are attacked, it appears useless to connect the approaches.

It is of more importance that the flanks of these attacks be protected against sorties by small works and field-guns posted in rear.

From the parallel, the Engineers will proceed against their objective, with three sap-heads, and they will construct a second parallel at a distance of 250 to 300 metres from the fort. In addition to the

Artillery, well-aimed Infantry fire from the first parallel should support these works. For this also, in the further approach, several short returns must be made at a distance from the fort of 450 metres. By day the fire of marksmen will cover the works. At night, on the other hand, they must be pushed to the front beyond the heads of the approaches. On the completion of the second parallel, which will have to be constructed with gabions, and, in the case of an energetic defence, by flying trenchwork from the approaches, the Riflemen will be posted in it to keep down the fire of the fort.

On account of the precision of modern guns, the use of light portable mortars in the parallels appears to be unnecessary and impracticable. The work of such mortars can be more conveniently done from the second Artillery position, and with shrapnel fire.

The saps to be executed from the second parallel will end with the crowning of the glacis, if the besieger has not previously been obliged to resort to mining.

If there are block-houses in the covered way, the construction of a third parallel will be necessary.

In mining, the attacker must endeavour to make large craters, which can be employed for the continuation of the approaches.

In effecting the descent into the ditch, mines are necessary for blowing in the counterscarp.

Covering walls against the caponiers must further be provided for the passage of the ditch ; for although these may have been partially destroyed, they may still perhaps be occupied by Infantry. Whether the passage is to be effected by a bridge, or by a covered way, depends on the nature of the ditch, and the power of the fort to continue firing, for it will still be able to bring light mortars into action.

On account of the tediousness of the underground Engineer attack, it is a question whether an attempt cannot be made, where the ditch is not wide, to take the forts by surprise by bridging the ditch from the crowning.

On a stormy night, bridging on to the caponiers does not appear impossible. If the passage of the Infantry to the dead angle on the berm is successful, the tedious underground work can be considerably curtailed. But it must not be forgotten, in carrying out such an operation, that the defenders will certainly have provided good obstacles at the dead angles, and will, by the exercise of a certain amount of vigilance, be on the spot to hinder such a passage of the ditch. Doubts have often arisen as to whether it is possible, where cover is good, to form a breach or destroy caponiers by indirect fire. It is true that the siege of Strasbourg showed that the formation of a breach is possible in badly-covered masonry, but no example can be given of the formation of a breach in well-covered escarps. The Engineers must, therefore, be prepared to make a breach by mining.

The necessity may also arise for breaching the caponiers by mines, since a covering wall will not be sufficient protection for the passage of the ditch against intact caponiers, because the defence could destroy it by Artillery fire. Such a covering wall can only serve as a protection against Infantry fire.

(*b*) *Examples.*—At Danzig, the besiegers commenced the Engineer attack, without Artillery support, at a distance of from 700 to 800 metres (*cf.* Part 1, Fig. 1).

The Siege Artillery only opened fire when the trenches had approached to within 300 metres of the fortress. Notwithstanding the superiority of the besiegers' fire, it was still possible for the defenders, after they had given up the fight with the siege batteries, to maintain a fire against the heads of the enemy's saps, because the attack had too few batteries for high-angle fire.

While the Engineers had in the first twenty-three days advanced their trenches 500 metres without Artillery support, they carried on their approach after the opening of fire a further 150 metres in four days, that is to say, at about twice the previous daily rate. In the latter period, however, the besiegers came within effective Infantry range, and on ground sloping towards the works of the fortress.

Nineteen days were required by the defence to advance 100 metres further to the front and to reach the crowning of the glacis. A trench-cavalier had to be constructed for the Riflemen—an operation which now-a-days would be necessary, wherever the forts are withdrawn behind the brows of heights, and where the glacis extends to the effective range of Infantry fire (250 metres), and falls gently towards the counterscarp. At any rate, the counter-mining operations, which were commenced by the defence on the 12th May, considerably delayed the progress of the attack at this stage.

Finally, it is generally admitted that the descent to the ditch was rendered much more difficult by the block-house in the covered way. After the burning down of this block-house, mining and Artillery fire having been employed in vain for its demolition, it still required about two days to complete the preparations for the assault.

At Sebastopol, the besieger had betrayed, by the manner in which he began his attack, the direction in which it was intended to proceed. Serious progress, in the central portion of the attack, between the harbour and the Woronzow ravines, was out of the question, because the line of the Engineer advance would have been up the ravines leading to the fortress, and could have been taken in flank by works commanding it by 60 to 70 metres.

The Engineer attack on the right flank between the dockyard and Woronzow ravines was stopped in its advance by the Malakoff commanding it, and was thus aimless. There, therefore, remained only one really possible course, viz., an advance against the Flagstaff battery on the left—that is to say, on the French flank. Here the approaches could be brought close up to the object of attack without being taken in flank.

The course of the Engineer attack shows the correctness of this appreciation of the conditions; for at the commencement there are no grounds for attributing to other reasons—such as to less energy and activity—the smaller success of the English.

The French left wing gained 740 metres of ground in twenty-two days, notwithstanding the weak, ineffective fire of the Siege Artillery. The approaches advanced to within 210 metres of the fortress. Under cover of this advance, the French brought up light Artillery, and armed the old batteries in rear with heavy guns and mortars.

Though the English, who opened the attack on No. 3 Bastion (the Redan), at a distance of about 1,200 metres, gained at first 400 metres of ground in eleven days, and pushed forward their batteries; they could, nevertheless, in the following thirty-one days only advance 300 metres. At this point, 600 metres distant from Bastion No. 3, the English attack remained inactive.

The French advanced in twenty-two days within 210 metres of their objective: after forty-four days the English were still 600 metres distant, notwithstanding that the English Artillery had produced more effect. The difference in the rate of progress of the Engineer attack seems to be due to the method of execution. The English right wing was insufficiently supported by the Siege Artillery, which should have extended its front so that no unreturned fire could have been brought to bear on the flanks of the English attack.

An Engineer attack between the Woronzow and harbour ravines seems to have been superfluous. The sapping work could have been saved here by placing Infantry in the ravines and by sweeping the plateaus with Infantry fire.

Also, when the besiegers determined to proceed against the Malakoff, their attack was so commenced that its object must have been immediately apparent. Similarly, the Artillery support to the Engineer attack, which at first had to be directed against the advanced Infantry positions, was very defective. The Engineers had to work from the 12th March to the 7th June to advance 700 metres, because the

Infantry and Artillery of the defence had learnt, during the siege, to support each other's fire in the sorties, and because the attack always suffered from want of ammunition and troops.

The close Engineer attack from the captured positions of defence, which was similarly commenced with insufficient Artillery support, came to a standstill when it had approached to within 180 metres of the Malakoff. Works, carried out with difficulty at night, were destroyed in the daytime by the Artillery of the fortress. It was only under cover of a general bombardment from all the guns that it became possible to approach within 40 metres of the Malakoff, and even then flying saps had to be employed.

The difficulties which may be occasioned to the besieger by mine warfare are exemplified in the attack against the Flagstaff battery, which, in spite of the quick progress made at the commencement, had to be relinquished owing to the defenders' well-arranged system of counter-mines. The soil, consisting of alternate layers of chalk and clay, had induced the besieger to carry on his system of mines in the first layer of clay, whilst the defenders had laid their countermines in the stratum of clay under the second layer of chalk. The Russians here blew up whole French batteries which had been established in the craters thrown up by the defence.

At Belfort, the opening of the Engineer attack followed the capture of the advanced Infantry positions on the 21st January. A greater development of Artillery for covering the attack was unnecessary in the presence of the badly-armed Perches fort: on the other hand, it was found advisable to proceed against the Château and the town with four new batteries on the left wing of the attack.

The parallel was 3,328 metres long and required $4\frac{3}{4}$ battalions for its construction, while two battalions covered the work. In one night, between 7 o'clock in the evening and 5 o'clock in the morning, the necessary cover was thrown up to enable three battalions (2,400 men) to continue during the day to deepen the parallel to 1·5 metres.

The following day also, one to two battalions and one to two Pioneer companies, worked at the completion of the parallel, to cover which, in addition to two battalions of guards of the trenches, a battalion of Infantry was stationed in Danjoutin, Péroun, and in the Taillis wood.

Under cover of the fire of the besieging batteries, which had to be further supplemented, the Engineers advanced 300 metres in nine days, and in nine days more had nearly reached the glacis of the fort. To enable this progress to be made, the guards of the trenches had to engage the forts and the troops in their neighbourhood vigorously.

It is a question whether it would not have been better to have sapped separately against each fort than to construct a continuous parallel against the whole front. But then a powerful preparation and Artillery support would have been the more necessary.

At Paris, a parallel was thrown up by degrees, under cover of a heavy bombardment, between the railway station of Meudon and the village of Chatillon, at a distance of from 900 to 1,000 metres from the forts. It was provided with a banquette, with several gaps for sorties, and bomb-proof cover for the guard of the trenches.

If a large number of batteries had been constructed here under cover of the occupied points of the redoubt of Notre Dame de Chamart and the village of Chatillon, and if the outposts had been pushed to the front after the batteries had opened fire, it might have been possible to gain a position from 200 to 300 metres nearer to the forts to be attacked, and thus to have effected considerable saving of work and time in the close attack.

VII.—The Assault.

Against works secure from assault, occupied by a vigilant defender, storming is impossible.

It is impossible to cross, with sufficiently large bodies of troops, ditches 6 to 8 metres deep, 12 to 14 metres broad, and swept by Artillery and Infantry fire. Even with the possibility of bridging over the ditch, so as to get troops to the berm in the dead angle, it must be acknowledged that it will be impossible for them to cross on a small front in face of the volleys of even weak Infantry. It must also be taken into consideration that the dead angles will be protected by obstacles. Storming seems only to offer a chance of success against works which are no longer secure from assault; but even then it is a necessary condition that the attack must be so near to the object as to be able to surprise the defence. On account of the necessity of a surprise, it seems requisite to leave to the commander of the garrison of the trenches to determine when and where the storming is to be effected. He alone will be able to correctly judge the moment and to lead the storming parties. He should be in telegraphic communication with the batteries, and with the commander of the besieging force, so as to be able to inform them of his determination to storm, and in order that the fire may be stopped and reserves immediately despatched.

The time of day chosen for an assault seems to be immaterial, if only the element of surprise is secured.

In practice, storming has been successfully carried out at all times of the day if the moment of surprise has been seized.

The great unsuccessful assault on Sebastopol on the 18th June, 1855, is the best proof that, even against works not secure from assault, storming must fail when undertaken from positions so far distant as to make the surprise of the enemy impossible. At the time of this assault the approaches had been advanced to within the following distances from the works of the fortress:—

Against Bastion II.	1,000	metres.
,, the Malakoff	480	,,
,, Bastion III.	240	,,
,, the Mast Bastion (IV.)	60	,,
,, the Central Bastion (V.)	90	,,

The place was to be stormed at daybreak after a bombardment of 24 hours.

609 guns, with a supply of from 100 to 150 rounds, opened fire at 4 o'clock on the 17th June. At 8 o'clock in the evening it was thought that the Artillery of the defence had been overpowered, and, when darkness fell, the Artillery fired at its former rate at greater ranges, so as to search the communications and the interior of the works.

At the assault on the morning of the 18th June, eight French divisions of 5,000–7,000 men and four English columns, each of 1,200 men, were prepared. These, on a signal being made, were to advance against the whole front in nine columns.

The premature advance of the right flank column is said to have caused the failure of the assault.

It appears, however, that this failure was due rather to the impossibility of a surprise, for the right flank column had to cover more than 1,000 metres of ground before reaching the object of attack.

Some of the attacking columns closer to the place succeeded in penetrating into the works, but were repulsed by the musketry fire and counter-attacks of the Russians.

The second and successful assault of Sebastopol was preceded by a bombardment of 21 days. In the last three days of this bombardment, from 700 to 800 guns are said to have been in action, firing against the works of the fortress at varying rates and with irregular pauses.

The trenches had been advanced to within the following distances of the works:—

Against Bastion II	. . . . .	100 metres.
,, the Malakoff	. . . .	36 ,,
,, Bastion III.	. . . .	135 ,,
,, ,, IV.	. . . .	60 ,,
,, ,, V.	. . . .	90 ,,

The assault took place at noon, and was directed in three columns, principally against the Malakoff and Bastion II.

The troops, which stood ready opposite the remaining fronts, were only to advance after the success of the principal attack. The storming of the Malakoff, for which bridging over the ditch was employed, succeeded, but not the attacks on the other fronts, for the Russians fired grape and advanced their reserves at the right moment. It almost seems as if the repulse of the remaining storming columns aided in the capture of the Malakoff; for, on account of the retreat of these columns, a portion of the siege batteries were enabled to recommence firing, and support the flanks as well as the front of the captured Malakoff.

If the two assaults are compared with one another, it will be seen that the successful one is distinguished by better preparation, and by a successful concentration of force on the object of attack.

A limitation of the front of assault, the occupation of all the ground in front of the fortress, and flank support by means of Artillery fire, can alone ensure the moment for surprise being turned to account.

The experience gained at the storming of the fortress of Kars on the night of the 17th November, 1877, seems to contradict the above view, for here the Russians, attacking from some distance, captured the forts on the east bank and the town, from an enemy of equal strength. But it must be remembered that Kars was hardly worthy of the name of a fortress.

The fact that as early as the 4th November, the retreat of the Turkish sortie gave two Russian battalions in pursuit the opportunity of penetrating in broad daylight into Fort Hafis, at a time when no siege batteries were in action, is sufficiently characteristic of the condition of Kars to justify the above assertion.

From the account of the assault (Sarauw, page 204 *et seq.*) it is further evident that these conditions cannot possibly recur in the case of modern fortresses if prepared and vigilantly defended.

This applies even more in the case of Ardahan, where, besides want of matériel, a want of system was apparent in the design of the forts which was eminently disadvantageous to the tactical conditions of the defence.

VIII.—Conclusion.

When the besieger has taken an important point, and established himself in it, the attack will be continued in such a manner that every operation is preceded by a thorough preparation by Siege Artillery.

Whether works lying on the flanks must be taken before the supply centre (*Vorrathscentrum*) of the fortress is proceeded against, will depend entirely on tactical considerations.

The bearing of the defenders will decide whether an abridged form of attack can be resorted to.

For the Artillery of the attack, only one task is of paramount importance: viz., the destruction of the matériel of the defence. For this work special batteries must be detached to fire at any magazines which are visible, or the positions of which are known.

The quick execution of this task will prove itself especially useful against a stubborn defence. It now remains, in conclusion, only to recapitulate shortly the stages of a regular attack, graphically shown on sketch No 5.

1. The advance of the besieger takes place on a broad front to within one day's march of the fortress. There the besieger, gaining touch of the fortress, but remaining at a distance of half a day's march, concentrates towards the flanks in two masses, completes the necessary passage of the rivers, and proceeds, if possible simultaneously, to the investment by deploying from these two masses, while the corps covering the siege advances sufficiently to the front.

2. The restoration of the broken line of communication, the reconnaissance of the fortress, the determination of the plan of attack, and the preparation for attack are carried on under cover of the blockade position at a distance of 4,500 to 5,000 metres from the fortress.

3. On the completion of the preparation for attack, the Infantry will be pushed forward as near as possible to the fortress, and the preliminary batteries will be built on such an arc as to secure concealment of the direction of attack, and provide for its safety against fire from the flanks and sorties.

4. During the bombardment by the preliminary batteries the Infantry of the defence occupying the foreground is forced back on such an arc as to ensure the concealment of the direction of attack.

5. Under cover of the captured Infantry positions, the besieging Artillery is pushed to the front so as to completely silence the fire of the forts as well as the fire from defensive positions in their rear and on their flanks, and for breaching.

6. After the silencing of the guns bearing on the direction of attack,

the first parallel is opened at a distance of about 700 metres, with a view to secure further positions and approaches for the columns of assault.

7. When the objective has been sufficiently approached, when its fire is silenced, and when there is a possibility of forcing an entry, the assault, based on surprise, is undertaken.

These principles are of course only applicable in the case of an energetic defence. They will be considerably modified in practice. For this reason, in the attack of a fortress, the method of defence and the character of the defenders are the principal factors which govern the decisions and the actions of the besiegers.

M. N.

London,
September, 1884.

Plate

STUDIES IN FORTRESS WARFARE, PART II. THE ATTACK.

PAPER IV.

FREQUENT REPETITIONS OF LOAD.

By Alexander B. W. Kennedy, M. Inst. C.E., Prof. of Engineering and Mechanical Technology in University College, London.

In the two lectures which I have been asked to give you on this subject, I propose in the first instance to describe to you the principal experiments that have been carried out with a view to the determination of the effect upon a material or structure of the frequent repetitions of load, and then to discuss with you the results which have been, or remain to be, deduced from these experiments.

Before considering in the present lecture our subject under the first of these heads or divisions, it is important that we should clear the ground by examining what we mean when we speak of *the strength of a material*, and how materials in general behave when subjected to any load. The phrase 'the strength of a material,' is used in several senses:

First, by the strength of a material, we may mean the ordinary or static breaking load, such as is found by an experiment in a testing machine. The load is gradually applied, increasing quietly and continuously from zero to a maximum, and with a given material only the magnitude of the final load here comes into consideration as a measure of strength. This load is the one which in all ordinary experiments is taken to represent the strength of the material.

Secondly, the strength of the material may be measured, not by a load applied once for a few minutes, but by a load continuously applied over a long interval of time. In such a case the resistance of the material may depend not solely upon the magnitude of the load, but also upon the time during which that load acts. It is quite possible for a load, which applied for five minutes will not break a piece of material, to destroy it entirely if it be allowed to act for five months.

Thirdly, a load may be frequently repeated, or, what amounts to the same thing, the amount of load may repeatedly change from a minimum to a maximum. In this case the resistance of a material may be affected not only by the magnitude of the load, or by the length of time over which the load is caused to act, but very greatly by the number of repetitions of load which have occurred in that time.

In all these cases it has been assumed that the load is applied quietly and without shock. If the load be applied with a jar, or shock, or vibration, the result may in any one of them be again very different, the manner of application of the load itself forming in each case an important factor in the 'strength.'

There is therefore no one load, the same in all three cases, which can be said of itself to measure completely the strength of the material. If we are, for instance, dealing with a piece of iron of which the strength is said to be 20 tons per square inch, in order to judge of it we must really know whether this load has been a mere testing machine load, or whether it has been applied continuously for a long time, or whether it has been over and over again repeated, or lastly, whether in either case it has been applied quietly, or with any amount of shock or momentum. A piece of iron, for instance, whose tenacity, measured in the ordinary way, is 22 tons per square inch, would very probably break with 15 tons per square inch if applied a sufficient number of thousands of times.

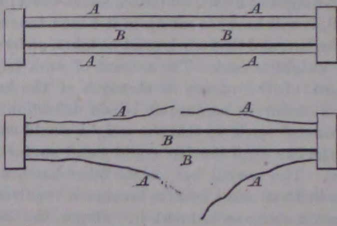
But in addition to the resistance of the material measured as tenacity—so many tons or pounds per square inch—there is another way of looking at the strength of a material, which must be kept distinctly separate in our minds.

Before a material can be broken, not only must a certain load be applied to it, but also a certain amount of *work* must be done on it. This amount of work, which must be measured in foot-pounds (or foot-tons or inch-tons), and not in pounds or tons, of course, depends both on the load and on the extension or deflection. In the case of a piece of material broken in the ordinary way in a testing machine, the amount of work depends entirely on the material itself, and is absolutely determined by it. It is not in our power to increase or decrease it in any way whatever. But it is very easy to arrange the experiment otherwise. Suppose we have two bars lying or resting on similar supports at an equal distance apart, and that one can support a load of six tons in the centre with 1-inch deflection before it breaks, while the other can support a load of three tons with 5-inch deflection. If a load were gradually applied in a testing machine there would be done on the first bar about 3 inch-tons of work, and on the second about $7\frac{1}{2}$ inch-tons of work before it broke, these amounts being exactly those which the material can naturally take up. But suppose the same bars placed under a monkey-weight of 2 cwt. 50 inches above them; if that weight be allowed to fall, it will have stored up in it 5 inch-tons of work by the time it reaches the bar, and that work must be taken up by the bar before it can bring the weight to rest. The amount of work here is therefore quite independent of the nature or strength of the bar. The first bar would break under it, because at 1-inch deflection it could only take up 3 inch-tons of work, so that the weight would continue falling and deflecting the bar until the bar could stand no further deflection without fracture. The second bar, on the other hand, would take up the whole work without being broken, because it requires $7\frac{1}{2}$ inch-tons of work to deflect it so far as to break it. Hence, the second bar will actually present the higher resistance, although in the ordinary sense of the word its strength is much less than that of the first. We shall find presently that this may be a somewhat important matter in connection with our special subject; the point of it lies in this, that when circumstances compel a particular material to take a certain amount of work, instead of exposing it only to a certain definite load or stress, it is not always the strongest material, in the testing-machine sense of the word, that will offer the greatest resistance.

In order to be able to understand the real nature of the effect of long-continued and repeated loads, it is further necessary first to have a clear notion of what happens to a material when it is broken by a single load in a testing machine. Let me remind you of the experiments you saw a few days since at University College upon a piece of soft steel, taken as an example of very ductile and homogeneous material. Extension began at once and was made visible to you even under the very smallest loads; and a particular length of piece was found to balance each particular load, the length increasing as the load increased. For a time these extensions continued so small as to be only visible by special apparatus and measurable in thousandths of an inch, but remained always strictly proportional to the loads causing them.

Then for a time there came a slight increase of strain (or extension) in proportion to stress or load, and a small permanent set made its appearance when the load was removed.

This we may call a second stage in the testing of the material; the first stage being represented by the period during which the material was perfectly elastic and without permanent set, and the strain exactly proportional to the stress. Next, at a very distinctly marked point, a change in the behaviour of the material occurred which might be best described by the expression 'breaking down.' The material behaved much* as if it consisted of two sets of fibres, one much stronger than



the other, of which, when a particular load was reached, the weak fibres AA broke, and the unbroken fibres BB stretched a good deal before the material could again resist the load. Perhaps what happens may be best seen from the following illustrative table :—

Length of specimen. Inches.	Load balanced at that length.
10·000	0
10·003	10,000 lbs. per sq. inch.
10·006	20,000 ,, ,,
10·009	30,000 ,, ,,
10·020	31,000 ,, ,,
11·030	specimen suddenly refused to hold up against 32,000 lbs., but its resistance diminished to about 24,000 lbs. and the length increased to 10·2 inches before the load balanced 32,000 lbs. per sq. inch.

After this the material goes on increasing in length at a much greater rate than that at which the stress increases. The whole phenomena are graphically shown in Fig. 1, Plate I., where a curve is drawn whose vertical scale represents extension, and its horizontal scale stress in pounds per square inch. The upper curve on the left hand side of the figure shows the first small extensions 200 times their full size. At about a stress of 30,000 lbs. per square inch the extensions cease to be uniform, and the permanent set begins to increase. At a stress of about 40,000 lbs. per square inch the breaking down point is reached. After this point extensions cannot be plotted out on the exaggerated scale any longer, they are shown on the right hand side of the diagram in their actual size. The small vertical line at the breaking down point shows the rapid extension which takes place there

* This rough illustration must not be taken as a real physical counterpart of what occurs. The 'break down' and increase of length at this point seems to occur successively at different points, and from point to point along the length of the bar.

and which was illustrated in the table just given. The stress does not in reality remain constant here, but diminishes, so that there is a backward loop in the curve instead of a vertical line, but into this matter I cannot enter here. The particular piece of material whose behaviour is shown in the figure stretched about $2\frac{1}{4}$ inches before it broke, and had a tenacity of about 70,000 lbs. per square inch.

The point which I have called the breaking down point corresponds very nearly to what is usually known as *limit of elasticity*, and we may use that expression for our present purposes without practical error.

It is obvious that in any structure or machine *a load exceeding the limit of elasticity, or breaking down point, cannot even once be applied under any circumstances whatever without destroying the form and usefulness of the structure altogether.* I ask you to notice this point particularly, as its neglect appears to me to have involved a very important and serious fallacy in conclusions drawn from the experiments on repeated loads which I am about to describe to you.

There is a great deal of difference of opinion as to whether it would not on this account be right rather to consider the limit of elasticity than the ordinary breaking load as a measure of the strength of the material, as that limit really does represent the maximum possible load which may come on our structure, without at least temporarily destroying its efficiency. I will not, however, go into this controversy further than to point out that there is an obvious advantage in having as broad a margin as possible between the load which first visibly strains the structure, and therefore calls our attention to its dangerous condition, and the load which breaks or destroys it completely, carrying it at once past all remedy. Therefore not only a high limit, but also a difference as great as possible between the limit and the breaking load, is most desirable in all materials which have to be used for structural purposes.

It has been known for many years, that a load which would only strain a piece of material to an exceedingly small extent if once applied, might eventually break it altogether if the applications were long continued, or repeated with sufficient frequency. This matter formed one of the subjects of 'The Report of the Royal Commission on the use of Iron in Railway Structures,' issued in 1849, a report which remains to this day a storehouse of much useful information on most subjects connected with the strength of materials. Captain James chiefly, with Captain Douglas Galton and others, made a number of experiments in this direction, which, carefully made and accurately reported, remain still interesting and useful.

A number of these experiments were conducted thus :—A cast-iron bar, two or three inches square, was placed against supports twelve or thirteen feet apart, and caused to deflect horizontally by a known load until it broke, the deflection just before fracture having been recorded for a number of bars. Another similar bar, placed against two similar abutments, was exposed to blows from a falling pendulum of from 120 to 150 lbs. weight, caused to swing from such a distance as to produce a deflection one-third as great as the deflection just before fracture, which corresponds to a stress in the metal of about five-twelfths of the breaking stress. The bar never broke, and apparently could stand an unlimited number of repetitions of this load. The swing of the pendulum was then increased so as to produce a deflection one-half as great as the maximum of deflection of the bar, which corresponds to a stress of about seven-twelfths of the breaking stress. With this deflection all the bars tested eventually broke after a few hundred blows. The same results were obtained by similar deflections given to similar bars by 'cams.' The same results were also obtained when rolling loads, equal to a third the dead breaking weight, were caused to traverse the bars quickly at a speed of about 80 feet per minute. Unlimited traverses of one-third the breaking load could apparently be sustained. Only one bar, however, could stand repeated traverses of a load equal to one-half the breaking load. No doubt these travelling loads caused, from their mode of application, a greater stress than equal static loads would have caused, and therefore a greater deflection.

The general conclusion arrived at from these experiments was, that a cast-iron bar which could stand any given stress *once* before it broke, could only stand about half that stress before fracture, if repeatedly applied. To this conclusion we shall return later on.

Cast-iron was then a material of very much greater constructive importance than it is now, and nearly all the experiments of that time were consequently made with it. A very few of Captain James's experiments were made with wrought-iron in a similar fashion, and gave the result that about two-thirds only of its maximum breaking stress could be applied unlimitedly. Any stress above this caused fracture ultimately, after it had been repeated a certain number of times. This result is remarkably similar to others obtained by more exhaustive experiments recently made, of which I shall shortly tell you.

The question then arose and was discussed—and has constantly been recurring since that time—when a piece of material has received a number of blows, or vibrations, or shocks, or repeated alterations of stress, is it changed in its own nature? particularly, does it, or does it not, become more crystalline and correspondingly more brittle?

The point is a very important one, and we shall have to consider it very carefully further on. Its importance lies in this, that if the mere repetition of a load is of itself capable of causing some deterioration of structure, then all the parts of all machines and structures must probably be deteriorating, and their giving way altogether must only be a question of time.

Robert Stephenson, examined before the Commissioners on this point, expressed himself with characteristic good sense: 'As to the question of change being produced in wrought-iron (which is a very popular and almost universal theory now), I have not known one single instance in which I have traced it to its origin, where the reasoning was not deficient in some important link.'

Brunel and Fairbairn agreed with him; Hawkshaw was, however, doubtful, and Fox scarcely more certain. As regarded Captain James's experiments themselves, however, it was quite certain that the cast-iron was not in itself weaker for the repeated blows, for the broken halves were often retested, and never showed any signs of inferiority.

The whole matter seems to have dropped out of the region of experiments for some years, until Fairbairn's often quoted experiments with a rivetted girder, which on account of their practical nature are well worth examination. These experiments were made for the Board of Trade, in 1860–61, and are described in the 'Philosophical Transactions of the Royal Society' for 1864, as well as in the third series of 'Useful Information for Engineers.'

The girder experimented on was a light plate web girder of the section shown in Fig. 2, Plate I. It was 16 inches deep, built up of plates and angles of the dimensions given. It was made to rest upon brick walls 20 feet apart. A load was applied to it by means of a large cast-iron lever placed underneath it, the free end of which was alternately raised and lowered by power, in such a way that when raised the girder was relieved of load, and that when lowered a known load was allowed to act from the lever on the centre of the beam, with, however, an unknown amount of jar and vibration. The actual static breaking load of the girder is not known. Fairbairn calculated it to be 12 tons, but it could not well have been really more than 10 tons, probably enough it was only 9 tons, for even this load would be sufficient to give a stress of 21 tons per square inch in the metal between the rivet holes.

First of all a load of 3 tons was applied to the girder, causing a stress of about 7 tons per square inch in the metal, and nearly six hundred thousand repetitions of this load failed to make any signs of failure show themselves in the beam (March 21st to May 14th, 1860).

An increase of load to $3\frac{1}{2}$ tons (8·2 tons per square inch) increased the deflection of the beam from 0·17 to 0·22 of an inch, but four hundred thousand applications of load (May 14th to June 26th), making one million applications in all, failed to cause any further increase of deflection, so that this load was assumed to be capable of doing no harm, however often it might be repeated. The load was then increased to 4·7 tons (equal to 10·8 tons per square inch), and the deflection at once went on increasing; while, after 5,175 repetitions of this load the beam broke in the tension flange (angles and plate). The girder was then repaired properly and again loaded, but by some accident the heavy load just mentioned was repeated, and, before it was stopped, one hundred and fifty-seven repetitions had caused 'a large but unmeasured set.' From this it is clear—a point of much practical importance—that 10·8 tons per square inch was a stress very close to the limit of elasticity of the structure. The load was then reduced to 3·6 tons, and afterwards to 3 tons on the centre, and 3,150,000 repeated applications of that load were made with no alteration from the original deflection (August 13th, 1860, to October 15th, 1861). Then 4 tons was again applied and, after 313,000 applications the beam broke a second time, the calculated stress in the flanges being 9·26 tons per square inch. From the experiment it appeared that the load did not at once cause any dangerous deflection; that, up to about 250,000 applications, it did not appear to be going to have any effect, but went on afterwards to cause great deflection and ultimate fracture. The case is altogether remarkable as being one in which, by an accident, a load exactly on the border line between safety and destruction had been reached.

The results of Fairbairn's experiments are not numerous, or of very great importance, because we do not know the real static strength of the girder, and so have no proper standard of comparing the loads which broke the beam when repeated, and the load which would have broken it in one application. But qualitatively the experiments are very important for two reasons, viz., they show first, that no number of repetitions of some loads appear to tend in the very least towards fracture; and, secondly, that after a certain load, about equal to the limit of elasticity, is reached, fracture is sure to occur ultimately, if only that load be often enough repeated.

The attention of engineers, however, has only been very specially called to this matter since the publication of Wöhler's experiments in 1870. These experiments, which extended over many years before that date, and which were brought to an end, so far at least as Wöhler was concerned, by his appointment as Director of Railways in Alsace, still form (in spite of their great incompleteness) the most important contribution yet made to our experimental knowledge on this subject. Their primary object was to determine the effect of the frequent repetition of load on a piece of material. For this purpose special machines had to be designed, two of which are sketched in Figs. 1 and 2, Plate III., respectively.

Fig. 1, Plate III., shows the machine for repeatedly applying a tension varying between zero and a maximum, or between some minimum load and a maximum one. In the figure, A is the bar to be tested; S and R the holders between which it is held. B is the main framing of the machine. The upper end of the test-piece is pulled by a knife-edge link from a lever C, whose fulcrum is at D, upon the top of the frame B. From the further end of C hangs a link E, carrying a knife-edge upon which rests one end of the bar F. The other end of F rests upon a knife-edge upon a lever G, whose fulcrum is at H, and which is held down by a spring P, acting through a spindle O. Q is a set screw by means of which the lever G can be adjusted. The bar N (entirely separate from the machine) is worked from an eccentric upon a revolving shaft. As it moves up it raises the lever M, and consequently depresses the slotted bar L, and so pulls down also the bar F, through the intervention of the bent steel spring K. The working of the machine is as follows: The spring P is first adjusted, so that the pressure which the bar F must exert in order to press down the short end of the lever G may be of any required amount. The bar N is then set in motion by its eccentric. The oscillation of the lever M alternately pulls down and releases the bar F. The pull on F is transmitted to the test-piece by the lever C, as long as it does not exceed the amount just mentioned required to depress the left hand end of G, and stretch the spring P. If, however, the lever M continues to move down, after this particular pull is reached, it no longer pulls the test-piece, but it causes the right hand support of the lever F to give way, as it has been only adjusted to this particular amount of resistance. In this way it can be insured that the test-piece A shall not receive a load accidentally too great on account of too great a motion of M, which may of course easily occur. Further, by adjusting the set screw Q, it may be arranged that this known load necessary to stretch the spring shall be exactly reached in each case, so that there may be no chance of a load *smaller* than that intended being repeated. By adjusting the nuts on the spindle L, it is possible easily to give any required minimum value to the pull in A, so that that pull instead of rising each time from zero to some maximum shall vary between any two desired limits.

The machine shown in Fig. 2, Plate III., is designed for testing the behaviour of a piece of material exposed alternately to tension and compression. The frame K carries two bearings FF, in which revolves a spindle A carrying sockets B. At each end of these sockets is placed a piece D, to be tested. At G on the outer end of this piece is connected a flat spring E, by means of which any desired pressure can be brought upon the over-hanging end of the test-piece. The spindle A, carrying the test-pieces with it, is caused to revolve continually by means of the pulley C. As D revolves each fibre of it is alternately brought to its top and bottom side. The fibre on the top side is always in tension because of the bending action of the pressure due to the spring E. The fibre on the bottom is always in compression from the same cause. As the top and bottom fibres are always changing places, each fibre in the whole piece is exposed alternately to tension and to compression. The rotating action of the machine is not therefore adopted for its own sake, but is only used as a convenient method of obtaining alternate tensions and compressions.

A similar machine was also used for measuring repeated bendings. This it is not necessary to describe in detail.

It will be seen that these machines could be worked continuously, and that by their means it was possible to apply different kinds of load to bars through an unlimited number of repetitions. Two remarkable sets of results were obtained in the experiments made by Wöhler, the nature of which results is shown in the diagrams Fig. 3, Plate I., and Figs. 1 and 2, Plate II. Fig. 3, Plate I., and Fig. 1, Plate II., show the effect of simple repetition of load, varying between zero and some particular maximum. Bars cut, for instance, from a cast-steel axle made by Krupp, and tested for repeated tensions in the machine in Fig. 1, Plate III., gave the following results: the tenacity of the material measured in the ordinary way being about 52 tons per square inch. The material stood 18,700 repetitions of 40 tons per square inch; 46,300 repetitions of 35 tons per square inch; 170,000 repetitions of 30 tons per square inch; 474,000 repetitions of 25 tons per square inch; and when the load was reduced a little below 25 tons per square inch, the material stood 13,600,000 repetitions of load without being in any way apparently injured. Exactly similarly a piece of soft steel tested in bending, which broke under one application of something over 60 tons per square inch, stood 39,900 applications of a stress of 50 tons per square inch; 72,500 applications of a stress of 45 tons per square inch; 133,600 applications of a stress of 40 tons per square inch; 199,400 applications of a stress of 35 tons per square inch; 468,200 applications of a stress of 30 tons per square inch; and when the stress was decreased to 25 tons per square inch, the piece stood 40,000,000 applications of load without showing the slightest sign of injury.

The diagrams in Fig. 3, Plate I., are simply graphic representations of these figures, the vertical heights representing the number of repetitions of load; horizontal distances, corresponding stress per square inch.

In Fig. 1, Plate II., are shown graphically the results of experiments in which the stress did not vary from zero to a maximum, but from some given minimum to a maximum. A piece of spring steel for instance, similar to that just described, was found to stand 62,000 repetitions of stress varying between 8 and 50 tons per square inch; 150,000 repetitions of stress from 17 to 50 tons per square inch; 377,000 repetitions of stress varying from 29 to 50 tons per square inch; but 20,000,000 repetitions of load varying from 33 to 50 tons per square inch. In each case, except the last, the material was broken after the number of repetitions stated. In the last case it remained unbroken and uninjured.

The other diagram shows exactly similar results, obtained with a bar of hard spring steel. Taking them together, we see that a fracture of a piece of material in this case has not been determined by the maximum load put upon it, but by what may be called the *range of stress* to which it has been subjected—or, the difference between the minimum and the maximum stresses—the maximum loads remaining the same in each case. The pieces broke after a comparatively small number of repetitions, if the minimum load was small (that is, if the range of stress were great), but remained quite uninjured without alteration of maximum stress, if only the range of stress were made small enough by increasing the minimum stress.

The case where a piece of material was exposed alternately to tension and compression might be considered as one with a very large range of stress, a range obtained by adding together the two stresses. Thus, if the minimum stress be zero, and the maximum 10,000 lbs. per square inch, the range of stress will be 10,000 lbs. per square inch; whereas with the minimum stress of 7,500 lbs. per square inch in compression, and the maximum of 7,500 lbs. per square inch in tension, the range of stress will be 15,000 lbs. per square inch, and we might expect that the materials would give way by a smaller number of repetitions than before, although the maximum stress was actually not so great, being, viz. 7,500 lbs. instead of 10,000 lbs. per square inch. This result was found to be substantiated by experiments made in the machine shown in Fig. 2, Plate III.

Fig. 2, Plate II., shows in form of diagrams a summary of the results of several of Wöhler's experiments. In each diagram the ordinates of the upper straight lines give the maximum intensity of stress per square inch. The ordinates of the lower irregular lines give the minimum intensity of stress per square inch. The vertical lines included between these two give the range of stress under which the material was found to remain practically uninjured by any number of repetitions. Thus, for instance, in the Krupp steel axles (the lower of the three diagrams), it it was found that a stress varying from 14 tons per square inch compression to 14 tons per square inch tension (these figures are rounded off), could be sustained an unlimited number of times. A stress varying from nothing to about 23 tons per square inch could also be sustained an unlimited number of times, as could a stress varying from 20 to 40 tons per square inch. Under each of these conditions the material was equally uninjured after millions of applications of load. In one case the piece was actually under test for more than a year continuously, receiving about 136 millions of repetitions of load without showing any permanent effect.

I have mentioned that Wöhler's experiments were interrupted by his removal from Berlin. These were subsequently continued by his successor Professor Spangenberg, who, however, died some few years ago, and since his time no further results have been published, although the machines are still in existence. They are now under the control of the Prussian State Testing Department, and further experiments are being made with them. Spangenberg's experiments did not give any new results, and it is not worth while to analyse them here. Wöhler's experiments were originally published separately under the title of 'Ueber die Festigkeitsversuche mit Eisen und Stahl' (Ernst u. Korn, Berlin. 1870). The substance of them was printed in 'Engineering,' Vol. XI. (1871), where also will be found drawings of the machines themselves. It is intended to publish the results of the new experiments in the 'Mittheilungen a. d. Königl: techn: Versuchs-Anstalten.'

In my next lecture we shall have to consider the real meaning of these experiments, and the effect which a consideration of them should have upon practical design.

We have now to consider the bearing, on practical work and design, of the facts and experiments already described. We must in the first instance notice to what extent structures or machines are actually exposed to repeated loads. In a steam engine the greater part of the framing, as well as the piston rod and the connecting rod, are alternately in tension and compression. The alternations are repeated at every stroke perhaps three or four thousand times in an hour, or ten or twelve million times in the course of a year. The connecting rod has also alternate bendings in both directions, in the plane of the crank, due to centrifugal force, and a locomotive side rod has also bendings in a horizontal plane due to curves on the line, or even anywhere along the line, in cases where axles have end-long play. Thus the principal parts of an engine are exposed to continual repetitions of stress, tension, compression, and bending, occurring so rapidly as to make up an enormous total in the life of the machine.

In a bridge, repetitions of load are far less frequent, and of a different kind. All the bars and plates of a bridge are permanently strained with some stress due simply to the permanent load or dead weight of the structure. This is continual, and therefore here, if anywhere, we may expect to find the effect of time upon the material. In addition to this stress caused by dead weight, whenever a train passes over the bridge the stress in each bar is increased to a maximum; if it has been in tension before it has now a greater tension, if it has been in compression before it has now a greater compression; in every case each part of the bridge is subjected to some range of stress varying between definite limits. This change of stress may happen ten or twenty times an hour or oftener, but would have to be extremely frequent to amount even to 150,000 in the course of a year, a very small number of repetitions in comparison with the number found in the case of steam engines.

It has been suggested that the effect of alterations of temperature, such as occur every day, may be to cause alterations of stress. In some instances this may be the case. The frequency and magnitude of such changes are, however, not great enough to make them worth taking into consideration in the present lecture. In the case of guns the repetitions of stress are of course even less frequent.

It is therefore only in machinery and structures intended for very long life, that repetitions can ever be numerous enough to make their actual number sufficient to cause probable deterioration or destruction.

The question which obviously seems to come first is, then, the one which has already been looked at, viz., 'Do these unavoidable repetitions of load cause slow but inevitable deterioration of the material?' It is obviously a thing which on scientific grounds is hard to believe, and cannot be believed without the production of very strong evidence. The evidence which has hitherto been given to support such a conclusion resolves itself practically into a statement of the brittle appearance, the largely crystalline structure, and so on, of broken axles and tyres. But on this point there are two things to be said, viz.: Firstly, that the metal may always have been crystalline and brittle, and that this brittleness may have been indirectly the cause of the fracture without having been itself produced by the vibrations; secondly, that the mere fact that the fracture is crystalline does not prove the metal to have been in the ordinary sense of the word *crystalline throughout.* Nearly every piece of iron can be broken so as to show crystal or fibre in the fracture, at pleasure. Perhaps this may be taken as indicating that the material is always in reality crystalline, the so-called fibrous appearance not being analogous to the real fibre in wood, but more or less an indication of want of proper continuity in welding. In any case the mere appearance of the fracture is practically no evidence at all; it proves absolutely nothing as to the point in question.

Another appearance in the fracture found by Professor Spangenberg has been considered by him to be distinctly traceable to the repeated loads. This is the appearance of a finely granular core surrounded by crystal, in which are visible lines distinctly radiating from the core, which may or may not be in the centre of the fracture. In his accounts of his experiments he connects the existence of this core with the gradual giving way of the pieces under 'fatigue.' As you will see, however, from the examples upon the table, this fracture is a quite common one in pieces tested in the ordinary way, so that its appearance may be said unquestionably to have nothing to do with the repetition of load.

On the other hand there is a total absence of any direct evidence of weakness in the material itself. I showed you the other day experiments on pieces of material cut from girders that had seen enormous traffic. I have similarly tested tyres that have been used till they were worn down so thin as to crack; of coupling rods and axles used till they had actually given way, cracked or broken; and I showed you also a piece cut from a locomotive weigh shaft, which had seen some wear and had been in appearance extremely unsound.

In no case was there any sign of weakening of the metal itself (I do not say of the piece of material as a whole, of that I shall speak presently), or of any abnormal crystallisation. Probably it would have been impossible for any one to have said from the appearance of the fractures, or the general results of the experiments in those cases, that any one of those pieces had had any special amount of work done on it, or was in any particular way remarkable. Such remarkable fractures as I have seen in 'fatigued' materials I will speak of presently.

I think we must then dismiss the idea that such repeated loads as occur in practice alter the structure of the material in any way.

It must next be asked, Does repetition of load in some other way weaken the material, so that any given part of a structure made of that material ought to be made larger in scantling if it has to stand repeated loads, than if it has to stand only a continuous load, supposing the margin of safety required be the same in both cases? It has been taken for granted—very hastily I think—that the answer to this question is experimentally proved to be *affirmative*.

Let us look again at Fig. 1, Plate I. Such a piece of steel as that whose behaviour is there shown would ordinarily work at from 9,000 to 12,000 lbs. per square inch of stress. Its breaking load is about 68,000 lbs. per square inch; that is, it would break *at the first gradual application of that stress.* It is commonly said in such a case to be working with a 'factor of safety' of $7\frac{1}{2}$ or 6. But independently altogether of repetitions of stress, we know what will happen to such a bar if by any chance a load equal to its limit of elasticity—say 40,000 lbs. per square inch—should be brought upon it *only once.* It would at once and inevitably be drawn out from one to two per cent. of its length (at what we have called the breaking down point). The particular bar diagrammed drew out about one-fifth of an inch in 10 inches. In a bridge tie bar 10 feet long, this would mean having its length increased by $2\frac{1}{4}$ inches.

I point out the magnitude of this extension just after the limit of elasticity is passed specially, because sometimes it has been thought that what happened at this point is nothing more than a slightly increased rate of extension, still only measurable in thousands of an inch and still quite neglectable for ordinary purposes. Instead of this it cannot be too distinctly remembered that such an extension as occurs just after the limit of elasticity is reached would involve the total destruction of the bridge, or such a distortion as is equivalent to rendering it entirely useless, even if it were not actually broken in pieces.

When we say, *if we do say*, that the working loads on such a bridge leave us with a 'factor of safety' of six or seven, we say it with the distinct knowledge that although it might take six or seven times the working stress actually to break in two a piece of the material, it would only take three or four times that stress to render our whole structure useless. We know beforehand, however, independently altogether of questions of repetition of load, that our maximum load must never, *even once*, exceed three or four times our working load (in the case supposed) or our whole structure gives way.

Now turn to Fig. 3, Plate I., to see what Wöhler's experiments tell us. It is perhaps at first sight a little startling. Samples of cast steel are taken which have a tenacity, as ordinarily measured, of about 52 tons per square inch; they break with a stress of only 40 tons per square inch after about 19,000 repetitions; 35 tons per square inch after about 46,000 repetitions; 30 tons per square inch after about 170,000 repetitions; and even 25 tons per square inch after some 500,000 repetitions. The result most obvious is certainly that a load *very much* lower than the ordinary breaking load will, after a number of repetitions which is not impossibly great, actually become a breaking load; and this point is the one upon which, naturally enough, the greatest stress has been laid as the result of Wöhler's experiments. But the next thing that is noticeable is certainly not less remarkable, viz., that nearly 14,000,000 of repetitions of a stress of 24 tons per square inch occurred without the material showing any signs of injury. Twenty-four tons per square inch is very close to 25 tons per square inch; and thus a change so great as that from fracture after half a million repetitions to non-injury at 14,000,000, seems to take place almost suddenly.

The curve representing the number of repetitions of load which the piece can stand (as in Fig. 3, Plate I., and Fig. 1, Plate II.) has to all appearance—and all the experiments agree in this—an asymptote at a considerable distance from the axis. It does not go on giving finite values of the repetition continuously, while the load diminishes continuously. It appears distinctly rather to show that there is always some finite load below which no increase in the number of repetitions of load have any effect whatever in injuring the material.

Very unfortunately the limit of elasticity of the different materials tested by Wöhler has not been stated in any published results, and I have not been able to find out by personal inquiries. From the results given, however, it is clear that the maximum load which could be applied an unlimited number of times was very close to the limit of elasticity—*very close*, that is, to the load which, *applied once only*, renders the material useless. It is some load which in Fig. 1, Plate I., for instance, would lie very close to 40,000 lbs. per square inch. It is, therefore, either *at* the break down point, or possibly as low as the point where the strain begins to increase more rapidly than the stress. For all practical purposes (in the absence of further numerical details), we may no doubt take it as nearly *equal to the ordinary static limit of elasticity*.

The matter then stands thus: if a load exceeding somewhat the limit of elasticity of the material, however far below its breaking load, be applied a considerable but measurable number of times, the bar will be actually broken. *But at the same time we know that if any load exceeding the limit of elasticity be but once applied, the structure to which the bar belongs is distorted and rendered useless.*

It may then, I think, be said safely, that the continued repetition of such a load 100,000 times, or 1,000 times, or ten times, is a thing which cannot be conceived to occur in actual work, and which, therefore, we need not as engineers take into account. In one word, knowing that our structures will break down if a load equal to the limit of elasticity* comes only once upon them, we need not trouble ourselves about the more decided breaking down which would occur if such loads came upon the structure 100,000 times.

Further, it is to be very particularly noticed that we have absolutely no evidence from these experiments, or any others, that the repetition —*any number of times*—of such loads as are called ordinary working loads, weakens the material in any way whatever, more than one single application of such loads does.

It may be asked how the statement that one single application of a load exceeding the limit of elasticity would destroy a tie bar at once, can be reconciled with the fact that, in Wöhler's experiments, bars stood ever so many thousands of applications of much higher loads before they broke. The explanation is this: that in these experiments a great proportion of alteration of length was not destructive, as it would be in a bridge, for example, and that this alteration of length in a tie (or form in a beam) did actually take place. For instance, in Fig. 3, Plate I., if the original length of the bar, the length which stood 13,600,000 applications of a stress of 24 tons per square inch without injury, were 10 inches, the length of the same bar, under 32 tons per square inch, was probably 10·5 inches, and under 40 tons, 11 inches. This condition of affairs is not analogous to anything occurring in engineering practice, where it is essential that no change of length, other than the very smallest, should ever occur. Wöhler was, in point of fact, working in these experiments with a new material—a material which had been already strained beyond its limit of elasticity, and was now to a measurable extent longer than before. Experiments show that with such a bar retested from the beginning the *modulus of elasticity* remained practically unaltered, but the total possible extension is less than before, just by the amount of extension which has already occurred.

Wöhler's experiments show us what is worth noticing, mainly as a matter of scientific interest, that a bar will be ultimately broken by the frequent enough repetition of *any* load higher than its limit of elasticity. This fracture appears to be *inevitable;* conditionally only on

* Or, in the case of cast-iron, a load which bears the same relation to the breaking oad that the limit of elasticity does in most iron, there being no distinct marked imit of elasticity in the case of a material so hard as cast-iron.

the bar being put into equilibrium; that is, the load entirely removed from it, after each application of the stress.

If, however, these experiments have caused somewhat needless anxiety on the one hand, I fear they have caused somewhat undue confidence on the other. The experiments on the effect of altering the *range* of a stress, whose results are diagrammed in Figs. 1 and 2, Plate II., are probably the most interesting and novel of all those made by Wöhler. I have already pointed out that many structures are always strained under conditions somewhat analogous to those of these experiments, viz., under the existence of a certain minimum of stress not equal to zero, caused by the continually acting weight of the structure itself. Under these circumstances Wöhler showed that one of his test bars could stand an unlimited number of repetitions of a stress much higher than its limits of elasticity, and that this stress might be made higher and higher by making the minimum stress also higher and decreasing the range of stress, until the maximum stress very nearly reached the breaking load.

We may take a numerical example from Fig. 2, Plate II. (iron axles). One application of 24 tons per square inch would break this iron; and if the bar was strained always from zero, its fracture with any stress exceeding 15 tons per square inch was only a matter of time and number of repetitions. But an unlimited number of applications of 22 tons per square inch would not break it, if only the minimum stress were never allowed to fall below 12 tons per square inch. Suppose, now, we have a bridge in which the ratio of dead and live load is 12 to 10; then the ratio of minimum to maximum stress is 12 to $(12+10)$, or 22. If, for example, the stress in the booms when the bridge is unloaded is 3 tons per square inch, and when the strain is on the bridge $5\frac{1}{2}$ tons per square inch, we should have just such a case. It has been argued that *our ordinary working stress may safely bear the same ratio to 22 tons per square inch, which if the minimum stress were 0 it would bear to 15 tons.* Numerically thus: If a bar may safely work between stresses of 3 and $5\frac{1}{2}$ tons per square inch, which is a rational assumption, we may multiply 22 by the ratio of 5·5 divided by 15, which gives us 8, and then say that a bar may as safely work between 4·4 tons per square inch and 8 tons per square inch as between 3 and $5\frac{1}{2}$ tons per square inch. I believe this reasoning has been actually acted upon in Bavaria under the regulations which there corresponds to the regulations of our Board of Trade.

The fallacy here is, however, pretty obvious. The piece of iron which has a repeated load up to 22 tons per square inch was not the same material as that which we use every day, but was a piece which had been already stretched far beyond its elastic limit. I have already explained that our iron is, for practical purposes, destroyed *the first time* it passes its elastic limit. Hence the condition of affairs is just this: so long as the limit of the load is kept below the limit of elasticity, the material is, in a certain sense, safe. The first time that by any accident the maximum stress reaches the limit, the material is destroyed, and this is quite independent of what the minimum may have happened to be; therefore the degree of safety—other things being equal—may be represented by the margin of stress between the maximum working stress and the limit of elasticity, and 5 tons per square inch is on this account just so much safer than 8 tons per square inch. If it is safe to work unlimitedly between $4\frac{1}{2}$ and 8 tons per square inch, there is nothing whatever in any of the experiments to show that it is not equally safe to work between zero and 8 tons per square inch, unless it can be shown that the larger range makes the occurrence of accidental stress more likely, which is, of course, quite possible, but not very probable, and certainly not proved. The matter is seen still more forcibly by supposing an extreme case. Instead of working between $4\frac{1}{2}$ tons and 8 tons per square inch, one can work between 8 and 14 tons per square inch, which stand in the same ratio. But here 1 ton per square inch additional would, the first time it was accidentally reached, break the whole thing down, and such an accidental excess may of course happen every week, or every day. There is absolutely no safety in the margin between 14 and 22 tons per square inch, unless we suppose the material to be endowed with some kind of prescience of its own. The material which stood so many repetitions of a range of stress from 12 to 22 tons per square inch was not in itself the same material at all which we use, but a material—such as we can prepare any day, but such as is of no value in practice—already stretched 10 or 12 per cent. of its original length.

There remains still one more point in Wöhler's experiments to be examined. They show us (Fig. 2, Plate II.) that a stress much less than the limit of elasticity, if, instead of alternating with a stress equal to 0, it alternated with a sufficiently large stress of opposite sign, the two together, giving a range as great as that from zero to the limit, might break a piece if repeated often enough. The piece of iron just dealt with, for example, would stand unlimited repetitions of stress, varying from 12 to 22 tons per square inch, from 0 to 15, or from minus 8 to plus 8, but it could not stand, for example, unlimited repetitions varying from 9 tons per square inch of compression to 9 tons per square inch tension, although the latter stress taken by itself was much below the limit. We are familiar with the use of alternate stresses in such a very common act, for example, as breaking a stick across; but in that case each stress is itself beyond the limit of elasticity, something that might correspond to minus 17 to plus 17 in a piece of iron. That the same effect could be obtained by alternate stresses, each one of which was below the limit, was, I think, unsuspected until these experiments were carried out. I have described to you the machine in which they were made (Fig. 2, Plate III.). You will remember that the results were only indirectly obtained, and it is not equally possible to feel certain that they are distinctly and fully applicable to a piston rod or a connecting rod. At the same time it is wise for the present to treat them as if they were. It is much to be hoped that we may get further experiments on these points, conducted in a more direct fashion.

So far, it must be said, our results are chiefly *negative;* we must now, in conclusion, look at the positive side of the matter. Fractures of certain parts of machines, particularly of locomotives, exposed to frequent repetitions of load, do often occur. It does not follow, of course, that these fractures are actually caused by the repetitions, for the matter is complicated by the fact that the mere effect of time may have something to do with it, and still more that the vibrations and shock by which the loads are commonly accompanied may affect the matter more than the mere number of repetitions. In spite, however, of the negative results given by so many experiments, I am certainly disposed to think that the mere repetition is in itself a possible cause of fracture in certain cases. The conclusions at which I have arrived are these (and I ought to say that while hitherto I have felt myself justified in speaking positively, because I was dealing with accurately observed and observable physical phenomena, I can now give only an opinion)—that with wrought-iron repetitions of load are, or may be, frequently the cause of ultimate fracture. Wrought-iron is an unhomogeneous material—what Sir Wm. Siemens has called a 'sandwich of iron and glass.' Continual straining does not appear to injure the good parts of the sandwich, but it does appear to destroy cohesion between the glass or dirt and the iron. Now this makes comparatively little difference in a tensile test. A dozen bars of iron placed side by side, and pulled equally, would have practically the same strength as one bar twelve times the size of one of them, so that what I may call the transverse adhesion of the fibres or laminations practically does not much affect the strength; but wherever bending comes into play, it may cause all the difference in the world. If three bars placed one on the top of the other, but not fastened together in any way, are bent, they will only stand one-third the load that a single bar of the same size as the three put together would stand. Now, a piece of iron badly laminated, in which the pieces of iron have been separated by layers of dirt only found to adhere to them, is much in the position of the three separated bars. We might therefore expect that anything which would tend to disturb the transverse cohesion between layers of which ordinary wrought-iron consists, would very much diminish its strength as a beam, but scarcely at all as a tie rod. This is exactly the result which one finds in practice. I do not remember hearing of an iron piston rod giving way in any fashion which connected itself with repetition of load, but a connecting rod sometimes does, and a coupling rod frequently. The piston rod is not subjected to any stress but direct tension or compression. The connecting rod, as we have already seen, and still more the coupling rod, is subjected to frequent bendings. My own belief is, that the gradual disintegration of the dirt and oxidation of the iron takes place, as much by vibration as by mere repetition, in all piled iron subjected to vibration and repetition of load, and that in consequence the intensity of stress in certain parts of the metal becomes gradually greater than its limit, and the metal cracks.

This of course may be called a deterioration of the metal, but is not properly a deterioration of the metal itself. It was for this reason that I qualified my former statements on this point and limited them to the metal itself. Recently I had a very remarkable case in point pass through my hands. I tested a number of pieces cut from links of the Conway Suspension Bridge erected by Telford, which had seen over 50 years of work, and which in that time must have been subjected to much vibration and very frequent repetitions of load, although, probably, with a very small range of stress. Whether the maximum of stress was high enough to be near the limit I have no means of saying. I found in the result that much of the iron showed, after fracture, many cracks running in towards its centre. Many of these cracks extended inside into a little spot of a reddish-gold colour, unmistakably rust. The vibrations or repetitions of load, or time itself, or all three, had gradually opened up these cracks, whose existence was owing originally to the imperfect nature of the material, and in spite of painting on the surface, damp had found its way through them and was gradually killing the heart of the iron.*

In a locomotive side-rod both repetition and vibration are more severe and frequent than in the suspension bridge link, so that an iron

* By careful experiment also I find that the modulus of elasticity of this iron is exactly what it might be expected to be—that is, the vibration and time do not seem to have affected the modulus in any way.

coupling rod may give way, if it is to give way at all, long before it has time to rust internally. Whether or not it does give way, no doubt, remains mainly dependent on the quality of the welding between the different layers, a quality necessarily somewhat uncertain.

In the case of steel I have been unable to hear of any such fractures as those I have mentioned. If they occur at all, they certainly occur very seldom. The reason is doubtless that the material is homogeneous, and cannot give way locally like iron, and consequently is never subjected to the same excessive local stresses, and remains uninjured by repetition, while there are no cracks in it caused by continual vibration. A very good example of this you saw in a piece cut from a dredger-pin. The pin had been subjected to such heavy stresses and such continual blows as absolutely to be worn into a crank shape, and yet you saw that the steel showed no deterioration, and the pins themselves no signs of cracking or opening out. The dredger links on the other hand, in the end of which the pins worked, in spite of being made of very high-class iron, and of not having had anything like the battering that the pins had been subjected to, were all opened out and one of them was even badly cracked across. It would have been impossible for a piece of iron, however good, to have stood anything like the usage of the dredger pins without opening out and probably breaking up altogether.

One more point only. I have confined myself to iron and steel for the good and sufficient reason that we have little practical knowledge of the corresponding effects in relation to wood and stone, in respect of which certainly they are less important. In wood, however, there is one distinctly marked difference from iron, which is important in connection with all timber structures intended to have a long life. The mere effect of time, quite independent of vibration or repetition, is considerable. Mere continuance of load does not appear to injure wrought-iron at all, or cast-iron, unless it amounts to very nearly the breaking load. On the other hand, a load equal to only 60 per cent. of the breaking load will break timber (according to Thurston) in 15 months; so that, apparently, time has very much the same effect on timber that unlimited repetition has upon iron; but it will be seen that 60 per cent. of the breaking load only corresponds to the limit in wrought-iron, a point above which the load would never actually be allowed.

EXPLANATORY MEMORANDUM AS TO TABLE OF TEST OF FATIGUED MATERIAL.

Appended to this paper is a Table giving the results of tests of 47 pieces of material, iron and steel, which had either been in constant use for many years, until they were so much worn as to require renewal, or which had broken in actual use. Particulars as to these points are given, in each case where it has been possible to do so, in the Table, as well as remarks as to the fractures, &c. To these there is little to add. The piece out of the Conway Bridge suspension link is interesting, as being a piece of one of the earliest erected large iron bridges in England. Special measurements were made of the modulus of elasticity of this iron, to see if long use had altered it in any way. The modulus was, however, found to be 30,960,000 pounds per square inch, which is quite a common value. In the various breaking loads plenty of variation will be found, irregularities which may have greatly affected the strength or the wear of the material, but in no one case does there appear to be anything which distinctly points to a weakening effect due to actual fatigue, the consequence of repetition of load. The steel pins (Nos. 2,084, &c.) were so worn and hammered, by working in sandy water, as to have actually the form of miniature crank axles, so that, although originally about two inches in diameter, test-pieces larger than the sizes given could not be cut from them.

For the pieces of iron and steel here tested the writer is indebted to the courtesy of Mr. Joseph Tomlinson, Mr. Worsdell, Mr. F. W. Webb, Mr. W. B. Worthington, Mr. Beloe, and Messrs. Hunter & English.

TABLE SHOWING RESULTS OF TESTS OF FATIGUED MATERIALS FOR TENACITY AND ELASTICITY MADE AT THE ENGINEERING LABORATORY, UNIVERSITY COLLEGE, LONDON.

A. *Wrought Iron.*

U.C.L. Test Number	Material and Dimensions					Limit of Elasticity		Breaking Load		Ratio of Limit to Break	Extension on whole length of — ins.	Remarks
	Material	Breadth	Thick-ness	Diam.	Area	Pounds	Tons	Pounds	Tons			
		"	"	"	sq. ins.	per sq. in.	per sq. in.	per sq. in.	per sq. in.		per cent.	
823	Suspension link from Conway Bridge (Telford's) [Tested in full length, exactly as it came from the bridge. The *min.* dimensions were at a place where (in absence of painting) corrosion had been specially bad.]	mean 1·027 min. ·961	mean 1·037 min. ·943	.. ..	mean 1·065 min. ·906	28,500	12·72	44,380* 52,180†	19·81* 23·30†	·642	on 10″ 11·7 on 90″ 4·7	The fracture of the iron was fibrous and silky, but the metal was faintly discoloured with oxide right to the centre, damp having clearly found its way in through cracks which had been left by original imperfect welding. The bar is badly split longitudinally in several places along its length, and fine transverse cracks appear in several places.
2,095	Forked dredger link, S.C. ♛ iron	1·580	·381	..	·602	39,620	17·68	54,820	24·47	·722	on 4″ 17·5	 Laminated thus.
2,096	Tee link, B.B.H. ♛ iron ..	1·444	·379	..	·547	36,380	16·24	54,100	24·16	·672	..	Broke inside clips at a weld; 50 % crystalline.
2,096 repeated	Do., do.	1·444	·379	..	·547	55,380	24·72	58,220	25·99	·951	on 4″ 28·0	Broke fair about 1″ from one end; about 10 % crystalline.
2,145	W. iron connecting rod, in use since 1859	..	..	1·102	·954	31,130	13·45	49,500	22·10	·608	on 3″ 31·7	Mainly silky; a little laminated.
2,146	Piston rod of S.S. 'Kent,' in use twelve years	..	..	1·101	·952	28,700	12·81	49,660	22·17	·578	10·7	Broke in thread; large crystal (1) open; welding not good; turned from centre of rod.
2,148	Connecting rod (side rod), in use since 1861	..	..	1·002	·785	31,910	14·25	52,680	23·52	·606	19·0	Silky; fractured → ; speck of crystal.
2,149	Waggon axle, in use since 1860	..	..	1·100	·950	34,630	15·46	49,600	22·14	·698	29·7	Silky and close-grained; a few specks of crystal.
2,150	Eccentric rod, in use since 1847	1·500	·728	..	1·092	35,710	15·94	52,580	23·47	·679	13·0	Broke close up to wedges at one end; mainly silky; small patch of crystal; welding not very good.

* Calculated on mean area. † Calculated on original area of place where fracture occurred.

2,152	Connecting rod (side rod), in use since 1847	..	..	·752	·444	36,480	16·26	51,980	23·20	·700	29·0	Silky; specks of crystal.
2,160	Broken side rod, Leeds iron ..	1·503	·382	..	·574	27,040	12·07	50,520	22·55	·535	on 10″ 25·0	Silky; very slight opening out at weld.
2,162	Do., do.	1·500	·379	..	·569	28,960	12·93	49,840	22·25	·581	24·6	Silky; welds slightly open.
2,164	Do., do.	..	..	·755	·448	27,590	12·32	49,820	22·24	·554	23·0	Silky; specked with crystal.
2,167	Do., do.	..	..	1·006	·795	28,420	12·69	50,620	22·60	·562	22·5	Fibrous; specked with crystal; weld not very good.
2,166	Broken trailing axle	..	..	1·005	·793	25,530	11·40	42,990	19·19	·594	12·3	Irregular; welding defective; metal appears burnt.
$4,706_1$	Old tyre (flange side)	..	..	·573	·258	33,820	15·10	51,280	22·89	·660	on 3″ 24·0	Silky and somewhat granular; slight trace of lamination.
$4,706_2$	Do., do.	..	..	·573	·258	42,740	19·08	56,320	25·14	·759	21·0	Silky; granular; a little lamination.
$4,707_1$	Old loco weigh-shaft	..	..	·515	·208	33,990	15·17	51,080	22·80	·665	on 1″ 27·5	Silky; specks of crystal; no lamination.
$4,707_2$	Do., do.	..	..	·515	·208	38,120	17·02	48,580	21·69	·785	15·0	About 10 % crystalline, 15 % granular, the rest silky; no lamination.
4,707	Do., do.	..	..	·705	·390	28,654	12·79	51,220	22·87	·550		
4,708	Do., do.	..	..	·515	·208	36,870	16·46	53,000	23·66	·696	on ¾″ 36·0	Silky; traces of crystal; slight lamination.
$4,975_3$	Angle from cross girder of bridge, in use since 1848	1·499	·257	..	·385	31,430	14·03	45,520	20·32	·690	..	Silky.
$4,975_4$	Do., do. (corroded from ½″ thick)	1·499	·246	..	·369	33.818	14·42	49,544	22·14	·651	on 5″ 19·2	Silky; cinder on surface; broke in two places.
$4,975_5$	Web plate from do., do., do...	1·004	·496	..	·498	37,040	16·53	47,290	21·11	·783	..	Silky; laminated; welding not good.
$4,975_6$	Do., do., do.	1·004	·510	..	·512	27,264	12·17	42,576	19·01	·640	on 5″ 3·0	Irregular fracture; defective welding.
$4,976_1$	Flange plate of cross girder put in to strengthen above girder, in use twelve years	1·490	·505	..	·752	36,170	16·15	48,030	21·44	·753	..	Silky; laminated; specked with crystal.
$4,976_3$	Web plate of do., do.	1·490	·508	..	·757	26,524	11·84	49,140	21·94	·540	on 3″ 8·7	Silky; laminated; specks of crystal.
$4,976_4$	Do., do., do.	1·490	·508	..	·757	26,260	11·72	48,876	21·88	·536	13·7	More silky than $4,976_3$.
$4,976_5$	Do., do., do.	·947	·342	..	·324	38,520	17·20	55,120	24·60	·699	..	Silky; laminated; speck of crystal.
8,032	Main bearing bolt of marine engine, in use since 1878	..	..	1·125	·994	32,230	14·39	46,480	20 75	·693	on 10″ 29·0	Silky.
8,033	Cross head bolt of do., do.	..	..	1·125	·994	28,130	12·56	50,950	22·75	·552	on 4″ 28·0	Silky; longitudinal welding bad.

B. *Steel.*

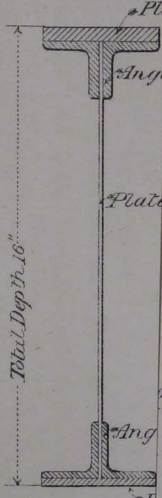
U.C.L. Test Number	Material and Dimensions					Limit of Elasticity		Breaking Load		Ratio of Limit to Break	Extension on whole length of —ins.	Remarks
	Material	Breadth	Thick-ness	Diam.	Area	Pounds	Tons	Pounds	Tons			
		"	"	"	sq. ins	per sq. in.	per sq. in.	per sq. in.	per sq. in.		per cent. on 2"	
2,084	Worn dredger pin, steel ..	..	..	·702	·387	41,990	18·75	60,090	26·82	·699	31·5	Silky granular.
2,085	Do., do.	..	..	·701	·386	80,580	35·97	111,800	49·90	·721	19·0	Very finely crystalline.
2,086	Do., do.	..	..	·702	·387	47,410	21·17	82,540	36·85	·574	30·0	Silky granular.
2,087	Do., do.	..	..	·701	·386	68,000	30·35	102,600	45·80	·662	15·5	Finely crystalline.
2,097	Do., do.	..	..	·702	·387	51,060	22·99	71,640	31·98	·713	35·0	Silky granular.
2,100	Do., do.	..	..	·702	·387	57,680	25·75	98,400	43·92	·586	18·0	Do.
2,101	Do., do.	..	..	·702	·387	54,160	24·18	83,710	37·37	·647	27·5	Do.
2,102	Do., do.	..	..	1·006	·795	52,070	23·24	88,220	39·38	·590		
2,143$_1$	Old rail top	1·128	·395	..	·445	31,460*	14·04*	94,480	42·17	·333	on 4" 6·2	Entirely crystalline.
2,143$_2$	Old rail bottom	1·126	·377	..	·424	46,580	20·79	94,000	41·97	·495	15·0	Entirely finely crystalline.
2,144	Old tyre	1·255	·379	..	·476	44,850	20·02	80,880	36·10	·555	on 3" 24·7	Very finely crystalline.
2,147	Old engine tyre, in use since 1876	1·528	·381	..	·582	29,890	13·34	36,230	16·18	·825	..	Crystalline, but very unsound right through, about 30 % of whole area.
2,161	Old Bessemer steel tyre ..	1·496	·382	..	·572	67,560	30·16	104,010	46·45	·649	on 10" 13·6	Finely crystalline granular.
2,163	Do.	1·502	·401	..	·602	41,360	18·46	69,560	31·05	·595	16·7	Silky.
2,165	Do.	..	..	1·006	·795	60,870	27·17	93,160	41·59	·653	19·5	Finely crystalline.
2,168	Do.	..	..	1·005	·793	49,400	22·05	71,340	31·85	·692	19·0	Silky granular.

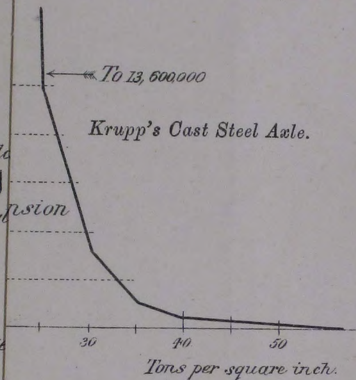
* Not well marked.

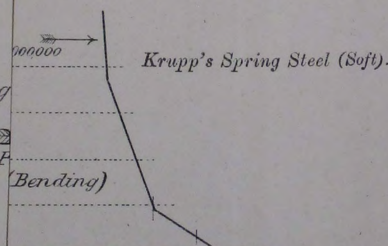
NT REPETITION

Plate I.

FIG. 11.







PAPER V.

RECENT ARMOUR-PLATE EXPERIMENTS.

By Major-General T. Inglis, C.B.

Some seventeen Papers on armour-plate subjects already lie scattered through the Corps Volumes, commencing with that for the year 1862, but the time has now come when this almost annual supply of information must cease, at least so far as the present authorship is concerned. The following Paper gathers up what has been done in the course of last year, and so the record of armour-plate experiments, extending over a period of more than a quarter of a century, is now brought to a close with the end of the year 1884.

Trial of Armoured Masonry at Shoeburyness in 1884.

In my remarks, under a similar heading to the above, in Paper XI. of last year's volume, I observed that, because it was anticipated that the trials which were then in progress, with the object of determining the best method of strengthening the masonry parts of existing sea forts, would ultimately be printed in extenso elsewhere, I would then only notice two results which had been obtained in connection with them, and which bore more closely upon the subject of armour-plate resistance. For similar reasons I now select, from this year's continuation of the same trials, certain results which belong particularly to the subject of the present Paper, and which may well be considered here without interfering with a full discussion afterwards of the general results of the completed trials of strengthened masonry.

The first case to be noticed is that of round called 2,394, which was fired at the sandwich target of two 8-in. wrought-iron plates, with 5 inches of elm between them, bolted together and to a masonry wall with 5 inches of elm between the armour and the stonework, as described in last year's Paper at page 160.

This target remained in the state in which it had been left after round 2,384, except that some timber had been fitted into the hole made through the armour by that round, and the continuation of that shot hole in the masonry had been run full of Portland cement, concrete and grouting.

It will be seen that last year's round (2,384) at this target was from the 16-in. M.L. gun of 80 tons, with a Service Palliser projectile weighted with sand to 1,700 lbs. which struck with a velocity of 1,568 f.s. and an energy of 29,000 foot tons. This projectile pierced the armour, and penetrating the masonry to a depth of 8 feet (3 ft. 6 in. of granite, and 4 ft. 6 in. of Roach Portland stone) was found embedded there, and broken into fair-sized pieces. The brick-work forming the back of the wall (total thickness 22 feet) was very slightly bulged and cracked.

The present round (2,394) was fired from the 12 in. B.L. gun of 43 tons with a Service Palliser projectile weighted with sand to 714 lbs. which struck the target with a velocity of 1852 f.s. and an energy of 17,000 foot tons. This projectile pierced the armour, and then, inclining a little to the left, and slightly downwards, it penetrated the masonry to a depth of 5 ft. 8 in. (3 ft. 6 in. of granite, and 2 ft. 2 in. of Roach Portland Stone), and was found there broken. The injury to the armour was of so local a character that no connection whatever was formed between the two shot holes, although they were only 4 ft. 8 in. apart, measuring from centre to centre of holes. The old cracks in the masonry were opened a little more, but very few new cracks were formed, and the general structure was not much shaken or displaced by this round. The back of the wall was even less injured than it was by round 2,384.

To compare the effects of these two rounds at this target it may be assumed that the projectile in 2,384 would have perforated an unbacked solid wrought-iron plate 24 inches thick, and that in 2,394 one 22 inches thick, while the actual penetration of the former exceeded that of the latter by only about two feet of boring in Roach Portland Stone, though perhaps the heavier blow of 2,384 had more effect generally upon the structure than 2,394 had. The apparent anomaly of two shot, with such widely different energies, penetrating a work of this kind to so nearly the same extent, is clearly to be reconciled by the difference of their diameters affecting their relative powers of penetration. The result of round 2,394 confirms the favourable opinion expressed in last year's Paper as to the efficiency of the way of armour plating masonry walls tried in this target.

The next case to be noticed is that of a mass of Portland cement concrete faced with wrought iron 3 inches thick composed of three 1-in. plates riveted together, the iron face being held to the concrete by long 2-in. w.i. bolts used in the proportion of one bolt to every 13 superficial feet of front.

This target was struck twice by projectiles from the 16-in. M.L. gun of 80 tons (rounds 2,403 and 2,405), one being a Palliser shell and the other a common, and both being weighted with sand to 1,700 lbs.

It must be mentioned at once that the concrete of this target had not had time to set and on the days of trial it was damp and soft throughout.

The principal points to be noticed in this experiment are these:

That the 3 inches of wrought iron seemed to offer much the same amount of resistance to penetration as did the facing of granite 3 feet 6 inches thick, which on the former occasion of this target being tried, (round 2,386) formed its front.

Next, that the behaviour of the 3-in. wrought-iron facing was very satisfactory, the effect upon it being confined to a clean hole cut through it by each projectile, and only a very slight bulge formed outwards over a circular surface of some four or five feet radius round the shot mark.

Also that 3 inches of wrought iron backed by a mass of comparatively soft concrete is sufficient to break up common shell from he 80-ton gun striking it direct with a velocity of 1,570 f.s. This latter point is established by the fact of the common shell, round 2,405, having made an oblong hole through the iron front, the hole being made up of two half circles of 16 inches diameter separated from each other by a distance of about 4 inches, which intermediate space was of course also cut away.

Trial of 18-in. Compound Plates at Shoeburyness, 1883–4.

In continuation of the notice under this heading in Volume IX. Paper XI. page 156, some additional practice can now be reported.

As explained last year the principal object of these experiments was to solve a problem of the greatest possible importance to both the land and sea services, namely, that of procuring a more suitable and effective projectile, than any yet manufactured, for the attack of hard armour, such as compound, or steel, plates and masses of chilled cast iron.

In discussing this question in last year's Paper and on other occasions, it has been shown that hard steel projectiles had not maintained in use against these hard substances that immense superiority over cast iron and other kinds of projectiles which they had indisputably established in the days of soft wrought-iron armour, and it was thought that in consequence of this there would be a tendency to revert to solid cast-iron projectiles of the Palliser type for the attack of all hard armour. This at any rate was the state of things in this country which had to be reported up to the end of last year, and it cannot be said to be a satisfactory one.

On the Continent great activity is being shown in this important matter, and steel shot made at Krupp's works, with a percentage of carbon as high as 0·8, have been said to have given excellent results. In France it is said that steel projectiles have been made to perforate, without breaking up, steel armour plates 15¾-in. thick made at Creusot, and also that 14-in. steel projectiles from the French 73-ton B.L. gun have pierced 19-in. armour plates without material alteration to their form. Both the Russian and French Governments are said to be ordering large quantities of steel battering projectiles.

On the other hand, it will be seen that the latest trials in this country have not contributed much towards a successful solution of this difficulty, and especially it is to be regretted that the further experience in oblique fire, which was looked forward to last year, seems still as far off as ever.

The following are the chief particulars of the rounds fired in 1884:—

In round 2,388 the 16-in. M.L. 80-ton gun was used with a service Palliser shell weighted to 1,700 lbs. Its striking velocity was 1,582 f.s., giving an energy on impact of about 29,500 foot tons. The target was precisely similar to those used in the former part of this series, as described last year, and consisted of a 5 ft. by 5 ft., 18-in. compound plate, 6 inches of steel (0·7 carbon) and 12 inches of wrought iron, made by Messrs. Brown and Co. of Sheffield, and confined in a strong frame embracing all four edges. The plate was backed by a mass of timber nine feet thick resting in rear against a massive iron structure. This plate proved to be a bad one through some fault in manufacture by which the steel became very imperfectly welded to the wrought-iron back, and the poured steel forming the heart of the plate was moreover very much honey-combed. Notwithstanding these grave defects the shell, which was a good specimen of its kind, did not penetrate deeper than about 8 inches into the plate, though it completely wrecked it. The plate was broken into seven main pieces and nearly the whole of the steel was separated from the wrought iron. No part of the shell however passed into the backing of the target.

In round 2,392 the same gun was used with a steel shell against a precisely similar target, in order to institute a comparison between chilled cast iron and steel projectiles for the attack of hard faced armour. The shell was one of a supply of forged crucible steel projectiles made in 1881-2 for H.M.S. *Inflexible*. It weighed 1,669 lbs., and struck the plate with a velocity of 1,595 f.s., giving an energy on impact of about 29,430 foot tons, or nearly the same as that in round 2,388.

This plate proved to be a better one than the last, but still the welding of the steel to the wrought iron was very indifferent over the greater part of it. Like the last plate this was broken into seven main pieces by the shot which was itself excessively disfigured and flattened about the head and broken in the body. The depth of penetration in this case actually measured no more than 5 inches, and, as before, though the plate was so much broken up no part of the projectile passed into the backing of the target.

One effect was produced in this round which, though not unusual under certain circumstances, is curious and interesting. This consisted in the shot having punched out a circular disc of the steel face of the plate about 6 inches in diameter and $2\frac{1}{2}$ inches thick. The steel of the disc appeared to belong to the very front part of the plate, which in armour of this particular make is slightly harder than the rest of the steel. As this phenomenon has been observed only on occasions when thick steel-faced plates of very hard material have been attacked, the explanation of it seems to be this—that the best projectiles hitherto used, being unable to retain their form of head on coming in contact with the steel of the plates, become either flattened or broken in their heads, so that instead of the armour being indented as by a sharp-pointed tool, it is subjected to intense pressure over a circular area of greater or less diameter, as it were by a flat-headed punch, and the steel so pressed being backed by other steel and wrought-iron, which are more or less compressible, a circular piece of the face becomes detached from the adjacent parts, which are not subjected to like pressure, and the separate disc is the result. It may be mentioned that this particular effect is more often observed when forged steel projectiles are used against compound armour than with hard cast-steel or cast-iron projectiles. It need scarcely be said that the whole exterior of one of these discs is invariably found to be highly blued and very hot. The back of the disc in the present case was quite smooth and highly polished, as was also that spot in the armour from which it had been separated.

In round 2,396, the 12-in. B.L. gun of 43 tons was used against a target precisely similar to those against which the last two rounds were fired. The object of this round was to test a forged steel shell which had been made in the Royal Gun Factories for competition with the other steel projectiles which had been tested. This shell weighed 728 lbs., and struck the 18-in. compound plate forming the target with a velocity of 1,893 f.s., giving an energy on impact of 18,090 foot tons. It will be seen that this was a considerably heavier blow than those given by the same gun in the former rounds of this series (Nos. 2,363, 2,371, and 2,381) reported in Paper XI., Vol. IX.

The plate was broken by the blow into six principal pieces, and part of the steel face was flaked off from the wrought-iron back. The shell formed an indent 8 or 9 inches deep, but was itself broken into a very great number of pieces. Of its head a small piece of the point retained its form, and showed a high degree of tempering. The bulge formed on the back of the plate was 3·2 inches high. On the whole, it was thought that the performance of this shell compared favourably with that of Messrs. Cammell's forged steel shell in round 2,371, but that it did not show sufficient superiority over the Service Palliser projectiles to justify the adoption of the much more costly and difficult process of manufacture which it would involve.

Round 2,399 was for the trial of a special shot which had been made in the Royal Laboratory Department, and was composed of 78 per cent. of scrap steel, mixed with 18 per cent. of pig iron of three different kinds and with other ingredients. The steel of the shell contained about 1·6 per cent. of carbon. It was cast from crucibles.

Unfortunately this shell was made for a gun of new calibre (11-in. B.L.), which circumstance somewhat hinders the comparison of its performance with that of other steel shell. The gun was the same as the service 43-ton gun except as to calibre. The shell weighed 583 lbs., and struck the 18-in. compound plate, which was set up as before, with a velocity of 2,176 f.s., representing an energy on impact of 19,146 foot tons. This, therefore, was a heavier blow by upwards of 1,000 foot tons than that of the last round.

The plate was broken into four principal pieces, and otherwise cracked. The shell penetrated to a depth of about 8 or 9 inches, and broke up into innumerable pieces, the head being entirely destroyed. 600 fragments of this shell were recovered, which weighed 318 lbs.

The bulge formed on the back of the plate was 4¼ inches high. The steel separated from the wrought iron of the plate over about one-third of its entire area.

So far as comparison could be instituted this shell was not thought to have proved superior to a Service Palliser shell for the attack of hard armour, though it must be borne in mind that we have had no actual experience with shell of that kind against steel-faced armour at the very high velocity attained in the present round.

In the summer of 1884, an $11\frac{1}{2}$-in. compound plate (one-third steel, two-thirds wrought iron) made by Messrs. Cammell & Co., of Sheffield, was tried in this country, and as this was another instance of steel of a high degree of hardness (0·8 per cent. carbon) being used in the face of a plate, and of a steel projectile being employed, a few particulars of the trial will be given. The plate measured 8 feet by 6 feet 3 inches, and weighed about 11 tons. It was slightly curved on the face, as it represented a ship's turret plate, and was bolted by eight $3\frac{1}{2}$-in. bolts to a thick butt of oak.

The gun used was the 10-in. R. M. L. gun of 18 tons, throwing a solid steel shot of 400 lbs., made by Messrs. Armstrong, Mitchell & Co., with a special charge giving a velocity on impact of about 1,450 to 1,500 f.s. An analysis of a piece of the shot gave the following result:—

Carbon	0·618 per cent.
Silicon	1·074 ,,
Manganese	0·642 ,,

This blow made an indent in the face of the plate some 13 inches deep with six radial cracks extending a good way across the plate, but only in one case reaching its edge. The shot broke up, leaving its head and a good part of the body sticking in the plate. On the back of the plate a bulge was formed $5\frac{1}{8}$ inches high, with two cracks across it, and one circular crack at the base of the bulge. This was a good deal more penetration than would have been effected by a Service Palliser shell, and was more than was expected from a steel projectile.

In the autumn of 1884 a somewhat instructive trial took place at Shoeburyness, in which the effect of a compound (cast-iron and steel) shot was compared with that of a Service Palliser shell against compound armour.

The target at which these two projectiles were fired consisted of a plate, 5 feet by 5 feet, and 12 inches thick (4 inches of steel, 8 inches of wrought iron) backed by fir timber and supported by a butt of shingle and earth. The plate was held to the timber by four 3-in. w.i. armour bolts screwed into its back.

The gun was a 9·2-in. B.L. steel gun.

The first round (2,407) was fired with a compound shot, consisting of a chilled-iron head and cast-steel body, weighing 394 lbs. It was fired with a velocity which gave at the target 1,811 f.s. and an energy of 8,960 foot tons. This blow is equal to the penetration of 18 inches of wrought-iron armour. The point of the shot penetrated to a depth of $7\frac{1}{2}$ inches, its head remained sticking in the plate, and the body in two main pieces rebounded 5 yards. There were small cracks on the face of the plate, both radially and circumferentially, and one large one. In rear a bulge was formed 5 inches high, with cracks on the bulge, and the wrought iron of the back was not thoroughly welded. The quality of the shot was very good; the steel of the base excellent. 71 pieces of the shot weighed 242 lbs.

In the other round (2,415) at this plate, a Service Palliser shell was fired from the same gun. It weighed 380 lbs., and struck the plate with a velocity of 1,845 f.s. and an energy of 8,969 foot tons. It struck within 20 inches of the last shot, and broke up small, but penetrated to a depth of 8 inches, though part of this was no doubt due to the proximity of the other shot hole. In rear a bulge was raised, 7½ inches high and joining on to that of the last round. One armour bolt was broken. 150 pieces of the shell weighed 127 lbs.

On the whole the performance of the compound steel and iron shot was better than that of the Palliser Service shell, though not to any very marked extent.

About the same time a blunt-headed chilled cast-iron shot was compared (rounds 2,411 and 2,412) with a Service Palliser shell, mark II, by being fired from a 6-in. B.L. gun at an 11-in. compound armour plate. Both projectiles weighed 100 lbs., and they struck with energies of 2,243 and 2,298 foot tons respectively. The result of the trial confirmed previous experience by showing once more that the blunt form of head is entirely unsuitable to Palliser material, and will in no case compare favourably with the pointed form of head for chilled iron projectiles.

One other trial was made in the autumn of 1884, which may be briefly mentioned here.

Two compound plates, made by Messrs. Cammell, each 6 feet by 6 feet and 12 inches thick (4 inches steel and 8 inches wrought-iron) and one ordinary wrought-iron armour plate, 7 feet by 4 feet 6 inches and 15½ inches thick, were set up, one after the other, in front of the sandwich target (two 8-in. plates with 5 inches of wood between them) which formed part of the structure of armoured masonry against which round 2,394 was fired as described in the early part of this Paper. The plates were merely blocked out from the target, not bolted to it, and were not held in any frames.

The 9·2-in. B.L. steel gun was used, throwing Cammell's compound shot (chilled iron heads, steel bodies).

Round 2,406 was fired with a 378 lbs. shot, which struck one of the compound plates with a velocity of 1,646 f.s. and an energy of 7,100 foot tons. This would have perforated an unbacked 16·2-in. wrought-iron plate. As it was it hit too near the edge of the plate to give a very satisfactory result, but it only raised a bulge 4 inches high at the back of the plate. The head of the shot remained in the plate, and the body broke in large-sized pieces.

Round 2,413 was fired with a shot of 387 lbs., at the other compound plate, and struck it fair with a velocity of 1,608 f.s. and an energy of 6,938 foot tons. The shot broke up, leaving its head in the plate, and the body, especially about the shoulder, broke into a good many pieces, but the material of it was very good. It raised a bulge on the back of the plate only $1\frac{1}{2}$-inch high.

Round 2,414 was fired at the wrought-iron plate, with a shot of 380 lbs., which struck with a velocity of 1,488 f.s. and an energy of 5,941 foot tons. This shot by calculation would have perforated an unbacked wrought-iron plate $14\frac{1}{2}$ inches thick, but it indented this one to a depth of 14 inches only, forming a bulge on the back $3\frac{1}{4}$ inches high, with a star crack across the bulge.

The trial shows that these compound shot may be expected to remain entire, though somewhat set up, on striking wrought-iron armour at a velocity of about 1,500 f.s., but not on striking steel-faced armour at about 1,650 f.s. Also it affords a useful comparison of the resistance of two kinds of armour to the penetration of shot, and shows that at any rate until the present projectiles are very much improved upon, a 12-in. compound plate may be trusted to give considerably better resistance to a single shot than a wrought-iron plate $15\frac{1}{2}$ inches thick; thus showing that a good margin of safety is allowed by the approximate rule given in Paper XII., Vol. IV., 1880, that 'for a single blow a good compound plate will stop a shot which would perforate an ordinary iron armour plate of from one-eighth to one-fourth greater thickness.'

Special Trial of Heavy Compound Armour, at Shoeburyness, 1884.

This trial originated with Messrs. Cammell & Co., of Sheffield, who made a large compound plate at their own expense, with a view to getting it tested before proceeding further with large contracts for this kind of armour.

Round 2,397. The plate was one of grand dimensions, measuring in length, as sent to Shoebury, 10 feet 8 inches, in width 9 feet, and in thickness $18\frac{3}{4}$ or 19 inches. It weighed, therefore, some 33 tons as set up for trial, and not less than 49 tons as it originally came from the rolls.

It was made by the process known as Wilson's Patent, and consisted of $6\frac{1}{3}$ inches of steel (carbon 0·724 per cent.), and $12\frac{2}{3}$ inches of wrought iron.

For the trial the plate was held by sixteen 4-in. steel bolts, 2 feet long, screwed to a depth of $4\frac{1}{2}$ inches into its back, and nutted inside the front wall of a supporting structure, which represented very nearly a section of a ship's side, of the *Camperdown* class, at the water line. This section was composed entirely of steel, and consisted of skin and frames, which were heavier than usual, though in consequence of certain defects of construction they did not give adequate or satisfactory support to the armour. The immediate backing to the armour plate consisted of $11\frac{1}{2}$ inches of teak wood and horizontal steel stringers attached to the skin of the ship by means of angles at intervals of 12 inches. The framework of the supporting structure rested at a distance of 7 feet 6 inches in rear against a massive target consisting of a 4-ft. wall of timber in front of a large wrought-iron case, measuring 15 feet by 15 feet, by 10 feet deep, filled with Portland cement concrete, and weighing complete upwards of 130 tons. The front of the case was made of very strong cellular construction.

The gun used for the test of this target was the 16-in. M.L. gun of 80 tons, at a distance of 120 yards.

The programme really included one round from this, aimed at the centre of the armour plate, and four rounds from an 11-in. B.L. gun of 43 tons, with various charges, aimed at points nearer to its corners, but, as will be seen, the state of the plate after the first round did not admit of this programme being carried out.

The projectile used in the first round (2,397) was a Service Palliser shell, weighing 1,700 lbs., fired with 450 Prism 1 powder, which gave a velocity on impact of 1,590 f.s. and an energy of 29,800 foot tons.

The main effect of the blow was to break the plate into five separate pieces by clean cracks radiating from the shot mark, and as eleven out of the sixteen bolts by which the plate was held on to the ship's side were broken, mostly through the first thread of the part which was screwed into the armour, one large piece, constituting nearly a quarter of the plate, fell to the ground, another large piece was just ready to fall off, and the other pieces were very insecurely held.

In addition to the main radial cracks, there were some circular cracks formed round the shot mark.

The actual penetration of the point of the shell did not measure more than about four inches in depth, and no part of the shell got into the backing. The shell broke up into small pieces, a portion of it being reduced to mere powder. The manufacture of the plate was exceptionally good as regards the welding of the steel to the wrought iron; the steel was close and fine, and free from much honey-combing, and the wrought-iron fractures showed fine crystals. The face of the plate had the appearance of great hardness.

A conical disc of steel belonging to the very front part of the plate was punched out. It was somewhat similar to those noticed above, under round 2,393, but in this case the disc was $6\frac{3}{4}$ inches thick, and from 5 to $8\frac{3}{4}$ inches in diameter.

The extreme point of the shell remained embedded in the disc to a depth of 2·4 inches.

As regards the bolting of this target, it will be seen on reference to Paper XI., Vol. IX., page 155, that after the trials of steel and compound armour in Italy and Russia in 1882–3, there was a disposition amongst the manufacturers to increase the number of bolts for holding these kinds of plate, and it is presumed that it was this that led to so large proportion as one 4-in. bolt to every area of six superficial feet of plate being used in this target.

In any case, however, it cannot be said that the result was a remarkable success, and the observations at the head of page 156 of the Paper above quoted seem to be borne out by the result of the present trial.

With bolts of better construction, as, for instance, on the plan mentioned in Paper XII., Vol. IV., of this series, page 178, greater efficiency might have been gained in the present target, even if much fewer bolts had been used, or say in the proportion of one bolt to ten superficial feet of plate.

The structure of the ship's side gave very unsatisfactory results, and its failure, as already intimated, was the chief cause of the complete collapse of the armour plate at the first round fired at it.

One of the most instructive lessons in the matter of compound armour that could possible be learnt is to be acquired by a study of this round in comparison with the result of round 2,385 as given in Paper XI., Vol. IX., page 161.

In these two trials we have a 12-in. compound plate presenting 49 square feet of face, and a 19-in. compound plate presenting 96 square feet of face. Both were made in the same factory by exactly the same patented process, the only difference as to quality of material being that the steel in the larger and thicker plate contained some 0·15 per cent. more carbon than that used in the other, rendering the former steel rather harder than the other. Carbon in steel of 12-in. plate, 0·57 per cent.; of 19-in. plate, 0·72 per cent. But there was a vast difference between the two ways in which the plates were set up.

The large thick plate had a comparatively yielding, weak, and faulty structure behind it; the smaller and thinner plate was secured to a massive, unyielding masonry wall, with a thin layer of five inches of wood between the plate and the masonry.

It is fair to mention again that the 12-in. plate was confined in a strong wrought-iron frame surrounding it on all sides, after the manner of a picture frame, while the 19-in. plate had no such lateral support; but, on the other hand, it is only right to explain that a frame of this kind has never yet of itself prevented a compound plate from splitting to pieces under a heavy blow if disposed to do so, and also that, so far as past observation goes, such a frame does not affect to any appreciable extent the depth to which a projectile will penetrate a plate.

The remarkable difference in the behaviour of the two plates under very nearly equal blows from precisely similar projectiles must, therefore, be accounted for by other causes, and this can only be traced to the difference between the backing and supports of the two targets. While the thinner and smaller plate was only so far penetrated that the shell remained sticking in it, with its point protruding some 13 inches to the rear, the plate remaining entire, with slight cracks only on its face and none at all on its back outside the area of the bulge formed round the head of the shell; in the case of the thicker and larger plate, while the depth of penetration was altogether insignificant, the plate was completely demolished by the one round. Also while the smaller plate was efficiently held by four 3-in. w.i. bolts (1 to $12\frac{1}{4}$ square feet), not one being injured, the larger plate was most insufficiently held by sixteen 4-in. steel bolts (1 to 6 square feet), nearly three quarters of them being broken off short.

It would undoubtedly have been more satisfactory if, before drawing final conclusions upon every particular of these two rounds, the trials could have been repeated with plates made of steel of precisely the same degree of hardness; but still, without this, it is not thought too much to say that, in cases where restriction as to weight is non-important, as it almost invariably is in land defences, the arrangement of backing and support applied to the 12-in. plate is one eminently suited to compound armour; and it is strongly urged that, if ever it should be determined to plate masonry with compound armour in this country, the arrangement which offered such splendid resistance in round 2,384 should be followed as closely as possible, even to the detail of having a little wood, or other crushable material, interposed between the armour and the stonework. Moreover, the quality of the 12-in. plate should be imitated exactly wherever compound armour may be required for the strengthening of masonry. Although it is not my business here to advise as to the method of applying ships' armour, I cannot help thinking that naval architects would do well to study the arrangements of backing and support which we gave to this 12-in. plate before designing another armour-clad ship. Also, it is not unfair to conclude, after these trials, that the subject of fastening armour of all kinds to masonry has now been thoroughly mastered.

No. 2,398. This 19-in. compound plate having, as above explained, been thus almost demolished by round 2,397, the rest of the original programme had to be abandoned; but before removing the guns one round was fired from the 11-in. B.L. gun of 43 tons at the proper right-hand lower piece of the five main pieces into which the plate had been split. This piece was held by only two bolts, and the support in rear of it had been more or less injured and weakened by round 2,397. There is, therefore, not very much to be learned from this trial, but it may be as well briefly to notice it here, if only for the sake of recording the depth of indent obtained.

The projectile used was a forged steel shell, specially made by Messrs. Cammell & Co. It weighed 578 lbs., and struck the piece of plate with a velocity of 1,891 f.s. and an energy of 14,330 foot tons. The shell broke up, a portion of it being in fairly large pieces, but the head was set up and flattened out excessively. The piece of plate struck was itself again broken into five principal pieces, and part of its steel face became detached from the wrought-iron back. A conical piece of the steel face was again punched out by the head of the shell. This time the disc was about 8 or 9 inches in diameter, and $8\frac{1}{2}$ inches thick, and the extreme point of the shell was embedded in it to the depth of $2\frac{1}{4}$ inches. The total penetration of the point of the shell was taken at $4\frac{1}{4}$ inches, but it was impossible to determine this with any exactness.

Both the bolts holding this piece of armour were broken, and the supporting structure received considerable injury in this round.

All that can be considered as gained by the round is a confirmation of the opinion formed after the previous trial as to the extreme hardness of the steel used in the face of this plate, and of the satisfactory welding of its steel face to the wrought-iron forming its back.

It is understood that, instead of repeating these trials against another target set up on the principles of this one, a better distribution of the material will be made, whereby some of the weight of armour in this target will be thrown, as it were, into backing and support, thereby diminishing the thickness of the armour, and gaining increase of stiffness in the backing and supporting structure. Probably front armour 16 inches thick, and even only 14 inches and 12 inches, will be substituted for the 19-in. plate. It is expected that a trial of this improved arrangement will shortly come off at Shoeburyness.

A resort to this principle in armour-clad shipbuilding has long been advocated in the iron fortification branch, and judging from what has now been witnessed at Shoeburyness there can be little doubt as to the correctness of the views which gave support to this principle.

Inclined Armour.

The question of defence by means of inclined armour has now assumed a place of so much importance from the uses to which it is likely to be applied in cupolas and other parts of land works, and from the great use to which it is being turned in strengthened decks for both armour-clad ships and unarmoured cruizers, that, before dealing with the subject of some recent trials of inclined targets, it may be well to recount briefly our previous experience in the same field of experiment.

On reference to Vol. XIX. of Corps Papers, 1871, page 109, it will be seen that a deck, consisting of wrought-iron beams 10 inches deep, spaced 2 feet apart, and covered with two thicknesses of ¾-in. wrought-iron plate, and 4½ deal planks on the top of all, can be easily pierced by a 13-in. sea service mortar shell (spherical), filled with sand, and fired with 20 lbs. of L.G. powder at an elevation of 45°, and a range of about 4,200 yards; but that a similar shell fired with a charge to give, at the same angle, a range of 2,800 yards, will not go through such a deck, though it will pierce a similar deck plated with only one inch of wrought-iron.

Also it was proved at the same time that a Service Palliser shell, fired blind from the 9-in. R.M.L. gun of 12 tons, with 43 lbs. R.L.G. powder, at 100 yards range, and with an energy on impact of 3,011 foot tons, will not quite pass through the same kind of deck when covered with two thicknesses of ¾-in. wrought-iron plate if it strikes at an angle of incidence of 8°, though it will very severely injure it.

In Vol. XX., 1872, at page 47, it will be seen that the last-named shell, if fired as a live shell at the same range and angle of incidences, was thought to be more than a match for the same deck covered with two thicknesses of ¾-in. wrought-iron, and that it will certainly pass through it, and explode in doing so, if fired so as to strike at higher angles with the deck.

In Vol. XXI., 1873, page 125, it is shown that the above experiments were followed by others, in which 9-in. and 10-in. R.M.L. guns were used against stronger decks.

These decks consisted of bulb beams 11 inches deep, spaced 4 feet apart, covered with three thicknesses of 1-in. wrought-iron plating, and 4 inches of oak on the top; also of 8-in. bulb beams, spaced as the others, covered with two thicknesses of 1-in. wrought-iron plate, and $3\frac{1}{2}$ inches of oak planking.

No instance of complete perforation occurred with either of the guns in this trial when the angle of incidence did not exceed 10°; and the general conclusion drawn from the trial was that the stronger of these two decks was just proof against the 10-in. live Palliser shell striking at an angle of 10° with the deck, and with an energy of 5,055 foot tons, while the weaker deck just kept out the 9-in. live Palliser shell striking, at the same angle, with an energy of 3,396 foot tons. Flat-headed steel shell did not prove more damaging to the decks than the service-headed (1·5d) Palliser shell.

In September, 1881, the above results were to some extent confirmed in the course of experiments made by the Admiralty at Eastney. In these trials there were used 2-in. wrought-iron plates, 2-in. steel plates by various makers, 2-in. compound plates, besides plates made of Whitworth steel scales (14 inches square) either $1\frac{3}{4}$ or 2 inches thick screwed to 1-in. steel plates. All these were screwed to 1-in. wrought-iron backing, thus making the targets 3 inches thick generally, and they were supported on transverse beams.

Unfortunately, in disregard of the experience gained at Shoeburyness in the early trials already mentioned, these targets were set up in front of the 10-in. R.M.L. gun of 18 tons, at such an angle of inclination that its Palliser shot fired with full battering charge struck the plates at an angle of 15°, and with an energy of upwards of 5,000 foot tons. Under these conditions the targets, as might have been expected, proved quite unequal to the gun, and little or no comparison could be instituted between the various materials of which the decks were composed.

It was, however, found that the 3 inches of steel or iron in these targets broke up all the projectiles fired at them, from which it was inferred by those who conducted the trials that the decks which these plates represented would have kept out the explosive force of shells from this particular gun.

Afterwards, when the 10-in. gun was used with the reduced charge of 60 lbs. P. Powder (striking energy about 4,330 foot tons) against some of the same targets at the same angle, the gun was found to be still overpowering and the 9-in. R.M.L. gun of 12 tons was used for a few rounds, but even this gun was too powerful for the targets when set up at 15° to line of fire, and much the same effect was produced by it as by the 10-in. gun. It is much to be regretted that these trials did not afford more positive information.

The next time that deck targets were tried was in April, 1882, at Eastney, when 2-in. wrought-iron, compound, and mild steel, plates were secured to 1-in. wrought-iron backs, resting on transverse bulb beams, were fired at by the 9-in. R.M.L. gun of 12 tons with Service Palliser shot striking at an angle of 10° with the face of the plate.

These trials gave results which agreed fairly well with those obtained at Shoeburyness nearly ten years before, and proved that a deck made up of a 2-in. wrought-iron plate on an inch back, is sufficient to keep out Palliser shot fired from the 9-in. M.L. gun, with battering charges, and striking at an angle of 10° at any range.

Moreover, this experiment gave colour to suspicions entertained after the trials of the previous year that wrought iron was as good a material as any other for shot-resisting decks. Also it appeared that mild steel came next in value to wrought iron, and steel-faced plates came last.

Next came the trials of deck armour in December, 1883, which were also carried out by the Admiralty, at Eastney, with the 9-in. R.M.L. gun firing Service Palliser shot and shell with 1½ diameter heads and battering charges. These were instituted for the comparison of decks covered with 2-in. mild steel plates on 1-in. mild steel backing, and three 1-in. plates of the same material. The decks were supported on 9-in. wrought-iron bulb beams, spaced 3 feet apart, resting on timber. The angle of incidence was made to be 10°, and the striking energy 3,500 foot tons. Some common shell were also fired.

The conclusions arrived at were not very important or well-established. No clear comparison between the two kinds of decks was obtained. The 2-in. mild steel on 1-in. of the same material seems to have given inadequate protection against the Palliser projectiles, inferior protection in fact to that which the 2-in. wrought-iron on 1-in. wrought-iron gave against the same projectiles in 1882. The effect of common shell, even when they burst, was inferior to that of Palliser projectiles. The latter were generally broken up on striking, the former always. The Palliser shell with 1½ diameter heads were thought to be more effective in this trial than those with the 2 diameter heads.

The only other trial of deck armour remaining to be noticed are those which took place at Amager, near to Copenhagen, for the Danish Government, in March, 1883. This deck was inclined to the horizon at an angle of 7°, and was made of plates 50 mm. (1·97 inches) thick laid on a steel deck 17 mm. (·669 inches) thick, resting on deck beams. The 50 mm. plates were made of Schneider steel, Cammell's compound armour, and wrought iron, supplied by Marrel Frères.

The guns were a 9-in. R.M.L. Armstrong gun, throwing a 230 lb. Palliser projectile with an energy of 3,128 foot tons, and a 6-in. Krupp, 35 calibres B.L. gun, throwing a steel projectile of 102 lbs., with an energy of 2,253 foot tons.

None of the 50 mm. plates was perforated and the effect of the two guns was essentially the same. The steel plates were thought to offer the best resistance.

The targets set up for these trials presented, in addition to these deck plates, various 100 mm. plates set up at an angle of 24° with the horizon. The same gun was used against them as against the decks. In this series the steel plates kept out all the projectiles, but after one round at each plate nothing but fragments remained. The compound plates kept out two projectiles out of four. The wrought-iron plates kept out four projectiles out of five. It was considered doubtful by the officers who conducted these trials whether the steel 100 mm. plates would have maintained this superiority against heavier guns. Some of the plates were covered with a facing of cork, but this, as might have been known from very old experience at Shoeburyness, was found to have no effect.

Trial of Armour in Denmark, 1884.

These trials took place at Amager in March and June, 1884, and were expected to settle the relative merits of wrought iron, steel, and compound, armour for the protection of the vertical sides of turrets; and at the same time to compare projectiles made of chilled Swedish gun iron with steel projectiles made by Krupp, all with pointed heads and all unloaded.

The plates, which were curved to a radius of 10 feet 6 inches, were about 228 mm. (8·9 inches) thick, and measured about 5 feet by 6 feet 6 inches; they were backed by 9 inches of oak, and were attached to structures representing the framing of turrets by armour bolts screwed a short distance into their backs.

The wrought-iron plate was of French manufacture produced by Marrel Frères. The steel plate was made by Schneider of Creusot. The compound plates were made by Messrs. Cammell and Messrs. Brown, of Sheffield, and consisted of one-third steel, two-thirds wrought-iron. The compound plates were slightly thicker than the others. The Sheffield plates were held by twelve bolts to each, the Marrel by eleven, and the Schneider plate by sixteen bolts.

The guns used were a 10-in. M.L. gun of 18 tons, throwing battering projectiles of steel and of chilled iron which struck with energies of about 5,550 foot tons and velocities of about 1,400 f.s., and a 5·9-in. Krupp B.L. gun of 95 cwt. throwing steel and chilled iron projectiles with energies of about 2,360 foot tons and velocities of some 1,740 f.s.

The result was generally as follows:

In the wrought-iron plate two through cracks were formed by the first round from the Krupp gun, showing that the plate could not have been of a quality at all approaching to our Sheffield wrought-iron armour.

The Creusot steel plate was completely broken in two by a similar round, and the two Sheffield compound plates were slightly cracked on the surface but less deeply indented. In every case the steel shell was broken up.

By a second round at each plate with steel shell from the 10-in. gun one of the halves into which the Creusot plate had been broken was completely demolished; the Marrel plate was penetrated and much broken, the shell remaining entire; the Sheffield plates were penetrated and a corner of each knocked off, the shell having struck too near their edges.

Cammell's compound plate having hitherto offered the best resistance a third round was fired at it with a 10-in. chilled iron shot, which however proved altogether too much for the target and threw the plate and its supports some distance to the rear. The shot however did not pierce the plate.

Marrel's and Brown's plates now alone remained fit for another round and for these the 5·9-in. gun was considered quite powerful enough. A chilled shot from this gun at each of these plates damaged the Marrel much more than the Brown plate; the penetration in each case being less than those by the steel projectiles.

On the whole it may be said that, on account of the insufficient dimensions of the targets, and the overpowering energies of the 10-in. gun used in these trials, they did not afford so much useful experience as might otherwise have been gained from them.

The conclusions drawn from the trial by the Committee of officers who conducted them were to the following effect:

That the preference was to be given to the Schneider steel and Cammell's compound plates, though the ground for this opinion as regards the former plate is not very clear.

That the nature of backing used largely influences the resistance offered by steel and compound plates.

That the perforation of steel and compound plates produces much more destructive effect than the perforation of wrought iron.

That hard steel projectiles are to be preferred to chilled iron, though where excess of *vis viva* occurs in the projectile the latter are very efficient.

That 9-in. steel and compound plates do not afford sufficient protection against the 10-in. M.L. gun at short range.

That a good compound plate requires for its perforation at least 25 per cent. more *vis viva* in a given projectile than a wrought-iron plate of the same thickness.

ITALIAN EXPERIMENTS IN 1884.

As these Papers have in previous years included reports of the very important trials of heavy armour which have been carried on from time to time by the Italian Government, the present Paper will conclude with a brief notice of one which took place at Spezia on 1st October last, though it must be explained that as this experiment occurred subsequently to my relinquishing the post connected with Iron Fortification which I have held for so many years, this account must be taken as a mere interim report, to serve until some one having access to better sources of information can more thoroughly sift the results.

The trial was instituted to bring out the relative merits of steel and compound armour for the protection of ships of the *Italia* and *Lepanto* class, in the Italian Navy, against guns of the type which they themselves will carry.

Three plates were tried on this occasion. Each was 48cm (nearly 19 inches) thick, about 9 feet 6 inches long and 8 feet wide, and weighed some 26 tons.

One was of forged Schneider steel from the works at Creusot, and two were compound plates (one-third steel, two-thirds wrought iron) made by Messrs. Cammell and Messrs. Brown of Sheffield by their usual patented processes.

The steel of those plates contained carbon as follows: Schneider's steel plate 0·42 per cent, Cammell's compound plate 0·87 per cent, Brown's compound plate 0·81 per cent.

Each plate was set up with a compound backing consisting of wood and iron stringers 20 inches deep immediately behind it, and these were bolted to a strong ship's side, representing one of the Italian war ships, by 18 armour bolts.

The first gun used was the 17-in. B.L. Armstrong gun of 100 tons with forged Krupp projectiles and battering charges of 350 kilos of Fossano Powder, which is somewhat less charge than the highest intended for this gun, but the range was only about a hundred yards.

The energy of each blow on impact was about 44,160 foot tons.

One of these blows delivered in the centre of each plate pierced the target and split the plate into from 3 to 5 pieces. The shot which passed through Cammell's compound plate went a shorter distance into the sand behind than that which went through the Schneider steel plate. In Brown's compound plate the steel face was not thoroughly attached to the wrought-iron back.

It is understood that the compound plates broke these steel projectiles into smaller pieces than did the steel plate. That fired at the latter plate being found practically in four pieces, all of which were inside the target.

Subsequently to the above practice a 10-in. B.L. Armstrong gun of 25 tons, delivering blows of about 15,000 foot tons each, was used with Krupp steel projectiles for a few rounds.

One of these blows at Messrs. Brown's plate left nothing more to be fired at. Two at Messrs. Cammell's plate reduced it to much the same condition. But the Schneider steel plate stood four of these rounds, though it was completely broken up by them; so much so in fact that at last it was reduced to a mere heap of fragments, it having been separated into more than 15 pieces. The indents made by these 10-in. projectiles measured from 12 to 13½ inches in depth in the steel plate, 13 to 13¼ inches in Messrs. Cammell's compound plate, and 14¼ inches deep in Messrs. Brown's compound plate.

It is said that in this case also the projectiles fired at the compound plates were broken into smaller pieces than were those which struck the steel plates.

It will be instructive to compare these results with those obtained in the former Italian experiments of 1882–3, reported Paper XI. Volume IX.

January 10th, 1885. T. I.

PAPER VI.

HYDRO-PNEUMATIC GEAR FOR SIEGE AND HEAVY ORDNANCE.

Two Lectures delivered at the School of Military Engineering, Chatham, during the Spring of 1885.

By W. Anderson, Esq., M.I.C.E.

HYDRO-PNEUMATIC GUN-CARRIAGES.

The object of the lectures, which the Commandant has done me the honour of asking me to deliver, is to explain the principles upon which Hydro-pneumatic Gun-carriages are designed, and the mechanical details involved in their construction.

I will assume that you are conversant with the laws of motion, and with the method of calculating the strength of structures when the strains affecting the several parts have been ascertained. I will therefore commence by saying a few words about the compression of gases; I will then describe some forms of Hydro-pneumatic Carriages; next, I will examine, in detail, a particular design; and, finally, I will describe some of the mechanical details on which the success of a carriage very much depends.

The recoil of guns can be taken up directly by the compression of air, without the intervention of any liquid, but there is a practical inconvenience in the method arising from the circumstance that it is impossible to construct a cylinder so that there shall be no clearances; that is, that the ram or piston shall completely sweep through the whole volume of the cylinder and expel all the air, a certain quantity will remain, and, as a margin must be left in the stroke of the piston or ram, this quantity may at times be considerable, and would be under a greater pressure than that necessary to balance the gun after its motion had ceased. A partial recoil would consequently take place, just like in the buffers of railway carriages, which react and force the carriages apart as soon as they have been brought to rest by the work of compressing the buffer springs.

By filling the cylinder full of water, and confining the air in a vessel separated from the cylinder by a passage fitted with an automatic valve, opening from the cylinder towards the air vessel, no elastic matter remains in the cylinder to affect the ram, while the air in the air vessel is prevented from doing so by the valve interposed.

Hydro-pneumatic compressors may be arranged to control the recoil of guns mounted on ordinary carriages; there is, however, no great advantage to be derived from such an application, because the recoil can be absorbed very efficiently by the simple hydraulic compressors, and the guns can be run out by giving a moderate inclination to the slides. The use of compressed air is always objectionable on account of the liability to leakage, the space occupied by the air vessels, and the necessity of providing pumps to keep up the pressure.

But when guns are mounted on the disappearing principle, the properties of elastic gases, as agents for storing the energy of recoil, become exceedingly valuable, and, in fact, form the sole means of accomplishing the object in view when the guns exceed, what is now considered, a very moderate calibre.

Gases, such as those constituting atmospheric air, which are far removed from their points of condensation or liquefaction, may have their volume and pressure varied, either without change of temperature, or, if the variation takes place very suddenly, before heat can escape or be communicated, with a rise or fall of temperature corresponding to the work performed on the gas or done by it.

In the first case the pressures will vary as the ordinates of an isothermal curve, in the latter of an adiabatic.

When gases are compressed or suffered to expand at constant temperature the volumes vary inversely as the pressures, so that if p and v be the pressure and volume at one time, and $p_1\ v_1$ at another, then

$$p_1 v_1 = p\ v = \text{a constant},$$

from which equation any one of the four values which is unknown may be derived. The work done in compressing along the isothermal

$$= p\ v \log^e \left(\frac{v}{v_1}\right).$$

When gases are compressed, or allowed to expand so that heat can neither escape nor be communicated, the temperature rises or falls to a degree corresponding to the work done in compressing the gas, or done by the gas in expanding, the number of units of heat corresponding to the work done is either imparted to, or taken away from, the gas; hence if gases are heated without being allowed to change their volume, although the pressure will increase, less heat is required than if the pressure is kept constant and the volume allowed to increase, the reason being that in the first case no external work is done, while in the latter the atmosphere or some other load is lifted.

The absolute zero of temperature is $-460°$ F. or 492° below the freezing point, and gases free to expand dilate in direct proportion to their absolute temperatures, or, if they are confined, the pressure rises in the same proportion. The absolute zero of *pressure*, that is absolute vacuum, is 14·7 lbs. per square inch $-$ 2117 lbs. per square foot below the atmosphere, and you must be very careful to remember that in all calculations connected with gases absolute pressures and temperatures should always be used.

One pound of air confined in a vessel requires ·169 units of heat to raise its temperature one degree F. At the freezing point, or 492° absolute, 1 lb. of air is represented by 12·387 cub. feet. If we double the temperature we shall raise the pressure to 29·4 lb. absolute and consume

$$1 \text{ lb.} \times 492° \times \cdot 169 u. = 83\cdot 150 \text{ heat units.}$$

If, however, we allow the air to expand, causing it to lift the atmosphere, keeping the pressure constant to 14·7 lb. absolute, we shall double the volume and displace 12·387 cubic feet of air. The work done will be =

$$12\cdot 387 \text{ c. ft.} \times 2117 \text{ lbs. per sq. foot} = 26{,}222 \text{ foot pounds};$$

dividing this by Joule's equivalent, 772, we get 33·966 units of heat absorbed in the work, and therefore one pound of air will require $83\cdot 150 + 33\cdot 966 = 117\cdot 116$ *u.* to double its temperature at constant pressure, the ratio

$$\frac{117\cdot 116}{83\cdot 150} = 1\cdot 408$$

is known in mechanics by the Greek letter γ, and is the ratio of the specific heat of gases at constant pressure (for air ·238) to that of constant volume (for air ·169).

Gunpowder gases are nearly three times the weight of air. 1 lb. measures 4·458 c. ft. at 492° absolute, and the specific heat at constant volume is ·183; therefore doubling the temperature and pressure of 1 lb. of gas at constant volume will absorb

$$1 \text{ lb.} \times 492° \times \cdot 183 = 90\cdot 03 \text{ units,}$$

and the work of displacing the atmosphere, caused by doubling the temperature and volume, that is, displacing 4·458 c. ft. of air, is

$$= \frac{2117 \text{ lb.} \times 4{\cdot}458 \text{ c. ft.}}{772^{u}} = 12{\cdot}22 \text{ units};$$

$$\text{therefore } \gamma = \frac{93{\cdot}03 + 12{\cdot}22}{90{\cdot}03} = 1{\cdot}143.$$

The equation to the adiabatic curve is

$$p = p_1 \left(\frac{v_1}{v}\right)^{\gamma} \quad \frac{p}{p_1} = \left(\frac{v_1}{v}\right)^{\gamma};$$

and if $t\ t_1$ be the absolute temperatures,

$$\text{then } \frac{t}{t_1} = \left(\frac{v_1}{v}\right)^{\gamma-1} = \left(\frac{p}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

The work done in compressing or expanding along the adiabatic curve, reckoning always in absolute pressure,

$$\text{W} = \frac{p_1 v_1}{\gamma - 1}\left\{1 - \left(\frac{v_1}{v}\right)^{\gamma-1}\right\}$$

$$\text{or W} = \frac{p_1 v_1}{\gamma - 1}\left\{1 - \left(\frac{p}{p_1}\right)^{\frac{\gamma-1}{\gamma}}\right\}$$

If the volumes are taken in cubic feet then the pressures must be in pounds per square foot.

I will now describe two or three types of carriages designed under the personal directions of Colonel Moncrieff, whose name, you are no doubt aware, is so closely associated with the system of Artillery on the investigation of which we are engaged.

MONCRIEFF HYDRO-PNEUMATIC CARRIAGE, FOR 9·2″ B.L.R.G.

By Messrs. Easton and Anderson.

Plate I.

The body of the carriage consists of a pair of V-shaped frames (A) made of boiler plate and angle iron, attached at their apex and lower end to a cast steel pivot (B) working in a pivot plate (C), embedded in and secured to the masonry or concrete at the bottom of a well formed in the middle of the gun-pit. The upper ends of the frames are connected solidly together by cross frames, and supported by six horizontal rollers or trucks (D), which run round a cast iron roller path (E) secured to the masonry of the upper edge of the well.

Through the forward upper portion of the frames passes a wrought iron rocking shaft (F), on to which are keyed a pair of wrought iron levers (G), the upper ends of which are formed into bearings for the trunnions of the gun and fitted with cap squares.

Between the levers, about one-third of their length from the fulcrum, is placed a crosshead (H), into which is keyed the upper end of a connecting rod, the lower end of which rests in the bottom of a hollow plunger or ram (I), sliding through a gland, packed with leather or hemp, into an inclined cast-iron cylinder (J) bolted securely between the two frames. The plunger is a little smaller in diameter than the cylinder, but terminates in an enlargement, or piston, which fits the bore and serves at once as a guide, an automatic throttle valve, and a stop to prevent the ram being forced out too far. To the lower forward end of the cylinder is fitted a recoil valve communicating with two wrought-iron air-vessels (L) placed inclined, parallel to, and under the cylinder. From the lower end of the air vessels a pipe, controlled by a screw stop-valve (M), communicates with the upper end of the cylinder just below the gland. This connection serves for raising the gun into the firing position, and the port or passage by which the pipe enters the cylinder is so arranged that the piston end of the ram, as the gun rises, gradually closes the opening, and so brings the gun gently to rest.

The elevating arrangement consists of a pair of trunnions (N) secured in any convenient manner to the breach end of the gun; of a pair of elevating bars (O), the upper ends of which are attached to the trunnions by elastic connections, and the lower ends turn round a shaft which crosses from side to side of the frames, and the ends of which are fitted into slide blocks working in guides (P) secured to the inner faces of the frames.

The slide blocks are elevated by screws passing through them, and the two screws are turned simultaneously by bevil wheels actuated by a shaft, common to both, crossing the frames, and brought into motion through bevil gear by means of an inclined hand-shaft (Q), which can be actuated either from the level of the gun-pit or from the bottom of the well.

The training-gear can also be operated either from the upper or lower level of the emplacement.

A rack (S) is formed just below the roller-path in the casting forming the upper margin of the gun-well. Into this rack gear a pair of pinions, actuated by vertical shafts passing up through the deck over the well, into gearing pillars (R) secured to it, and having hand-shafts connected with the vertical shaft by means of bevil gear. The lower ends of the vertical pinion shafts are produced downwards, and, by means of inclined shafts, are also operated, through bevil wheels, by a hand-shaft (V) attached to the lower ends of the main frames.

The well is completely decked over by splinter-proof plating (W), and access to it may be obtained either by trap-doors through the deck and ladders, or by a covered way from the side.

To protect the men loading, a screen (X) is fitted to the framework and revolves with the carriage. An aiming platform may be arranged to suit the particular situation of the emplacement.

Two sets of small pumps (Y) are fixed, one on each side of the main frames, and actuated by hand wheels, one set for charging the air vessels with air, and the other for lowering the gun from the firing to the loading position, by pumping water from the cylinder into the air vessel.

The following are the principal dimensions :—

	ft.	in.
Diameter of gun-pit	30	0
Depth of ditto	10	6
Diameter of well	20	0
Fall of gun vertically	10	6
Length of path described by trunnions . .	17	6
Diameter of recoil cylinder	0	30
Stroke of ditto	5	3
Depth of well	12	0
Average air pressure	234 lbs.	

MONCRIEFF HYDRO-PNEUMATIC CARRIAGE, FOR 10″ B.L.R.G.

By Messrs. Easton and Anderson.

Plate II.

The body of the carriage consists of a pair of wrought-iron beams (A) connected together so as to form a solid frame. Towards the middle of the lower side of the frame is a pivot plate (B), fitting on to a pivot piece (C), securely bedded in the masonry or concrete of the emplacement. The outer ends of the frames are carried on two pairs of cast-iron wheels or rollers (D), travelling on a roller-path (E) embedded in the floor of the emplacement.

On the upper side of the frame, towards the middle, are secured a pair of cast-steel pedestals (F), which carry a wrought-iron rocking-shaft (G), on to which are keyed a pair of bent wrought-iron levers (H), the upper ends of which are formed into bearings for the trunnions of the gun, and fitted with cap squares.

The lower ends of the bent levers are connected by a wrought-iron shaft (I), round the middle of which is clasped the outer end of a connecting rod, the opposite end of which abuts into a recess in the bottom of a hollow trunk or plunger (J), which works into the horizontal recoil cylinder (K) through a gland packed either with leather or hemp packing.

The plunger is a little smaller in diameter than the cylinder, but terminates in an enlargement or piston, which fits the bore, and serves at once as a guide, an automatic throttle-valve, and a stop to prevent the ram being forced out too far.

The cylinder is of cast-iron, and is secured to the side girders of the main frame.

Planted on the rear end and top of the cylinder are two automatic recoil valves (L), which communicate with two wrought-iron air vessels (N) placed horizontally, one on each side and over the cylinder. A branch pipe from the lower sides of the air vessels, common to both and controlled by a screw stop-valve (O), serves for elevating the gun into the loading position, and communicates with the recoil cylinder close behind the gland at its outer end, entering it by a port, which is gradually closed, as the gun rises, by the passage of the piston-shaped enlargement, which forms the outer end of the ram, so soon as the gun is nearly up to its full height, thus bringing it to rest in a very gradual manner. Buffers (P) are provided to check the gun, both in its downward and upward movements.

The elevating arrangement consists of a pair of trunnions (Q) secured in any convenient manner to the breach end of the gun, and a pair of elevating bars (R), the upper ends of which are attached to the trunnions by elastic connections, and the lower ends turn round a shatt which crosses from side to side of the frame, and the ends of which are fitted into slide blocks working in guides (S) secured to the inner faces of the girders forming the frames.

The slide blocks are elevated by screws passing through them, and the two screws are turned simultaneously by skew-wheels, actuated by a hand-shaft which crosses the carriage and is worked from either side by a hand-wheel (T). A scale properly graduated will indicate the degree of elevation of the gun.

To soften the kick-up of the carriage at the moment of discharge, the front end of the main frame is fitted with a pair of short-stroke hydraulic compressors (U), the piston-rods of which are attached to brackets (V), which slide along a rail secured to cantilevers (W) built into the wall of the emplacement, and securely held down. The cantilevers carry a splinter-proof platform, which runs round the gun-pit, and serves as a banquette from which the operations of the detachment may be directed and the gun laid.

The compressors act both ways; that is, they will resist the upward kick of recoil, and will also lower the carriage gently after the motion of the gun has ceased. The compressor cylinders are solid at the bottom, so that the liquid used, once filled in, cannot leak out.

The training of the carriage is effected by hand-wheels (X) on each side of the front end of the frame, which actuate the front wheels or rollers by means of suitable gearing.

The hand-wheels and shaft for training can also be used for working a pair of pumps (Y), intended for forcing air or water into the air vessels, or for lowering the gun from the firing into the loading position; this is effected by pumping the water from the cylinder into the air vessels.

The men attending to the training and elevating are protected by the parapet from the enemy's fire.

The drawing shows an arrangement of a shield, by which the detachment can be protected; also arrangements for facilitating the loading operations.

The following are the principal dimensions:—

	ft.	in.
Diameter of gun-pit	32	6
Depth of ditto	13	6
Fall of gun vertically	9	0
Length of trunnion path	14	3
Diameter of recoil cylinder	0	26
Stroke of ditto	3	8
Average air pressure	430 lbs.	

MONCRIEFF HYDRO-PNEUMATIC CARRIAGE, FOR 6·6″ M.L.R.G.

By Messrs. Easton and Anderson.

Plate III.

The body of the carriage consists of a pair of wrought-iron frames (A), composed of plates and angle-irons framed together at the ends and connected likewise at the centre, underneath, by the pivot plate (B), which turns round the pivot (C) formed on a casting solidly imbedded in the masonry of the emplacement, and secured to it by foundation bolts. The rear end of the carriage is carried by a pair of trucks (D), which traverse on the cast-iron racer (E) imbedded in the masonry. The trucks are each fitted with trains of wheels (R) actuated by winch handles, through the instrumentality of which the training of the gun is effected. The front end of the carriage is carried by a single truck (D′), which also runs on the racer (E).

The vertical kick of the forward end of the carriage is controlled by a pair of hydraulic cylinders (S), shown in detail in Plate IV., the lower ends of which are hinged to a sliding-piece which traverses in the grooved racer (T), while their piston rods are secured to a cross beam riveted on to the end of the carriage. The extreme lift allowed is six inches. The pistons fit loosely in the cylinders, allowing sufficient leakage to enable the water to pass with the necessary rapidity from the upper to the lower side of the piston. The cylinders having solid bottoms, there is no danger of the water leaking out, and as in the normal position of the carriage the pistons are down, and their rods are as far in the cylinder as they can be, there is no risk of too much water being put in when the compressors are being filled.

A shaft (F) rocks in bearings formed in the upper forward end of the carriage frames, and has keyed on it a pair of arms (C), the upper ends of which terminate in bearings which receive the trunnions of the gun, which are secured in the usual manner by cap squares. Half way up the arms is pivoted the crosshead (H), secured to the outer end of the ram (I), the lower end of which works into the cast-iron cylinder (J), arranged to oscillate on trunnions resting in bearings formed in the main side frames of the carriage. The ram works through a gland packed with a U leather collar, and the lower end is enlarged to form a solid piston, which not only prevents the ram being forced out too far, but also serves to shut off the water by which the raising of the gun is effected, by covering the port (*a*) by which the water enters the cylinder. Communication from the upper annular space to the lower part of the cylinder is provided by means of four holes through the piston.

The cylinder (J) communicates with a steel air vessel (L) through a passage fitted with a recoil valve (K), opening from the cylinder towards the air vessel. The valve is well supported by guides, and is held up to its seat by means of a spiral spring.

In the left-hand trunnion (*b*) is the raising valve, worked by a handle (M), which opens a communication by means of the pipe (C) between the water space of the air vessel and the upper end of the cylinder, so that when the valve is opened the water in the air vessel is forced by the pressure of the air into the water cylinder, and so presses out the ram and raises the gun.

A pair of trunnions (N) are fixed in any convenient manner on the rear end of the gun, and connected by the elevating bars (O) to pivots formed in blocks sliding in the frames (P) secured to the main frames of the carriage. The blocks are actuated by screws, the upper ends of which carry tangent wheels operated by a cross shaft, common to both, fitted with a hand-wheel on each side. For the purpose of hauling down the gun when not fired, a recessed drum or barrel (V) receives a chain which passes over a sheave attached to the rear cross frame of the carriage, and hitches on to a hook secured to the upper end of one of the main arms.

The barrel is operated through a train of wheels by a winch handle (W) projecting on the right hand of the carriage.

An aiming platform (*d*) is supported on bars hinged to the main arms, and to the upper side of the carriage; this platform rises and falls with the gun.

For the purpose of making good any small leakage of air or water, a small differential pump (U) is attached to the rear cross frame of the carriage, and is connected to the cylinder by a coil of ¼ inch copper pipe.

MONCRIEFF HYDRO-PNEUMATIC CARRIAGE, FOR 6″ 5 TON B.L. ARMSTRONG GUN.

By Messrs. Sir W. G. Armstrong, Mitchell, and Co.

Plates V. and VI.

The body of the carriage consists of a pair of frames (A), composed of steel plates and angles, tied together at each end by segmental arcs (B), which rest on a ring of live rollers (C), which in their turn travel round a fixed roller path (D), which forms part of a massive casting secured to the masonry of the emplacement. The live rollers are made with flanges at each end, which overlap the upper and lower paths, and thus afford both lateral and vertical support to the carriage, and enable a central pivot to be dispensed with.

To the upper forward end of the main frames cast-steel brackets are attached, and take a rocking shaft (E), on to which is keyed a pair of cast-steel main arms (F), in the upper ends of which are formed the bearings for the gun trunnions (G), which are retained in their places by cap squares, arranged to slide in under snugs in the arms, thus dispensing with bolts and nuts. The cast-steel hydro-pneumatic cylinder (H) is fitted with trunnions (I) about its centre, and is carried by bearings attached to the inner sides of the main frames (A). The cylinder has its air-vessel (J) cast on its back, and is fitted with a recoil valve (K), accessible through a cover conveniently placed.

The ram terminates at its upper end in a cross-head (L), which works on to a pin keyed into the main arms, and its lower end is formed into a piston of slightly greater diameter, which works in the truly bored cylinder, and serves as a stop to prevent the gun rising too far.

The valve (M), for raising the gun by opening a communication between the water space of the air-vessel and the cylinder, is in the bottom of the latter, and is actuated by a handle (N), conveniently placed at the rear end of the carriage, the said valve being also closed automatically when the gun has risen to the proper position by a cord (O), one end of which is attached to one of the main arms, and the other to a lever actuating the valve. To prevent the gun falling too low buffers (P), are fixed on the rear ends of the main frames, and so disposed as to receive the backs of the upper ends of the main arms just behind the trunnions.

The elevating gear consists of a pair of bars (Q), the upper ends of which are pivoted on trunnions, fixed to the breech end of the gun, and the lower ends to curved racks (R), which work in guides secured to the outsides of the main frames ; the racks are so curved that when the gun is in the loading position their traverse does not affect the gun. The elevating is operated by a hand-wheel (S), on one side of the carriage, actuating the racks through a train of wheels.

The training of the gun is effected by hand-gear (T), attached to each side of the forward end of the carriage. A large hand-wheel gives motion through a pair of bevil wheels to a vertical shaft, the lower end of which carries a pinion (U), which engages into a circular rack cast on to the base plate of the carriage. On the same plate is arranged a clip ring (V), into which engage clips in front and rear to prevent the carriage kicking up. A chequered plate platform is attached to each side of the carriage, and covers the roller path and rack.

Having discussed the laws relating to the properties of gases, and described, generally, several types of hydro-pneumatic carriages, I think that I shall best make my subject clear to you by going step by step through the designs of a particular example, and I will select a carriage recently made and now under trial at Shoeburyness. This carriage, the same as that which is illustrated on Plates III. and IV., is intended for a permanent emplacement; it pivots completely round in a pit 13 feet diameter by 9 ft. 6 in. deep, and carries one of the old 6 ft. 6 in. M.L.R.G.

The chief dimensions are the following :—

Diameter of bore	6 ft. 6 in.
Volume of bore	1·922 cubic feet
Length passed over by the shot . .	6 ft. 6 in.
Weight of shot	100 lbs.
Weight of powder	25 lbs.
Weight of gun	7,595 lbs.
Extreme vertical fall of gun . .	4 ft. 5 in.
Muzzle velocity	1,460 feet

The first point to be determined is the energy of the discharge. This consists, so far as recoil is concerned, of three items only.

1. The energy imparted to the shot.
2. The energy expended in ejecting the powder gases.
3. The energy expended in displacing the atmosphere.

1. The energy absorbed by the forward motion of the shot is easily calculated when the muzzle velocity is known. It is in this case

$$\text{W. shot} = \frac{100 \text{ lbs.} \times 1460^2}{2240 \times 64{\cdot}4} = 1477{\cdot}6 \text{ foot tons.}$$

The energy expended in rotating the shot does not affect the recoil, but tends to turn the gun on its longitudinal axis in the opposite direction.

2. The energy expended in ejecting the powder gases is, unfortunately, a matter of conjecture. We are still in complete ignorance as to the pressure of the powder gases in the bores of guns during the time the shot is travelling out. The only indications we have are those afforded by crusher gauges, but there is good reason to believe that these are utterly untrustworthy. The indications of crusher gauges depend upon the shortening of standard copper cylinders, which are exposed to the pressures in the bore; the shortening is compared with changes of length produced by known pressures slowly applied, and, at first sight, very accurate results might be looked for; but in all changes of form in metals *time* is an essential element, therefore in order that crusher gauges should give comparable indications they must either be exposed to pressure for a sufficient time to enable the shortening due to the pressure to be completed, or else the time during which they are exposed to the known standard pressure, and to that of the powder gases, must be the same. As neither of these

conditions are attainable in practice, it follows that the records of crusher gauges must be erroneous, and that, too, on the dangerous side—they must be too low.

I find a confirmation of this view in the circumstance that Captain Noble ascertained that the pressures registered by crusher gauges agreed very closely with the pressures calculated from the increments of velocity of the shot only; but this, we shall presently see, leaves out of the record the energy absorbed in expelling the gases, in displacing the atmosphere, and in overcoming some internal resistances with which we are not now concerned.

The usual way of treating these items of the energy of discharge, when they are not neglected altogether, is to add the whole, or a portion of the weight of the powder to that of the shot, and suppose that the two are ejected with the same velocity. Colonel Kemmis, R.A., has constructed his tables of the energy of recoil upon this basis, adding the whole of the weight of powder to that of the shot.

There is no rational foundation for this method; it takes no account of the length of the gun, the volume of the bore and powder chamber, the mode of ignition, or the quality of the powder, yet it is well known that all these points have an important influence on the flight of the shot, and therefore on all the motions which take place in the chase.

In a recent lecture at the Society of Arts (January 29, 1885), in treating of a gun as a heat engine, I indicated how the pressures in the bore may be ascertained from observations on recoil, by means of the Sébert velocimetre, and I trust that the Ordnance Committee will give my method a trial; but as the experiments have not yet been made, and therefore no law has been determined, I must point out to you the methods by which an approximation to the energy of discharge may be arrived at.

We have already seen that 1 lb. of pebble powder produces 4·458 cubic feet of gases at 14·7 lb. per inch pressure, and at the freezing point. If we suppose the surrounding temperature to be 60° or 520° absolute, then the charge of 25 lbs. of powder will develope $25 \text{ lbs.} \times 4{\cdot}458 \text{ cubic feet} \times \frac{520^\circ}{492^\circ} = 117{\cdot}8$ cubic feet of gases. Now, if these gases are forced slowly into the gun, so that there should be no change of temperature, the pressure would rise according to the ordinates of an isothermal curve, and the work done would be

$$\text{W. gases} = \frac{117{\cdot}8 \text{ c. ft.} \times 2{,}117 \text{ lbs.}}{2240 \text{ lbs.}} \times \log^e\left(\frac{117{\cdot}8}{1{\cdot}922}\right) = 458{\cdot}2 \text{ foot tons.}$$

If the gases are allowed to expand under the same conditions they would do the above amount of external work, and the reaction, made evident in recoil, would be the same.

The pressure of the gases at 60° in the bore, after they had all been pressed into it, will be

$$P. = \frac{14{\cdot}7 \text{ lbs.} \times 117{\cdot}8 \text{ c. ft.}}{2{,}240 \text{ lbs.} \times 1{\cdot}922 \text{ c. ft.}} = {\cdot}402 \text{ tons per square inch.}$$

But the temperature is much higher than 60° at the moment when the shot leaves the muzzle. How much is not known, but it may be estimated at bright red heat, which is about 1,700°, or 2,160° absolute; and if this be so, then the actual final pressure will be

$$P. = \frac{{\cdot}402 \text{ tons} \times 2{,}160^\circ}{520^\circ} = 1{\cdot}67 \text{ tons per square inch.}$$

The gases produced by 25 lbs. of powder at 2,160° temperature, pent up in a bore having 1·922 c. ft. capacity, weigh $\frac{25 \text{ lbs.}}{1{\cdot}922 \text{ c. ft.}} = 13$ lbs. to the cubic foot, and therefore the pressure of 1·67 tons per square inch would correspond to that of a homogeneous column of gases

$$= \frac{1{\cdot}67^t \times 2{,}240 \text{ lbs.} \times 144 \text{ sq. ft.}}{13 \text{ lbs.}} = 41{,}410 \text{ feet}$$

high. Now, the velocity with which the gases will spring out of the bore, as soon as released by the shot, will be proportional to the square root of this column $= 8\sqrt{41{,}410 \text{ ft.}} = 1{,}633$ feet per second, and the energy will be

$$W. \text{ gases} = \frac{25 \text{ lbs.} \times 1{,}633^2}{64{\cdot}4 \times 2{,}240} = 462{\cdot}1 \text{ foot tons.}$$

But you must bear in mind, on the one hand, that the whole of the gases do not escape at the same velocity; and, on the other, that a certain amount of energy is absorbed in moving the centre of gravity of the gases from the centre of the cartridge to the centre of the chase just before the shot leaves the muzzle, doing therefore a certain amount of work simultaneously with the shot. Had we perfect gases to deal with, the problem of calculating the energy of discharge would be beyond the reach of mathematics, much more is it so when the evolution of gas continues at an unknown rate the whole time that the shot is travelling out of the gun.

We have yet another method for forming an estimate of the work done in expelling the powder. If the gases were suddenly compressed into the bore of the gun, the pressures would rise according to the ordinates of an adiabatic curve, and we should have a final pressure

$$= 14{\cdot}7\left(\frac{117{\cdot}8}{1{\cdot}922}\right)^{1{\cdot}143} = 1{,}623 \text{ lbs. per square inch, or } {\cdot}725 \text{ tons.}$$

The work done in compressing would be

$$W. \text{ gases} = \frac{117.8 \text{ c. ft.} \times 2{,}117 \text{ lbs.}}{{\cdot}143 \times 2{,}240 \text{ lbs.}} \left\{1 - \left(\frac{117{\cdot}8}{1{\cdot}922}\right)^{{\cdot}143}\right\} = 629 \text{ ft. tons.}$$

Comparing these results we get:

Compression along isothermal = 458·2 ft. tons.
Energy derived from pressure = 462·1 ,,
Compression along adiabatic = 629.0 ,,

For our present purpose, I will take the work of expelling the gases as that derived from the observed or calculated final pressure.

Let W = weight of powder in lbs.;
p = final pressure of gases in tons per square inch;
e = velocity with which gases are ejected; and
c = vol. of bore in cubic feet;

then weight of gases per cubic foot $= \frac{\text{W. lbs.}}{c \text{ c. ft.}}$ Height of gas column $= h = \frac{p^t \times 2{,}240 \text{ lbs} \times c \text{ c. ft.} \times 144 \text{ sq. in.}}{\text{W. lbs.}}$ and $e = 8\sqrt{\frac{p \times 2{,}240 \times 144 \times c}{\text{W.}}}$.

$$\text{Work} = \frac{We^2}{64 \cdot 4} = p \times 2{,}240 \times 144 \times c \text{ foot lbs.},$$

$$c = 144\, p\, c. \text{ foot tons,}$$

In this case $= 144 \times 1{\cdot}67^t \times 1{\cdot}922 = 462$ foot tons.

Therefore, the work of expelling the gases in foot tons may be taken as the product of the final pressure in tons per square inch, into the number of square inches in a square foot, into the volume of the bore in cubic feet. You will observe that this is, at any rate, a rational expression, for it takes account of the form of the gun, the nature of the powder, the mode of ignition, and all other circumstances which influence the final pressure. In default of direct determination, the final pressure must be estimated in the manner I have indicated.

The third item, the energy expended in displacing the atmosphere, is easily calculated. It is quite plain that while the shot is travelling along the bore it is pushing the air before it, and the work of doing this is equal to the pressure of one atmosphere on the end of the shot multiplied by the distance the shot travels. But, over and above that, we have 117·8 cubic feet of gas at 60°, and 3,740-5 lb. pressure suddenly produced out of about ·4 cubic feet of powder. The temperature at the moment of the shot leaving the muzzle we have assumed to be 2160° absolute, hence the gases in expanding and displacing the atmosphere would cool

$$\text{to} = 2160^\circ \left(\frac{14{\cdot}7}{3740{\cdot}5}\right)^{\frac{\gamma - 1}{\gamma}} = 2160^\circ \left(\frac{14{\cdot}7}{3740{\cdot}5}\right)^{\cdot 125} = 1081^\circ.$$

The volume will be $\frac{117{\cdot}8 \text{ cubic feet} \times 1081^\circ}{520^\circ.} = 250$ cubic feet.

The work done will be $\text{W} = \frac{250 \text{ cubic feet} \times 2117 \text{ lbs.}}{2240 \text{ lbs.}} = 235{\cdot}6$ foot tons.

Collecting these items, we have

Work in expelling shot . . .	1477·6	foot tons.
" " gases . .	462·1	" "
" displacing air . .	235·6	" "
Total . . .	2175·3	" "

Of this amount no less than 697·7 foot tons, or 48 per cent. of the energy of the shot, is due to the expulsion of the powder gases. According to Colonel Kemmis's tables, it would have been only 25 per cent., the proportion which the weight of powder bears to that of the shot.

Now, according to the third law of motion, this action must have a corresponding reaction in recoil, that is to say,—while the work of ejecting the shot and gases is going on, an equal work, in pushing back the gun and carriage, is being performed; these, therefore, according to the first law of motion, must acquire a certain velocity during the same time that the discharge is taking place, and after that, supposing the gun and carriage perfectly free, the motion would continue uniform for ever.

We do not know the law according to which the pressures vary in the bore while the shot and gases are moving out, we will therefore assume that the pressure is uniform and equal to the mean pressure, and that, consequently, motion takes place in accordance with the laws applicable to uniformly accelerated velocity.

The space passed over by the shot being 6·3 ft., the average pressure along the bore to produce the energy of discharge we have just calculated must be $= \frac{2175{\cdot}3 \text{ feet tons}}{6{\cdot}3 \text{ feet}} = 345{\cdot}2$ tons.

Dividing this by 34·2 square in., the area of the bore, gives a mean pressure of 10·13 tons per square inch.

The powder and shot together weigh 125 lbs. or ·056 ton, the velocity which would correspond to the energy of the discharge would be found thus—2175·3 feet tons $= \frac{{\cdot}056^t \times v^2}{64{\cdot}4}$.

$$\therefore v = \sqrt{\frac{64{\cdot}4 \times 2175{\cdot}3}{{\cdot}056}} = 1584{\cdot}6 \text{ ft. per second.}$$

The quantity of motion or momentum $= 1584{\cdot}6' \times {\cdot}056$ tons $= 88{\cdot}73$, and this is equal to the moment of recoil; that is, the effective weight of the gun and carriage multiplied by the maximum velocity attained.

The effective weight recoiling is composed of the weight of the gun, and the effective resistance of the pair of main levers and elevating bars. To ascertain the amount of these we must ascertain the radii of the circles of gyration.

The circle of gyration is the path described by the mean energy of motion, that is to say, the square of the radius of gyration multiplied by the weight of the revolving body is equal to the sum of the weights of the particle of the body multiplied by the square of their respective distances from the centre of rotation. The velocities being proportional to the distances from the centre of rotation, the squares of those distances will be proportional to the squares of the velocities, and therefore to the energies.

In irregular shaped bodies, such as we have to deal with, the easiest way to get at the radius of gyration is to suspend the body on an axis so that it can swing freely, ascertain the number of beats per minute, and thence calculate the length of an equivalent pendulum by the formula

$$p \text{ in.} = \left(\frac{375 \cdot 36}{\text{No. of single beats per minute}}\right)^2.$$

Next ascertain the distance of the centre of gravity from the point of suspension, then the radius of gyration (r) is a mean proportional between the distance of the centre of gravity from the point of suspension (c), and the length of the pendulum (p).

$$c : r = r : p.$$
$$\therefore r = \sqrt{c \times p}.$$

The two elevating bars in this case weigh 270 lbs. $c = 48 \cdot 7''$, the bar suspended made 47 single beats per minute.

$$\therefore p'' \left(\frac{375 \cdot 36}{47}\right)^2 = 63 \cdot 78''.$$

$$\text{and } \therefore r'' = \sqrt{63 \cdot 78'' \times 48 \cdot 7''} = 55 \cdot 74'';$$

that is to say, the work of rocking the bar may be supposed concentrated at a point 4'·7·74" from the centre about which it turns. The total length of the bar is 90", therefore the equivalent force at the axis of the gun will be

$$= \frac{270 \times 55 \cdot 74''}{90''} = 167 \cdot 2 \text{ lbs.}$$

The main arms which carry the gun weigh 952 lbs. each, and are 6' 6" long. I had no opportunity of swinging them, and in such case it is best to make a wooden model to scale as accurately as possible. I have one here $\frac{1}{8}$ full size. Suspended on the centre line of the shaft it is keyed on, the model swings 134 single beats per minute; this corresponds to a pendulum 7·847″ long, the centre of gravity is 4·95″ from the centre of suspension, hence the radius of gyration is 6·236″, or, multiplying by $8 = 50$ inches, very nearly, on the actual arm; hence the equivalent weight of the two arms at the axis of the gun will be

$$1{,}904 \text{ lbs.} \times \frac{50''}{78''} = 1{,}221 \text{ lbs.}$$

The total effective weight moving in recoil, supposed concentrated in the trunnions, is therefore:

Weight of gun	7,595 lbs.
Effect of main arms	1,221 „
Effect of elevating bars	167 „
	8,983 lbs.,
	or 4·01 tons.

For making the first rough designs, the radius of gyration may be taken at two-thirds the length of the levers and bars.

The maximum velocity of recoil is now easily obtained. Let it be V: then $4{\cdot}01 \text{ tons} \times V' = 88{\cdot}73$ the momentum of discharge $\therefore V = \frac{88{\cdot}73}{4{\cdot}01} = 22{\cdot}12$ feet.

You observe that I equate the momentum, or quantity of motion, of the powder and shot to that of the moving parts connected with the gun. The reason for this is, that the effect of a force is measured by the velocity which it produces per second in a given weight. According to the second law of motion, the velocities imparted to a body are in proportion to the impressed forces, and if the impressed forces are equal, then the velocities attained in the same time will be inversely as the weights of the bodies acted upon.

Now, the powder gases act with the same total pressure, in one direction, in expelling the powder and shot, and in the opposite direction in pushing back the gun and carriage. The impressed force is, in this case, equal in both directions, and acts for the same time; but the gun and carriage weigh about 73 times more than the powder and shot, and hence the maximum velocity of recoil will be 73 times less than the maximum velocity of the projectiles.

You must not confound energy with quantity of motion, or momentum. The unit for the former is the foot pound or foot ton; for the latter it is the unit of weight, or mass of the body multiplied by the unit of velocity per second; the two things are not, therefore, comparable.

The energy of the recoiling mass, which has to be absorbed by the hydro-pneumatic apparatus, is:

$$W = \frac{4{\cdot}01^{t} \times 22{\cdot}12^{2}}{64{\cdot}4} = 30{\cdot}48 \text{ foot tons.}$$

Besides recoiling, the gun falls, and the energy expended in this way must also be met by compressing air. The centres of gravity of the several moving parts of the carriage fall according to the following table:

	Fall	Weight	Work
Gun	4′ 6″	7595 lbs.	34177·5 foot lbs.
Main arms . . .	2′ 4″	1904 ,,	4442·7 ,,
Elevating bars . . .	2′ $6\frac{1}{2}$″	270 ,,	685·8 ,,
Ram	2′ $6\frac{1}{2}$″	757 ,,	1922·8 ,,
Total . . .	—	10526 lbs.	41228·8 foot lbs.
			= 18·41 foot tons
			Equivalent to 4·09 tons raised 4′ 6″ high.

Now we have more than 30 foot tons energy in recoil to be utilised in overcoming friction, and other losses caused by the fall of the gun; the work of balancing the gun itself requires no expenditure of energy, because the fall of the gun would perform work on the air, which would be competent to raise it again were there no loss of heat, and nothing expended in friction. We shall see presently that we have an excess of power, and consequently we need not provide air pressure enough to do the whole work, but sufficient merely to raise the gun smartly, and we may absorb the rest of the energy of the discharge by means of narrow water passages and a loaded valve.

Let us suppose that the gun is raised in eight seconds, allow one second for checking the velocity of rise, this interval will correspond to about $\frac{1}{20}$ of the height, so that the gun must rise 4·27 feet in seven seconds, what will be the accelerating force?

Because $S = \frac{gt^2}{2}$ $\quad g = \frac{2S}{t^2}$

$$g = \frac{2 \times 4{\cdot}27'}{49 \text{ secs.}} = {\cdot}1742 \text{ feet,}$$

$$\therefore \text{ accelerating force} = \frac{{\cdot}1742 \text{ ft} \times 4{\cdot}09 \text{ tons}}{32{\cdot}2} = {\cdot}022 \text{ tons,}$$

$$\text{work of acceleration} = {\cdot}022^{t} \times 4{\cdot}27' = {\cdot}0945 \text{ foot tons.}$$

Besides the dead weight to be raised and the accelerating force, we must provide for friction. By direct experiment, I ascertained that when the carriage was freshly put together, and the oil clean and fluid, the friction amounted to 7 per cent. of the work done in raising the gun; but as gun-carriages stand a long time without being used, and are often allowed to get very dirty, it will be well to double this figure, and call friction 14 per cent.

$\therefore$ work of friction $= (18{\cdot}41 \text{ f.t.} + {\cdot}0945 \text{ f.t.})\ {\cdot}14 = 2{\cdot}59$ foot tons.

The total work required to raise the gun in eight seconds will be :

Work of raising weight	18·41 foot tons
" " acceleration . . .	·09 "
" " friction	2·59 "
Total	21·09 "

We next come to the choice of a hydraulic cylinder of suitable size. This depends on the circumstances of the design and the air pressure it is desired to employ. We must first, however, determine the volume of air to be used. Experience has shown that from two to three times the volume of the ram, when the gun is up, is a good proportion, and in the particular carriage we are considering it is $2\frac{1}{4}$ times, but the precise relation of the volume of the ram to the volume of air depends upon the pressures necessary to support the gun in various parts of the stroke. To determine this, we must construct an indicator diagram of the pressures in the hydraulic cylinder.

Divide the stroke of the ram into, say, 4 equal parts of 10 inches long each, representing a total stroke of 40 in., corresponding to a fall of the gun of 4·43 ft.; this will allow a little margin at the end of the stroke. Construct a diagram (Plate IV.) which will represent the centre lines of the mechanism supporting the gun in the several positions corresponding to the five points of the stroke selected, and measure the angles α, which the centre line of the main arm makes with the vertical, and the angles β, which the ram makes with the line joining the centre of the cross-head, with the centre of the rocking shaft of the main arms. Then, bearing in mind that the ram is attached half way down the main arms, the pressure along the ram at any point will be twice the effective weight of the falling parts multiplied by the sine of α and divided by sine β.

$$p = \frac{2 \times W \times \text{sine } \alpha}{\text{sine } \beta} =$$

The total work of the falling parts when the gun fell 4 ft. 6 in. we have seen was 18·41 foot tons; hence the effective weight supposed concentrated at the trunnions will be $\frac{18{\cdot}41^{-t}}{4{\cdot}5 \text{ ft.}} = 4{\cdot}091$ tons; introducing this into the equation, and doubling on account of leverage, we get the pressure along ram $= \frac{8\cdot18 \text{ tons sine } \alpha}{\text{sine } \beta}$. Calculate this value for each point, and arrange the data in the form of a table.

Points	0	1	2	3	4
Angles α	8° 30′	26° 20′	42° 40′	57° 30′	72° 10′
Angles β	49° 0′	61° 10′	72° 30′	85° 30′	100° 10′
Strain along ram, tons .	tons 1·602	tons 4·142	tons 5·831	tons 6·921	tons 7·909
Strain due to friction .	·766	·766	·766	·766	·766
Strain due to acceleration .	—	·032	·032	·032	·032
Total strain . .	2·368	4·940	6·629	7·719	8·707

Next, to ascertain the pressure due to friction, taking the work of raising the gun to be $4{\cdot}091^t \times 4{\cdot}43$ ft. $= 18{\cdot}12$ foot tons, and the work of acceleration at ·0945 foot tons, the work of friction will be

$$(18{\cdot}12 + {\cdot}0945) \times {\cdot}14 = 2{\cdot}55 \text{ foot tons.}$$

The stroke of the ram is 3·33 ft.; hence the work will be represented by $\frac{2{\cdot}55}{3{\cdot}33} = {\cdot}766$ tons acting during the stroke.

My experiments show that the strain due to friction is nearly constant throughout; it is a little more when the gun is down, because the pressure on the leather packing is greater, but the extreme variation is only as 12 to 10·5; so we may, without sensible error, take it as constant, and add the amount ·766 to each point in the table.

There is one other item of resistance, which depends entirely upon the velocity with which the gun is raised, and that is the pressure necessary to drive the water through the narrow pipe from the air vessel into the cylinder. This pipe is 5 ft. long and $1\frac{1}{4}$ in. diameter. The raising valve is 1 in. diameter. At the rate of 40 in. travel of ram in 8 seconds, which is 5 in. per second, the speed of the water in the pipe will be 28 ft. per second, and in the valve 43·8 ft., the column of water therefore necessary to produce the velocity of flow, and to overcome friction, will be:

$$= \frac{43{\cdot}8^2}{64{\cdot}4} + \frac{28^2 \times 5 \text{ ft.}}{2500 \times {\cdot}104 \text{ ft.}} = 29{\cdot}75 \text{ ft.} + 15{\cdot}08 \text{ ft.} = 32{\cdot}83 \text{ ft.}$$

This column corresponds to a pressure of 14·3 lbs. per square inch all over the base of the ram; hence the work done will be:

$$= \frac{82{\cdot}51 \text{ sq. in.} \times 14{\cdot}3 \text{ lbs.} \times 3{\cdot}33 \text{ ft.}}{2240 \text{ lbs.}} = 1{\cdot}75 \text{ foot tons.}$$

We shall see presently where this power is to come from.

Lastly, we have the small quantity represented by the force of acceleration, equal to ·0945 foot tons in 3 ft. of the stroke of ram = ·0315 tons, acting during that portion of the rise of the gun.

We must now draw a base line (Plate VII.) which shall represent the stroke of the ram, erect ordinates at 0 in., 10 in., 20 in., 30 in., and 40 in., and plot the values we have calculated; the result will be curves which show at any point the pressures necessary to raise the gun. If the calculations have been made correctly, then the area of the figure, bounded by the curves and the base line, will be equal to the work done, estimated in the direct manner; and it is always well to apply this check, in order to make sure of the correctness of the calculations.

We shall see, presently, that the curve representing the pressures due to the expansion of the air in raising the gun will be convex to the curve we have just drawn, and would touch it near its centre.

The air-pressure curve must not come below the curve of pressures necessary to raise the gun: because, if it do, the gun will stick when it reaches that point.

We must now proceed to find out what will be the least air pressure required when the gun is down in order to raise it.

Let V = volume of ram at 40 in. stroke.

Let 2·25 V = volume of air when the gun is up.

Let X = absolute pressure of air with the gun at any other point.

Let 6·7 tons be the pressure above the atmosphere along ram required at half-stroke.

The maximum pressure will be rather more than double the pressure necessary at half-stroke—call it 14 tons—and suppose we wish to limit ourselves to 400 lbs. absolute pressure per square inch, then the area of the ram should be $\frac{14 \times 2240}{400} = 78{\cdot}4$ sq. in., or 10 in. diameter. This dimension, however, will depend also upon the surroundings of the cylinder, and may be increased or diminished to suit the convenience of the design. In the particular carriage we are considering, the ram is $10\frac{1}{4}$ in. diameter = 82·51 sq. in. cross section.

We must never forget, in dealing with gases, that the pressures must be referred to absolute vacuum, or 14·7 lbs. per square inch below the atmosphere; hence we must add a base line to our indicator diagram, $\frac{14\cdot7 \text{ lbs.} \times 82\cdot51 \text{ sq. in.}}{2240 \text{ lbs.}} = \cdot541$ tons, lower than the atmospheric line, and refer all the pressures to that; consequently the pressure to sustain the gun in the middle of the stroke will be $6\cdot7 + \cdot541 = 7\cdot241$ tons absolute.

The air in expanding and raising the gun will fall in pressure nearly according to the ordinates of an adiabatic curve, the volume of air at half-stroke will be $1\cdot75$ V; hence, at any other point,

$$X^t = 7\cdot241 \left(\frac{1\cdot75\,V}{a\,V}\right)^{1\cdot408},$$

the value of a being $2\cdot25$, 2, $1\cdot75$, $1\cdot5$, and $1\cdot25$ at the five points selected.

Having obtained the corresponding values of X, we plot the curve of pressures, which you see just touches the curve representing the strain necessary to lift the gun. When, therefore, the gun is down air must be pumped in till the pressure stands at $11\cdot63$ tons at the temperature of the atmosphere.

Now if the gun is allowed to rise slowly, the pressure will fall according to the ordinates of an isothermal, and the pressures will be

$$X_1 \text{ ton absolute} = 11\cdot63 \left(\frac{1\cdot25\,v}{a\,v}\right)$$

and the value so obtained will enable the curve to be traced.

The pressure, $6\cdot46$ tons, gun up, will be that to which the air will settle down after a few minutes when the gun is raised smartly, although, at the moment of attaining its highest point, it will be only $5\cdot08$ tons. When it is fired, compression along the adiabatic will commence from $6\cdot46$ tons pressure and

$$X_2 \text{ tons absolute} = 6\cdot46 \left(\frac{2\cdot25\,v}{a\,v}\right)^{1\cdot408}$$

the values of X_2 plotted down will give us the curve, and we find a terminal pressure of $14\cdot78$ tons.

In a few minutes after recoil is over, the heat will be dissipated, and the pressure will settle down to the $11\cdot63$ tons we started with.

Next let us calculate the work done along the two adiabatics. The pressures being all measured from absolute zero, we must not forget the work of the atmosphere represented by the volume of the ram $\times$ the pressure against its end.

In the indicator diagram this corresponds to the rectangle between the absolute zero and the atmospheric line.

The work of compressing the air, or done by the air in expanding, is represented by the areas of the two figures bounded by the adiabatic curves and the absolute zero line. The work of compressing is equal

$$\text{W foot tons} = \frac{p_1 v_1}{\gamma - 1}\left\{\left(\frac{v_1}{v}\right)^{\gamma-1} - 1\right\}$$

where

$$\frac{p_1 v_1}{\gamma - 1} = \frac{\text{pressure per sq. in.} \times 82{\cdot}51 \text{ sq. in.} \times 40 \text{ in.} \times 2{\cdot}25}{2240 \times 12 \times {\cdot}408}$$

$$\frac{p_1 v_1}{\gamma - 1} = \frac{6{\cdot}46^t \times 40 \text{ in.} \times 2{\cdot}25}{12 \times {\cdot}408} = 118{\cdot}7$$

$$\text{W foot tons} = 118{\cdot}7\left\{\left(\frac{2{\cdot}25}{1{\cdot}25}\right)^{{\cdot}408} - 1\right\} = 32{\cdot}19 \text{ foot tons.}$$

The work against the atmosphere is

$$= \frac{82{\cdot}51 \text{ sq. in.} \times 14{\cdot}7 \text{ lbs.} \times 40 \text{ in.}}{2240 \text{ lbs.} \times 12 \text{ in.}} = 1{\cdot}81 \text{ foot tons.}$$

Therefore the nett work $= 32{\cdot}19 - 1{\cdot}81 = 30{\cdot}38$ foot tons.

In expanding and raising the gun from 11·63 tons pressure, and 1·25 volume to 2·25 volume, the work will be

$$\text{W foot tons} = \frac{11{\cdot}63^t \times 40 \text{ in.} \times 1{\cdot}25}{4{\cdot}896}\left\{1 - \left(\frac{1{\cdot}25}{2{\cdot}25}\right)^{{\cdot}408}\right\} - 1{\cdot}81 \text{ foot tons}$$

$$= 23{\cdot}49 \text{ foot tons.}$$

In these two equations you will note that, because of the two points from which we start being on the same isothermal, the products of the volume into the pressure is constant, and hence the value on the left side of the brackets is the same in both cases.

The difference between the work done in compressing and expanding=30·38 foot—23·49 foot tons=6·89 foot tons is represented by the area of the figure, bounded by the two curves, and is lost at each complete cycle of operations, the heat due to compression being dissipated in the surrounding space, while, in expanding, the heat from the same space is not communicated fast enough to replace that converted into the visible energy of raising the gun. This source of loss, added to that incurred in the friction of the mechanism, and in producing fluid motion, sets a limit to the height from which a given charge will raise a gun mounted on the disappearing principle.

The total work of raising the gun in eight seconds we have seen is 21·09 foot tons, and the work done in expanding along the adiabatic is 23·49 foot tons, leaving an excess of 2·4 foot tons. This excess is the power I rely on to overcome the resistance, amounting to 1·75 foot tons due to the rapid flow of water through the valve and pipe connecting the air vessel and the cylinder.

The work to be absorbed in recoil consists of two parts—the falling of the gun and the energy of discharge.

The work in the gun falling 4·43 ft. is, we have seen, 18·12 foot tons, but only a portion of this reaches the air which is being compressed, at least 7% is expended in overcoming friction: so we must take 93%, or 16·85 foot tons only, as available. In the same way, of the energy of discharge, which we have calculated to be 30·48 foot tons, only $30·48 \times ·93 = 28·35$ foot tons will be expended in compressing the air, making altogether 45·2 foot tons.

The work of compressing the air we have found to be 30·38 foot tons, so that a resistance equal to 14·82 foot tons remains to be provided for in the throttling of the water passage and load on the recoil valve.

The recoil valve is $2\frac{7}{8}$ inches diameter in the smallest part, and the clear area through it, deducting the centre boss 1 inch diameter, and three wings $\frac{1}{4}$ inch thick each, is 5 square inches. The approach to the valve is tolerably gradual, so that a pretty high co-efficient of discharge may be assumed—say, ·8. If V = velocity with which the water will rush through the valve, and V_1 the velocity of the ram, then

$$V = \frac{V_1 \times 82·5 \text{ sq. in.}}{5 \text{ sq. in.} \times ·8} = 20·63\ V_1$$

and the height of a column of water corresponding to this velocity

$$h = \left(\frac{20·63}{8}\right)^2 V_1^2.$$

The pressure in tons along the ram

$$P = \frac{82·51 \text{ sq. in.} \times h \times 62·2 \text{ lbs.}}{144 \text{ sq. in.} \times 2240 \text{ lbs.}} = ·0159 \text{ h tons.}$$

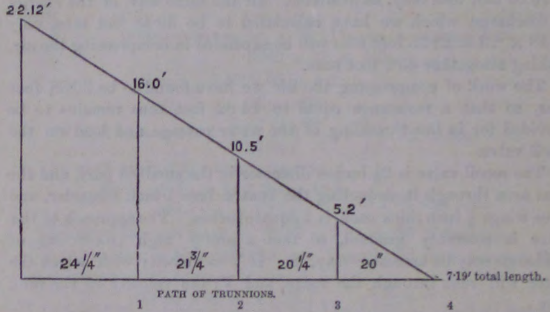
therefore in terms of the velocity of ram

$$P = ·0159\left(\frac{20·63}{8}\right)^2 V_1^2 = ·106\ V_1^2.$$

We shall see presently that the sum of all the resistances to recoil is tolerably uniform throughout the stroke, hence we may assume that the motion is uniformly retarded. The path described by the trunnions is 7.19 feet long, the initial velocity of recoil we have calculated is 22·12 feet, hence the time occupied will be

$$t = \frac{2S}{v} = \frac{2 \times 7·19 \text{ ft.}}{22·12 \text{ ft.}} = 0·65 \text{ seconds.}$$

Draw a base line equal to the length of trunnion path, and set off on it ordinates at the points corresponding to the points 0–4 of the stroke. Set off at point 0, 22·12 ft. the initial velocity of recoil, and join the extremity with the other end of the path by a diagonal line, then erect ordinates at the other points, and measure their lengths up to the diagonal; these will represent the velocities at each point.



You notice that the spaces between the ordinates are not equal, but they each correspond to 10 in. stroke of the ram, hence the velocity of the ram V_1 will be found roughly by multiplying the speed of the trunnions by 10 in., and dividing by the corresponding space.

Points	0	1	2	3	4
Velocity of trunnion .	22·12′	16·00′	10·50′	5·20′	0
Velocity of ram V_1 . .	9·02′	7·36′	5·18′	2·60′	0
Pressure on ram, tons .	8·63	5·73	2·84	·715	0

In the above table the results of the calculations are collected, including the pressures deduced from the equation $\cdot 106\ V_1^2$.

Plotting the ordinates so obtained, and drawing the curve, we measure, say 10 ordinates, and obtain a mean pressure acting on the ram of 3·335 tons, and therefore the work expended in forcing the water through the valve is

$$W = 3\cdot335 \times 3\tfrac{1}{3} \text{ ft.} = 11\cdot12 \text{ foot tons.}$$

The recoil valve, however, is not free; it is loaded by means of a spiral spring, which, by direct experiment, is found to compress $\frac{17}{16}$ in. under a load of 56 lbs., or 3·35 lbs. for each $\frac{1}{16}$ in.

When the valve is closed, the spring is compressed $\frac{1}{2}$ in. or $\frac{8}{16}$ in., so that the load on it will be $8 \times 3{\cdot}35 = 26{\cdot}8$ lbs.

The valve, as the water rushes through, will probably open till the annular opening at the seat is equal to the area of the waterway, which is 5 square inches, hence, the valve, being 3 in. diameter and 9·4 in. circumference, if l be the lift

$$l = \frac{5 \text{ sq. ft.}}{9{\cdot}4 \text{ in.}} = 0{\cdot}5 \text{ in. very nearly ;}$$

hence the compression of the spring will be $\frac{16}{16}$ in., and the load $3{\cdot}35 \times 16 = 53{\cdot}6$ lbs.

The area of the surface of the valve is about 7 square inches, hence the pressure per square inch will be 3·83 lbs. and 7·66 lbs. respectively. These pressures will react on the ram, and will amount to $\frac{3{\cdot}83 \text{ lbs.} \times 82{\cdot}51 \text{ sq. in.}}{2{,}240 \text{ lbs.}} = {\cdot}141$ tons and ·282 tons respectively. We may suppose that this pressure will diminish uniformly with the decrease of velocity, hence the mean pressure will be $\frac{{\cdot}282 + {\cdot}141}{2} =$ ·211 tons, and the work of forcing the water out against the spring will be

$$W = {\cdot}211 \times 3\tfrac{1}{3} \text{ ft.} = {\cdot}703 \text{ foot tons,}$$

adding this to 11·12 foot tons due to the velocity of flow, we have a total of 11·82 foot tons out of the 14·82 foot tons we require, leaving 3 foot tons still to be provided. It is probable that the friction of the water passing from the cylinder to the air vessel, the eddies which will be formed in the irregular shaped passages, and the friction of the packing of ram, will absorb the unbalanced energy ; but if they do not, a little extra air pressure must be added in the air vessel. From the nature of the case, it is impossible to attain great accuracy in these calculations, more especially as the front end of the whole carriage is purposely allowed to rise as much as 6 inches on the vertical compressors in order to soften the blow on the masonry of the emplacement. The work expended in this way will be deducted from that which the discharge can perform in the cylinder and air vessel.

Plotting the ordinates due to the head of flow and to the resistance of the spring on to the adiabatic compression curve (Plate VII.) we get a curve attaining to 15·37 tons in the cylinder at the commencement of recoil corresponding to $\frac{15{\cdot}37^{t} \times 2240 \text{ lbs.}}{82{\cdot}51} = 417{\cdot}1$ lbs. absolute, or 402·4 lbs. per square inch above the atmosphere ; and, in the air vessel, at the end of recoil, 14·921 tons absolute, corresponding to 404·8 lbs. absolute or 390·1 above the atmosphere.

We can now consider the strains on the several parts of the carriage.

At the commencement of the recoil, we have two forces acting on the gun.

1. Centrifugal force. The effective weight of the moving parts concentrated in the trunnions we have taken at 4·01 tons. The main levers are 6·5 ft. long; the velocity of recoil is 22·12 ft. Therefore the centrifugal pull will be:

$$F = \frac{4{\cdot}01 \text{ tons} \times 22{\cdot}12^2 \text{ ft.}}{32{\cdot}2 \times 6{\cdot}5 \text{ ft.}} = 9{\cdot}374 \text{ tons.}$$

The weight of the gun itself is 3·39 tons, acting almost exactly in the opposite direction; hence the unbalanced pull will be $9{\cdot}374^t - 3{\cdot}39^t = 5{\cdot}98^t$.

2. The effect of reaction to the discharge acting tangentially to the trunnion path. This cannot be greater than the resistance to the descent of the ram plus the allowance for friction. The effect produced by the weight of the gun itself is neutralised by centrifugal force. The pressure along the ram capable of being transferred to the trunnion path we find from the indicator diagram to be:

$$\frac{15{\cdot}37 - {\cdot}54}{{\cdot}93} = 16 \text{ tons,}$$

and the value at trunnion $= \frac{16^t}{2} \times \text{sine } 49° = 6{\cdot}04$ tons.

The tendency of this force is to turn the carriage over on the rear trucks, the gun is 10·8 ft. above the racer; hence the turning moment is nearly $10{\cdot}8 \text{ ft.} \times 6{\cdot}4^t = 65{\cdot}2$ foot tons.

The pull of centrifugal force is applied 8·5 ft. from the rear trucks; its moment $= 5{\cdot}98 \times 8{\cdot}5 = 50{\cdot}83$ foot tons, making a total over-setting moment of 116 foot tons. The weight of the carriage is 4·38 tons, and its centre of gravity is about 6 ft. from the rear trucks; its moment is, therefore, 26·28 foot tons acting on the opposite direction, leaving 89·72 foot tons to be met by some mode of securing the carriage to the masonry of the emplacement. If this be at the centre pivot, 4·5 ft. from the trucks, the upward pull will be nearly $\frac{89{\cdot}72 \text{ ft.}}{4{\cdot}5} = 20$ tons; if in the front of the carriage, 10 ft. from the trucks, the pull-up will be $\frac{89{\cdot}72 \text{ ft.}}{10 \text{ ft.}} = 9$ tons nearly. In addition to the vertical pull, a shearing stress of 6·04 tons on the pivot must be provided for. At the end of the recoil, just as the motion ceases, centrifugal force also ceases to act, and the weight of the gun, falling inside the base, helps to keep down the carriage. The upward push of the ram is 14·38 tons, to which must be added ·07 of friction, making 15·39 tons in all; but of this pressure 7·909 tons, less ·07 of friction, is employed in balancing the weight of the falling parts, leaving $7·909 - ·554 = 7·355$ tons to be deducted; this leaves $15·39 - 7·355 = 8·04$ tons acting along ram representing the reaction to the external work of recoil.

The effect along trunnion path$=\dfrac{8·04 \text{ sine } 79·50}{2}=3·95$ tons, and the horizontal component is$=3·95$ sine $17°·50=1·21$ tons. This force is applied 6 ft. $3\frac{1}{2}$ in. above the racers, hence its effect on the carriage will be much less than the corresponding effort at the commencement of recoil; we may therefore confine our attention exclusively to that.

Constructing a parallelogram representing the two forces acting at the trunnions at the commencement of recoil, we find the diagonal which represents the resultant inclined to the rear at an angle of about 45°, hence the bearings in the arms for the trunnions should be open to the front, and the cap squares should be arranged so as to cramp the two sides of the bearings to each other and prevent the outer portion being broken off. In the carriage we are considering, the cap square is hinged at one side and is secured to the other, which it clips, by a stud and key, the latter being attached by a strong chain to the arm. This arrangement is made to avoid loose pieces, which easily get lost or misplaced.

The resultant force at the end of recoil is nearly at right angles to the arm, hence the strain will, in no part of the recoil, come on the cap squares.

The strain tending to break the arms transversely is easily calculated.

The pressure along the ram is about the same at the beginning and end of recoil, but in the latter case the ram is nearly at right angles to the arms, hence the resultant pressure at right angles is greater, and is composed of the total pressure along the ram, plus 7 per cent. friction $= (14·92 - ·54) \times 1·07 = 15·39$ tons; we may therefore consider the arms as a pair of girders 6 ft. 6 in. span, loaded with 15·39 tons in the centre, and calculate the section of metal necessary by the usual rules.

The maximum pressure in the cylinder per square inch will be at the commencement of recoil, and will$=\dfrac{(15·37^{t} - ·54^{t}) \times 2240}{82·51 \text{ sq. in.}}=402·6$ lbs.; hence the tension per inch long of each side, the diameter being 11 in., will be 402·6 lbs. $\times$ 5·5 in. $= 2214$ lbs., or nearly one ton. If the material be cast iron, we should allow a factor of safety of ten on account of the sudden shock, and assuming eight tons per sq. inch to be the ultimate strength of cast iron, we have the thickness $=\frac{1^t \times 10}{8}=1\frac{1}{4}$ in. The cylinder was actually tested to 1200 lbs. per square inch for several hours. It should be noted, that in all tests of this kind, time is an important element, therefore tests should be applied continuously for three or four hours at least.

The trunnions of the cylinder have to carry the same load as the arms, plus the weight of cylinder, ram, air vessel, and water, amounting to $1\frac{1}{4}$ tons, hence the total strain is $15{\cdot}39^t+1{\cdot}25^t=16{\cdot}64$ tons, or 8·32 tons on each trunnion. The dimensions are settled by the diameter required to contain the elevating valve, the thickness of metal must approximate to that of the rest of the cylinder, so that an immense excess of strength is necessarily obtained. In addition, a rib on each side extends over the trunnion, giving it great support.

This excess of strength is necessary to guard against the blow caused by the gun striking the buffers, which are placed on the top of the cylinder, if the air pressure is allowed to get too low.

The air vessel is of mild steel, it is 16 in. internal diameter. The maximum pressure per square inch will be at the end of recoil, and will amount to $\frac{(14{\cdot}78^t-{\cdot}54)^t \times 2240}{82{\cdot}51 \text{ sq. in.}}=386{\cdot}6$ lbs. per sq. in.

The strain on sides of air vessel$=386{\cdot}6 \times 8$ in.$=3093$ lbs., a factor of safety of 5 will be ample, and the ultimate strength of the steel may be taken at 28 tons per square inch, therefore the thickness of the sides will be $\frac{3093 \text{ lbs.} \times 5}{28^t \times 2244 \text{ lbs.}}= {\cdot}25$ inch.

This thickness would be too little to resist external violence, such as a gun carriage is liable to, hence the thickness was increased to $\frac{7}{16}$ inch. It is, of course, very important that the cylinder, ram, and air vessel shall be absolutely air and water-tight; great care must therefore be used in manufacture.

All castings are very liable to have porous places, especially where the continuity of surface is interrupted by ribs or branches. Water and air under high pressures will ooze through such places. If the cylinder be of cast iron, and the defect be not very serious, the leakage can be stopped by forcing in a weak solution of sal ammoniac, and then allowing the casting to stand for a day or two. If any very pronounced leak shows itself, a hole may be drilled, tapped, and filled with a tight-fitting screw plug. It is often very desirable to drill a hole in a suspicious place, because it enables the real condition of the metal to be ascertained. Leaks often occur by the side of 'chaplets,' or the wrought-iron supports inserted in the mould to carry the cores. These leaks can often be stopped by riveting over the end of the chaplet, or, if obstinate, by drilling it out and closing the hole by a screw plug. Similar difficulties occur with gun-metal and steel cylinders, and must be met in the same way when not sufficiently serious to condemn the casting altogether.

The next strain to consider is that on the elevating bars. The carriage is arranged to give an elevation of 15° and a depression of 10°, the loading being done at a depression of 5°. If the gun happens to be fired at this depression of 5°, it will recoil parallel to itself, and there will be no strain on the elevating bars beyond that due to the friction of the trunnions.

The gun weighs 3·39 tons, the trunnions are 8 in. diameter, the elevating bars are attached 2 ft. 8 in. from the centre of the trunnions, we may take the coefficient of friction at ·14, therefore the force tangential to the trunnions will be $3{\cdot}39 \times {\cdot}14 = {\cdot}48$ tons, acting at the end of an arm 4 ins. long, and counteracted by the radius bars at 32 ins., hence the pressure on the bars will be $\frac{{\cdot}48 \times 4 \text{ ins.}}{32 \text{ ins.}} = {\cdot}06$ tons or 134 lbs. When, however, the gun has to turn on its trunnions, a force sufficient to produce the motion must be exerted. Recoil is composed of two periods. The first, occupying very little time and space, in which the moving parts attain their maximum velocity, and the second when the energy, represented by the weight and velocity, are gradually absorbed.

According to the first law of motion, acceleration of velocity can only take place by the action of an impressed force. The moment the force ceases to act, motion continues to be uniform, unless arrested by some other force.

Now the only force acting on the gun is the pressure against the base of the bore; this lasts only so long as the shot and gases are being expelled; hence, if we know the time which this occupies, we know also the time in which the full velocity of recoil is attained.

We do not, at present, know the laws which govern the discharge of canon—and by discharge, I mean not of the shot only, but of the powder gases as well; hence I must make an assumption, and suppose that the motion of the matters ejected is uniformly accelerated like the motion produced by gravity, and therefore produced by the action of a uniform force, which may be taken as the mean pressure on the base of the bore. The terminal velocity of the shot we know to be 1460 ft. per second, and the space passed over is 6·3 ft., hence,

$$S = \frac{t\,v}{2},\ t = \frac{2\,s}{v} = \frac{2 \times 6{\cdot}3 \text{ ft.}}{1460 \text{ ft.}} = \tfrac{1}{116} \text{ second};$$

the gases follow the shot, and take an appreciable time to get out. Let us add 50 % to the time for this purpose, the discharge will therefore take place in $\frac{1}{78}$ of a second.

The work to be done is to overcome the inertia of the gun turning about its trunnions. To ascertain this, we must first find the radius of gyration, which gives the circle in which the mean energy of the resistance is concentrated. The energy of each particle of the gun is $=\frac{W}{2g}v^2$; $2g$ is a constant, the velocity v varies as the radius or the distance of the particle from the centre of the trunnions; the weight of each particle is, in a body of uniform density, proportioned to its volume; call this volume c, and we have the energy of each particle proportional to $c\,r^2$.

Make an accurate drawing of the gun, and divide it into a number of sections, say about 6 in. long, to right and left of the trunnions, ascertain the volume of each section, and the distance of its centre from the centre of the trunnion, and then calculate the value of $c\,r^2$ for each section, and arrange the results in a tbaular form, giving c and $c\,r^2$ separately. Next add the columns c and $c\,r^2$ respectively, then dividing $c\,r^2$ by c and extracting the square root, we get the mean value of r, which will be the radius of gyration. I have thus divided the rear end of the gun into nine sections, and the muzzle end thirteen; the sum of the columns is as follows :—

	c	$c\,r^2$
Rear half . .	14790 *c i*	7761929
Muzzle half . .	12221 *c i*	11122571
	27011 *c i*	18884500

radius of gyration $=\frac{\sqrt{18884500}}{27011}=26{\cdot}44$ in., corresponding to a circle whose circumference is 13·84 ft.

When fired at the extreme elevation of 15°, the gun in recoiling describes an angle of 20°, or $\frac{1}{18}$th of a circle, by the time it reaches the loading position, hence the space passed through by the circle of gyration will be $\frac{13{\cdot}84}{18}={\cdot}77$ ft., and this occurs in ·65 second, hence, if the motion is uniformly retarded the maximum velocity must be

$$v=\frac{2s}{t}=\frac{2\times{\cdot}77\text{ ft.}}{{\cdot}65\text{ ft.}}=2{\cdot}37\text{ ft. per second.}$$

This velocity is got up during the time in which the shot and gases are being ejected. We have estimated it at $\frac{1}{78}$ second; hence the velocity of acceleration, corresponding to g in gravity, is

$$=\frac{v}{t}=\frac{2{\cdot}37\text{ ft.}}{\frac{1}{78}\text{ sec}}=2{\cdot}37\times78\text{ in.}=184{\cdot}8\text{ ft. per second;}$$

the accelerating force therefore, the weight of the gun being 3·39 tons,

$$=\frac{3{\cdot}39' \times 184{\cdot}8 \text{ ft.}}{32{\cdot}2 \text{ ft.}}=19{\cdot}46 \text{ tons acting}$$

at the circle of gyration, whose radius is 26·44 in. The elevating bars are pivoted 32 in. from the centre of the trunnions, hence the strain on them will $=\frac{19{\cdot}46 \times 26{\cdot}44 \text{ in.}}{32 \text{ in.}}=16{\cdot}08$ tons,

Resistance due to friction = ·06

Total strain 16·14 tons;

so that each bar will have a momentary strain of a little over 8 tons to endure. In some cases this strain may have to be resolved, if the elevating bars are not pretty nearly at right angles to the gun. The retarding force arresting the rotatory motion is much smaller, on account of the longer time during which retardation acts, but the position of the bars becomes less and less advantageous, so that the resolved force may be considerable. It can be calculated in the manner I have indicated for the accelerating force. The shock on the bars and pivots at the commencement of recoil is severe; to soften it three or four thicknesses of leather are introduced between the bottoms of the brasses and the ends of the elevating bars. When the gun is fired, with its maximum depression of 7°, it has to turn in the opposite direction to attain the loading position, but the arc is only 2°; the strain is a tensional one and much less severe.

The elevating bars should be made much heavier than is necessary, to resist the strains passing through them, because their upper ends are exposed to machine gun fire, and the fragments of shells, when the gun is in the firing position; and, moreover, one elevating bar should be competent to carry the whole strain in the event of the other being disabled.

The maximum strain along the elevating bars being known, the resultant pressures along the slides and elevating screws at their lower end are easily calculated. The elevating screws must be made strong enough to carry the strain we have calculated, but the hand gear for turning them needs, obviously, to be only sufficiently powerful to overcome friction and the weight of the elevating bars.

I have now indicated the way in which the strains in a hydro-pneumatic carriage for disappearing guns are arrived at. Our ignorance of what takes place in the bore of a gun during discharge precludes any great acccuracy being attained; but still, on the assumption which I have made, and with a good factor of safety, carriages for any sized guns may be designed with confidence.

It is necessary to be able to lower the gun from the firing into the loading position without discharging it. For the smaller calibres this is most readily done by a rope, or chain and winch.

In the service siege carriages for the 6·6 in. M.L.R.G., a rope is carried round a system of pulleys, attached to the cylinders and ram, and then wound round a winch operated by capstan bars. In the carriage which we have been discussing in detail, a single chain is attached to one of the arms, is then led over a pulley in the rear cross-frame of the carriage, and thence conveyed to a winch in the front part of the framing, operated by a pair of handles projecting on each side. This arrangement gives better cover to the men than they would have in the rear of the gun.

In carriages for larger guns the best plan is to arrange an ordinary hand pump, by means of which the water can be pumped from beneath the plunger into the air vessel beyond the recoil valve. The size of pump will depend upon the number of men available for pumping, or the time in which it is desired to lower the gun. The work to be done is represented by the area of the figure between the isothermal curve and that representing the pressure necessary to support the gun throughout the stroke, after deducting 7 per cent. for friction. A man working at a winch handle will exert about 18 lbs. average pressure, at a rate of 5 feet per second, and keep up the effort for a considerable time—say ten minutes at a stretch.

If ever Moncrieff carriages are applied to large guns in batteries, with mechanical appliances for loading, the work of hauling down and pumping in air will be done by power. The steam or other engine and pumps will be placed in a bomb proof, from which water and air mains will be laid through the battery, and branches will be taken off to each gun. The pipes may be arranged to pass through the centre pivot, so that the traversing of the carriage will not affect them.

To lower the gun, the water from under the ram will be allowed to run to waste, and this should be done through a gauge vessel—such, for example, as I have contrived—for the purpose of restoring the proper quantity of water from the pressure main to the air vessel. This apparatus (Plate VIII.) consists of a cylindrical vessel, fitted with a free water-tight piston (N), of such volume that the full stroke of the piston displaces a little more than the volume of the ram. One end of the vessel is connected to the cylinder of the gun-carriage by means of a pipe (R), fitted with a self-acting valve opening *from* the cylinder, and communicates also with the water space of the air vessel by means of a pipe (T) fitted with an automatic valve (U) opening towards the air vessel. The opposite end is connected to the pressure main (P), and to exhaust by means of a two-way slide valve (o). When it is desired to lower the gun, either from the firing position or from the point to which it has recoiled, in order to bring it down to the exact loading position, the slide valve is pushed over, so that the water in the gauge vessel may escape from the pressure side of the piston, and then, the cock between the cylinder and the gauge apparatus being open, the weight of the gun forces the water out from under the ram into the other end of the gauge vessel, and its piston is forced back by just the amount of water driven out by the fall of the gun. As soon as the gun has been lowered, the slide valve is reversed; the pressure from the main is thereby turned on, and, acting through the free piston on the water which had escaped from under the ram, forces it through the automatic valve into the air vessel, thus restoring the proper relations between the volume of air and water, without the necessity of gauging it in any manner.

A certain amount of water is, of course wasted, at every operation; but there is nothing to prevent it from being collected and conducted to a cistern, from which it could be pumped into the pressure main again. Such a provision may be necessary in cold climates, where glycerine has to be mixed with the water to keep it from freezing.

To supply air under the required pressure, a double-acting hand-pump (Plate IX.) is used. It consists of a small iron box secured to a short plank, and fitted with a pair of pump barrels, actuated by a T-shaped lever, which is operated by two or more men standing on the ends of the plank. The pump barrels, which are $3\frac{1}{2}$ in. and $1\frac{1}{2}$ in. diameter respectively by 3 in. stroke, are so disposed that their plungers move in opposite directions. The volume of the larger cylinder is four times that of the smaller one, so that at the end of a double stroke the large cylinder full of air is compressed to one-fourth its bulk, and therefore raised to four atmospheres pressure. The next half-stroke completes the compression in, and expels the contents of, the smaller cylinder.

The cylinders are surrounded by water, so that the temperature of the air does not rise much, and the pressures follow nearly the ordinates of an isothermal curve. The object of dividing the work of compression between two cylinders, instead of completing it at once in one, is that the clearances at the ends of the cylinder, which must of necessity exist, would contain sufficient air at high pressure to fill a great part of the cylinder by its re-expansion on the inlet-stroke, and so prevent the entrance of anything like a cylinder full of air at each stroke. By dividing the work, the pressure in the large cylinder is limited to four atmospheres, and in the small one, whatever may be the ultimate pressure, the minimum is always four atmospheres, into which the air in the clearance must expand, instead of expanding into the volume due to atmospheric pressure. There is, of course, also the convenience of distributing the strains more evenly. In using air-pumps, which do not make a positive stroke such as is produced by a crank, care must be taken always to rock the lever over to the stops; if this is neglected, the full amount of air is not pressed out, and its re-expansion interferes with the quantity of fresh air taken in.

The following is the time actually occupied in charging the carriage which I have described with these pumps. Four men, working in relays of two each, at from 52 to 56 double strokes per minute, raised the pressure in the air space, measuring 27 gallons, from the atmospheric pressure, to 175 lbs. above the atmospere, in 1 hour and 6 minutes.

Attached to the carriage is a small differential air-pump, constructed on the same principle as the larger pump I have described, but the small cylinder is represented by the plunger piston-rod $1\frac{1}{16}$ in. diameter, working in a cylinder $1\frac{1}{4}$ in. diameter and 12 in. stroke. The plunger is actuated directly by a cross handle. In the up-stroke the air in the annular space above the piston is forced out into the air vessel, and a cylinder full of air at atmospheric pressure is drawn in. In the down-stroke, this charge of air is forced into the annular space above the piston, whereby it is reduced to about one-fourth the volume and increased to four times the pressure. This pump is intended to make good any slight leakage. Two men working in relay at about 34 double strokes per minute, raised the pressure of 27 gallons of air from 160 lbs. above the atmosphere to 170 lbs. in 8 minutes. Both pumps can be used for pumping water into the air vessel, by allowing a little to flow into the pump at each stroke from a small reservoir provided for the purpose; but in large carriages it will be better to provide a special water pump, which need only be of very small capacity.

For getting the carriage ready for action, two plugs are provided in the air vessel—one in the top, through which water can be poured in, and one at the side, at the proper level at which the water ought to stand when the gun is quite down. There is also a screw plug, just under the neck leather, in the highest part of the cylinder, for the purpose of letting all the air out of it. The gun being down, perfectly clean water is poured into the air vessel, until it flows out at the lower plug hole; the plugs are screwed home, and air is pumped in till the required pressure, gun down, is reached. This is ascertained by means of an ordinary pressure gauge, which should have been verified by some standard gauge, because all Bourdon gauges are very inaccurate, and soon get out of order. When the desired pressure is reached, the gun should be raised by opening the lifting valve, which allows the water to flow from the air vessel into the cylinder, and after a few minutes the plug under the neck of the cylinder should be slackened back, and all air allowed to escape. When this has been done, the gun should be hauled down and raised again a couple of times, so as to get all the air that may be lurking about into the top of the cylinder; the plug should be again tried, and if solid water comes out, then the cylinder may be considered as fully charged.

Glass gauges for ascertaining the water level are much too delicate appliances for war purposes, so the water level, after the first charging, must be inferred from the pressures.

The volume of air, gun up, is $2\frac{1}{4}$ times that of the ram, and gun down, $1\frac{1}{4}$ times; therefore—

$$\frac{p_1}{p} = \frac{2{\cdot}25}{1{\cdot}25}$$
$$\therefore p_1{}^{ab} = 1{\cdot}8 p^{ab}$$

p_1 and p being in absolute pressures; but the readings of the gauge are always above the atmosphere, hence we must add 14·7 lbs. to each, and taking p_1 and p now as readings above the atmosphere,

$$14{\cdot}7 + p_1 = 1{\cdot}8\,(14{\cdot}7 + p),$$
$$\therefore p_1{}^{\text{above atmos.}} = 11{\cdot}76 + 1{\cdot}8 p^{\text{above atmos.}}$$

If the pressure, gun down, should be more than the calculated amount, it means that the volume of air is less than 1·25 v, there is therefore too much water, and some should be let out. If the pressure is less, then the contrary course should be pursued.

For obtaining quickly the pressures, gun down, corresponding to a given pressure, gun up, the formula is put in the form of a scale, which may be engraved on a plate and attached to the carriage. (Plate X.)

The abscissæ represent the pressure, gun up; while the ordinates give the corresponding pressures, gun down, when the quantity of water is right. If the pressures fall outside the diagonal, there is too much water; if inside, there is too little.

When a carriage of a new pattern is first used, the maximum charge of powder and shot must be reached by degrees, because of our ignorance of even the approximate value of the energy of discharge.

Once a carriage is in good working order, the time the gun takes to rise into the firing position should be noted: this will form an excellent guide as to the state of the air pressure.

The result of the trials made at Shoeburyness justify the calculations which I have laid before you.

With the pressures and volumes indicated in the diagram, the recoil produced by 42 rounds, ranged from 36 inches to 38 inches out of 40 inches, or from 90 to 95 per cent. of the expected amount. The muzzle velocities of the shot, however, were about 15 ft. per second lower than was expected, and would cause a loss of energy amounting to 2 per cent.

The front part of the carriage rose $2\frac{1}{4}$ inches at each discharge, the motions being very free from shock or blow, either in the upward or downward movement.

The gun rose in 10 to 11 seconds from the loading to the firing position; the computed time was eight seconds, but the carriage seemed to work more and more easily as the trials went on, and I have little doubt but that in regular work, and with full muzzle velocity, that the results arrived at by calculations would be very nearly attained.

In the year 1878 I had the honour of delivering a course of lectures in this theatre on hydraulic machinery. You will find, in those lectures, drawings and descriptions of the various forms of leather packing, stuffing boxes, pipe joints, cocks and valves for high pressures. I will therefore not take up your time in describing them again. I have here some varieties of leather packings, together with one of the moulds used for making them. The leather used should be the best and closest that can be procured, dressed with oil or tallow, which is done by rubbing those substances in with a stick, after the tanning it completed. The leather, before it is pressed, is soaked in cold water for about 12 hours, then pressed into the mould, where it is left for 12 hours more; it is then taken out, the surplus leather cut off, dried a little, replaced in the mould for a couple of hours, after which it is taken out and finally trimmed to the exact shape.

With respect to the use of leather or hemp packing in gun carriages, I should recommend, for home stations, or wherever good leather can be readily got, that leather packing should be adopted, because, when good, they keep absolutely tight under the heaviest pressures, and the friction caused by them, being in proportion to the pressure, is less than the friction of hemp packed glands. But in out-of-the-way stations, where good leather cannot be got, I would recommend the carriages to be made with hemp packings—at any rate, in the larger sizes. When leather is used, a complete set of moulds should be supplied to each carriage or to each battery.

I do not think it necessary to describe the traversing and mirror sighting arrangements, because these are common to all carriages.

I must say a few words about the care of modern guns and carriages. There is a belief abroad among military men, that material of war must be able to stand any amount of bad weather and rough usage, and such, no doubt, is the case in active service. But in times of peace, and even during the intervals of inactivity in war, it is absolutely necessary that the complicated guns and carriages now in use should be protected from the weather, should be kept clean, and worked now and then, a little fresh oil being added to the bearings, in order to prevent the working surfaces becoming clogged.

In olden days, a cast-iron smooth-bore gun, mounted on a wooden carriage, with wooden elevating quoins, was not much injured by exposure to weather, and even by the rain making its way through the vent and slowly eroding a channel for itself along the bore; but modern guns, especially breechloaders and their carriages, will not continue efficient under such treatment. I advocate the use of wooden or iron houses, made up in panels, arranged to be easily taken asunder, which could be placed round and over the guns, leaving sufficient room for supervision and occasional oiling. The carriages, if not required for drill or training purposes, should have all their packings removed, the water drained off, and the working parts exposed to it dried as well as possible and oiled. The leathers should be kept like harness, and dressed with oil now and then. If the guns are required occasionally, they should never be allowed to stand more than a month without being moved a little, and left standing in different positions; otherwise the neck leathers and glands will corrode and indent the places they bear against. As many of the parts as possible should be painted; bright work is quite out of place in gun carriages. The most suitable oil to use is the best quality of Rangoon: it is a mineral oil, free from acids, and does not corrode, dry, or clog. Mr Willmott, one of the Engineers of the Post Office Telegraphs, made, a few years ago, some careful experiments on the relative value of oils for lubricating telegraph instruments, and found Rangoon to be best in every way. I have since used it for my turning lathe, which often stands for months without being worked, yet, when I require to use it, I find it always quite free, and running as lightly as if it had been newly cleaned. With respect of the cistern and pipes connected with a battery, it is important that they should be made of materials that do not scale from the effects of rust, and the pipes should always be kept full of water, and so laid that the water could never run out, even partially. Any material commonly used in pipes will remain free from rust under such conditions. The cistern, in which the water level necessarily varies, should be lined with lead or copper. The reason for these precautions is that minute pieces of scale, which drop off from exposed surfaces, are apt to get under the valves and prevent their closing tightly.

I should recommend lead to be used for low pressure pipes, copper or cast-iron for pressure pipes, and this is especially important where the guns are rarely used and the pipes are laid under ground.

I will conclude my lecture by relating the history of the gun-carriage which I have described in so much detail, and I do so because it will serve as a warning against jumping too readily to the conclusion that, because experience happens to agree with theory, that, therefore, the theory is correct. The carriage is, in one sense, an unfortunate one, but in another it deserves the highest respect, because it has led to investigations which I trust will end in the determination of the law of discharge of cannon and the true pressures in their bores.

When the first Moncrieff hydro-pneumatic siege carriages were designed, I accepted the received mode of calculating the energy of discharge; I added half the weight of the powder to that of the shot, and supposed both ejected with the same velocity. I then assumed that the work of compressing the air would be 86 per cent. of the energy so estimated, and calculated the air pressures accordingly. On trial the result justified my calculations in a remarkable manner, and I felt quite satisfied that I had got to the bottom of the theory of hydro-pneumatic carriages.

In 1883 the Ordnance Committee desired to get a carriage of the same kind for permanent emplacements, but of as cheap a pattern as possible. I accordingly, with the utmost confidence, undertook the design and construction of the carriage which has been the subject of our investigation. I had not the least fear as to the result, and allowed it to be tried while I was abroad. It broke down; one of the trunnions of the cylinder was knocked off. The accident was attributed to a faulty casting; a new cylinder was made, and that also failed. Various theories were propounded to account for the failure, such as: want of water in the cylinder, error of pressure-gauge, &c. The trials with third cylinder I witnessed myself, and, to my surprise, found that the calculated air pressure was not nearly sufficient, and had to be greatly increased. The cylinder stood very well, but the strain tending to turn the whole carriage over on the rear trucks was so great that the pivot plate and disc springs were broken. I was fortunately able to get the pressures due to the last shot fired, which was under a full charge, and to calculate, from that, the work of discharge, which, to my surprise, I found to be very much greater than could be accounted for by the received mode of calculation, and the ascertained muzzle velocity of the shot. The late Captain Goold Adams, R.A. (in mentioning whose name I cannot refrain from adding my tribute of regret that an officer of such ability, such unwearied energy, and such kindliness of manner, should have been lost to the service in so terrible a manner) assured me that there could be no mistake as to the velocity of the shot, and attributed the failure to want of air pressure.

He had found, he stated, in some recent trials at Lydd, that 700 lbs. per square inch was required in the siege-gun carriage to control the recoil; yet in the exhaustive trials at Shoeburyness 500 lbs. had been sufficient under exactly the same conditions. It struck me then that the apparent increase of energy might be due to the carriage having been more securely anchored, and, on inquiry, I found that Captain Goold Adams had used, instead of the single diagonal anchorage, a compound one, consisting of vertical and horizontal members, fitted with right and left hand screws, which had enabled him to secure the carriage immovably: whereas at Woolwich and Shoeburyness the carriage used to jump a couple of inches, and recoil six or seven. This movement of the whole carriage which I had neglected and thought of no consequence, really absorbed a large portion of the energy of recoil.

In the permanent carriage, the attachment to the masonry is still more rigid, and hence the violence of the action. These circumstances set me to investigate the law of discharge, and resulted in the mode of calculation which I have laid before you, and which was submitted to the Ordnance Committee last June.

In investigating the properties of powder, I had occasion to examine Captain Noble's experiments with crusher gauges and chronograph, and found that he had fallen into an error similar to mine—that is, he had found, as I have already stated, that pressures indicated by crusher gauges agreed in a remarkable manner with pressures calculated from the rate of acceleration of the shot ascertained by the chronograph; hence it has been concluded that the indications of crusher gauges are accurate. But, besides the work of expelling the shot, there is that required to expel the powder gases, to displace the air, to overcome friction of gases and gas checks, to rotate the shot and to stretch the gun, all of which I estimate amount to at least 40 % of the work of expelling the shot only, and hence the indication of the crusher gauges must be erroneous to that extent.

The whole subject is beset with difficulties; but yet is so important that the War Office ought to set the ablest men in the service, *and furnish them with adequate means,* to investigate and get to the bottom of the matter.

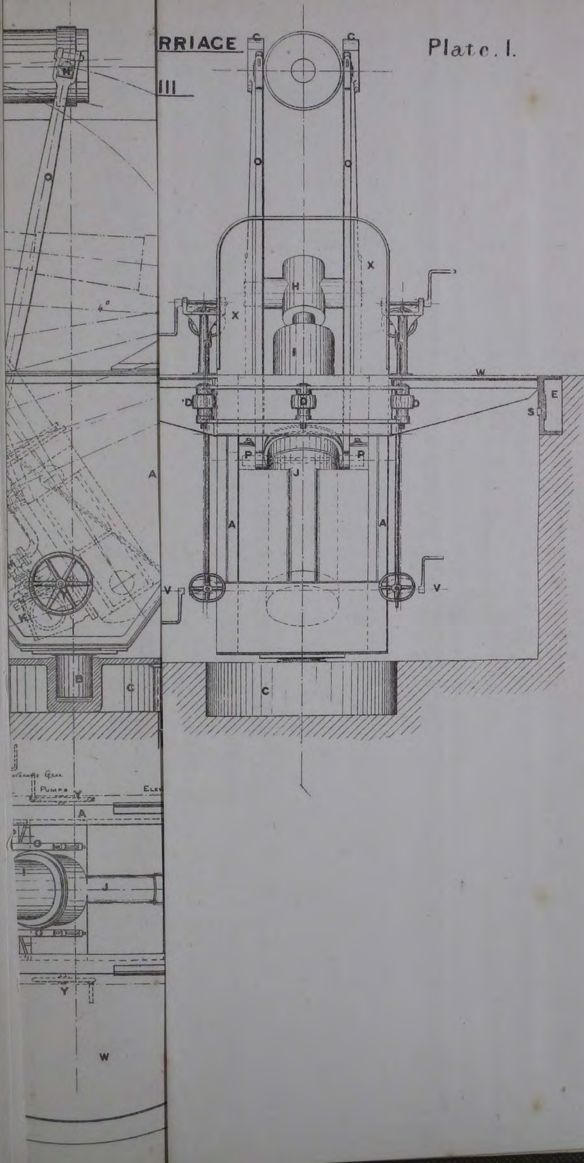
The cost of hydro-pneumatic carriages ranges from £900 for the 6·6″ B.L.G. to £6,700 for the 10″ B.L.G.

The opponents of the Moncrieff system allege that the excessive cost of the carriages is a bar to the introduction of the disappearing principle. It is hardly necesary to point out that comparisons, to be fair, must embrace the whole cost of the battery. But first it must be shown that the batteries are equally efficient. Now the Moncrieff system depends for protection on an earth bank, about the efficiency of which there can be no question at all, and moreover upon being perpetually masked—that is to say, if the battery is properly laid out, there should be nothing in the landscape to indicate the position of the guns.

The works connected with the emplacements are of the simplest and cheapest description. In any other system of fortification, we are still in ignorance of the power of resistance of armour-plated embrasures or revolving turrets. The probability is that under the fire of heavy guns their endurance will prove very indifferent, especially as they afford a conspicuous mark to the enemy's fire ; but still, allowing that a Moncrieff battery and an iron-plated fort are equally well protected, the comparison should be made between the complete works, including guns, carriages, machinery, &c., and it will then be found that the Moncrieff system is the cheapest.

I do not expect that you have been able to follow me through the intricate investigation I have laid before you. It has cost me years of thought, of persistent labour, and of costly experience, to work out the subject ; but when the lecture comes to be printed in the admirable establishment attached to this school, I hope that by careful study you will be able to master the difficulties. I havee ndeavoured to communicate all I know myself; and if any points still remain obscure, I shall be glad to do my best to make them clear.

Plate. I.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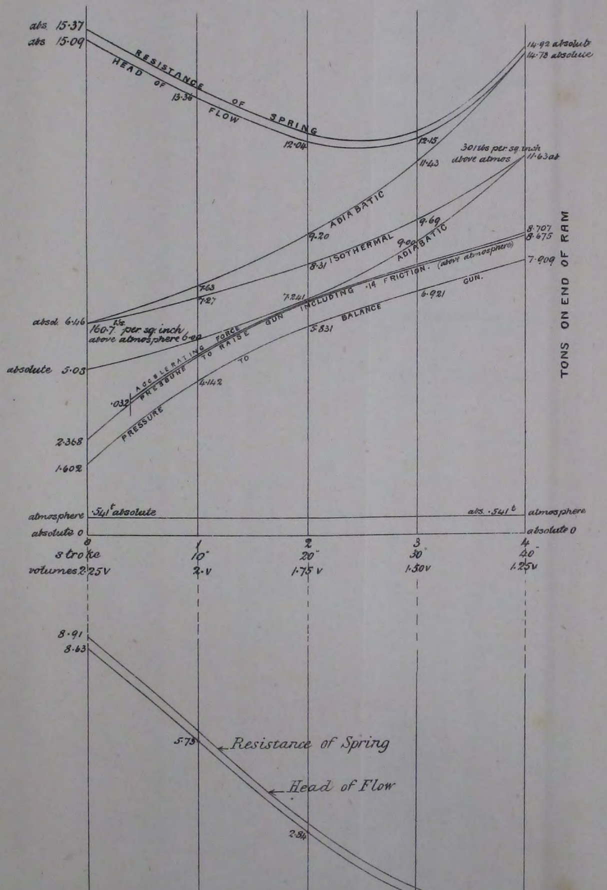
6.6" Hydropneumatic permanent Emplacement

Diagram of Strains

Plate VII.



PAPER VII.

THE LYDD EXPERIMENTS OF 1884.

A Critique by Captain G. S. Clarke, R.E.

Far too little is known by the Corps at large of the valuable experiments annually carried out at Lydd and elsewhere. The tendency of late years has been towards a more liberal experimental expenditure; but the practical use of experiments is much restricted by the fact that comparatively few officers ever have the opportunity of learning their nature and results. The greater number of minds that can be brought to bear on all questions of fortification, the better ordered our progress will be, and the less the chance of those ill-considered decisions which our successors would excusably curse. We need above everything some means of discussion, failing which there is no sufficient guarantee that the results obtained by experiment and the teaching gained in the field will be properly applied in future practice.

It is proposed, therefore, to give a short *résumé* of the Lydd experiments of last year, with certain deductions open to question and criticism.

The following were the principal points to the determination of which these experiments were directed:—

1. Penetration and effect on parallels and approaches—6-in. B.L., 5-in. B.L., 12-pr. B.L., and 6-pr. Hotchkiss quick-firing guns.

2. Effect of field, quick-firing, and machine guns on saps—12-pr. B.L., 6-pr. Hotchkiss, 3-pr. Hotchkiss, 1-in. Nordenfelt, 0·45-in. Gatling.

3. Security of field magazines against 8-in. M.L. 70 cwt. howitzer.

4. Effect of curved fire with reduced charges against a concealed object—6-in. B.L. gun.

5. Effect of gradual earth slopes in deflecting projectiles—slopes, 15°, 8°; 6-in. B.L. gun, 8-in. 70 cwt. howitzer.

6. Number of rounds required to dismount a hidden gun on an overbank carriage at 2,400 yards range—6-in. B.L., 5-in. B.L., 6·6-in. M.L. guns, 8-in. 70 cwt. howitzer.

The whole of the experiments were carried out against parapets composed of clay, always admitted to be the worst material for resisting penetration and shell-action. All the breaching experiments, therefore, require considerable correction. Some of them will be repeated this year against targets of loam, representing a much fairer average material.

Further, it is to be remembered that the works were essentially and necessarily targets put up to be shot at, standing boldly up from a glaring plain of shingle. The art of the engineer had no scope, therefore, and the works represented skilfully traced siege and permanent works, much as a Wimbledon target represents a man or men. In some cases observations, such as it was considered might be expected in an actual siege, were reported back to the firing point. In others, to save ammunition and rapidly obtain positive effects, information which could not have been thus counted upon was supplied. The ranges were, of course, known to a yard, and each gun was laid by an expert.

The human factor exercises a disturbing element in calculation, and defies measurement.

If full consideration is given to the conditions above enumerated, the extreme difficulty of arriving at positive deductions applicable to siege warfare will be at once apparent. That modern siege artillery will obtain results considerably exceeding those realised in 1870–71 and 1877 is granted. That results are to be anticipated bearing any resemblance to those obtained at Lydd cannot be admitted for a moment.

It is proposed to consider the Lydd results seriatim :—

1. Parallels.

(*a*) *First parallel*, thickness at ground line about 17 feet; range, 800 yards. Fused common shell.

6-in. B.L. gun.—A single round cut through the parallel, trenching it down 1 foot 6 inches. Two rounds close together breached it nearly to the ground level, mean top breadth, 7 feet 6 inches.

5-in. B.L. gun.—A single shell trenched the parallel through to a depth of 2 feet, mean top breadth about 5 feet. Two hits occurring close together breached it nearly to the ground level; mean top breadth 5 feet. Out of 7 plugged shells subsequently fired, 2 scooped up and went to sea, and 4 broke up on striking near the ground line.

12-pr. B.L. gun.—Three rounds striking *exactly* at the same spot breached the parallel half through; mean top breadth 4 feet 6 inches. A single round appeared to make a very small crater, 3 feet in diameter. No other rounds were fired, as it was judged that 4 rounds hitting on the same spot would have breached the parallel completely.

Deductions.—The 6-in. B.L. and 5-in. B.L. guns can evidently breach a parallel constructed in Lydd clay with ease, and would probably be able to trench through any parallel. As, however, it would require 12 rounds *exactly placed* to lay bare 10 yards of trench, it would never be worth while to fire at a parallel, unless it was ascertained that some specially desirable objects—say a general and his staff—were concealed behind a particular portion, and the general might not elect to await the completion of the breach. The construction of the first parallel means the establishment of an artillery superiority on the part of the attack, and a 6-in. B.L. gun surviving to this period could scarcely be spared to fire at the parallel. On the other hand, the knowledge, proved by an occasional experience, that the parallel could be trenched through by a single well-aimed shell might exercise a certain amount of moral effect on infantry manning it, and might possibly tend to restrict free communication behind it.

The 12-pr. B.L. is apparently quite unable to penetrate a 17-ft. parapet with a fused shell at 800 yards, and to place 6 shells exactly in the same spot is beyond the possibility of service conditions. Moreover, it is certain that 6 shells exactly placed in a loam or sand parapet could not breach it. A 17-ft. parapet, built of average soil, with a flat exterior slope, may probably be taken as sufficient protection against the 12-pr. B.L. at 800 yards.

(*b*) *Second parallel*, thickness at ground level 17 feet; gabion revetment; range, 400 yards. Plugged common shell for penetration.

5-in. B.L. gun, cast-iron shell.—Parallel never penetrated. Maximum penetration, 15 feet 6 inches at 1 foot above ground level. Every shell which struck the parallel and was held by it broke up. Out of 18 rounds, 6 grazed and went on

12-pr. B.L. gun, steel shell.—Out of 17 hits, 6 penetrated completely, 5 grazed and went on. Maximum penetration 21 feet, the shell burrowing into the ground under the gabion revetment.

6-pr. Hotchkiss quick-firing gun ; cast-iron shell.—Out of 20 rounds there were 19 hits, and 7 shells broke up. Maximum penetration 12 feet.

Deductions.—This experiment serves to illustrate the well-known unfitness of cast-iron shell for high velocity guns against earth parapets. A large proportion even of the 6-pr. shells broke up. The tendency of those shells which grazed to be deflected up is remarkable. The angles of descent were, however, very small—42 mins. for the 5-in. B.L., and 22 mins. for the 12-pr.

The penetration of the 12-pr. steel shell is remarkable. If a 12-pr. shell can be driven through 21 feet of normal parapet, and burst beyond by a delay action fuse, the fact would have a significance in relation to field works. But, on the other hand, the range was very short, and field guns could rarely or never be served within 400 yards of any defended earthwork.

(c) *Second parallel.* Same conditions. Fused common shell.

5-in. B.L. gun, cast-iron shell.—Parallel breached nearly to ground level in 2 rounds; mean breadth, 4 ft. 6 in.; 5 gabions displaced. A single round trenched through the parallel to a depth of 2 ft.; breadth, 3 ft. 6 in.; 2 gabions displaced. Out of a total of 15 rounds, only 5 hits were obtained.

12-pr. B.L. gun, steel shell.—Parallel breached by 4 rounds; depth, 3 ft.; breadth, 4 ft. 6 in.; one gabion displaced. A single shell made a crater 2 ft. deep and 4 ft. 6 in. in diameter at top.

6-pr. Hotchkiss quick-firing gun, cast-iron shell.—Range a little over 300 yards. Parallel breached in 15 rounds; mean breadth, 3 ft. 6 in.; depth varied much, but parallel still afforded cover. Individual shells made trifling craters.

Deductions.—A second parallel can easily be breached by fused shell from the 5-in. B.L. and 12-pr. B.L. at 400 yards; but not by single hits. Whether it would be worth while to attempt to make a breach which could be repaired by trifling labour is questionable. It should be noticed that two-thirds of the shells fired from the 5-in. B.L. under peace practice conditions missed the target. Four of these rounds were, however, fired from an indifferent or unstable platform. To attempt to breach a parallel systematically with a 6-pr. Hotchkiss would be throwing away ammunition, and this portion of the experiment must be regarded in the light of a *tour de force.*

2. Saps.

(a) *Single sap*; 300 yards. Fused common shell.

12-pr. B.L. gun, steel shell.—Out of 20 rounds, 14 effective hits. Saphead destroyed. Two dummies hit. First and second stages breached.

6-pr. Hotchkiss quick-firing gun.—Out of 20 rounds, 13 effective hits. Saphead destroyed. Only 1 dummy hit.

3-pr. Hotchkiss quick-firing gun.—The saphead, formed of sandbags filled with balls of clay; height, 2 ft. 6 in.; thickness at ground level, 3 ft. 6 in.; was laid bare in 4 rounds. Leading dummy hit.

Deductions.—Single sap could not be carried on by daylight in face of the fire of any of the above guns, unless the natural features of the ground were specially favourable to the operation. The possibility of sapping, therefore, turns upon the power of the artillery of the attack to prevent any such guns being brought to bear on the sap-heads. On the whole, it appears probable that the defender, by moving his guns about judiciously, will be able to stop sapping by day on any part of the terrain which can be seen from his position.

(*b*) *Double sap*. 300 yards range. Fused common shell.

12 *B.L. gun, steel shell.*—A single round laid bare one of the sapheads, formed of sandbags, filled with shingle and having earth in front. Thickness at ground level, 5 ft. 6 in. The traverse, 15 ft. thick at the ground level, was breached in 4 rounds out of 12 fired. Mean depth of breach, 3 ft.; breadth, 4 ft. All the dummies were hit.

Deductions.—As for single sap (see above). Double sap cannot be carried on by daylight against the fire of the above gun.

(*c*) *Blinded sap*. 300 yards range. Fused common shell.

12-*pr. B.L. gun, steel shell.*—No saphead. Blinded portion exposed to direct fire. Damage in 8 rounds very great; 16 ft. of overhead cover destroyed.

6-*pr. Hotchkiss quick-firing gun.*—The saphead covering blinded portion was formed of sandbags filled with shingle; 3 ft. thick, 2 ft. high. Saphead destroyed in 10 rounds. Great damage to overhead cover, which fell in during the following night.

Deductions.—Blinded sap is useless against any of the guns named above. Except to resist vertical fire from light mortars, it is difficult to imagine any circumstances in which this sap will be useful. Cover must be sought by deep trenches, not by timber and earth covering.

(*d*) *Single sap. Double sap. Blinded sap.* 300 yards.

Nordenfelt 1-*in.*, *Gatling* 0.45-*in. machine guns.*—Effect trifling. No dummies hit.

Deductions.—The above machine guns are unable to stop sapping at this range. The moral effect of their fire might at first be considerable; but, as its real harmlessness would soon be recognised, men would become accustomed to it. Doubtful moral effect would scarcely justify the enormous expenditure of ammunition required to keep up a continuous fire for hours.

3. Field Magazine, 2,400 Yards, Common Shell, with Delay Action Fuse.

8-*in. R.M.L. howitzer*, 70 *cwt., cast-iron shells*, 14-*lb. bursters.*

(*a*) Overhead cover 10 in. by 10 in. fir baulks; double layer 36-lb. rails; 6 ft. earth. Top of magazine 27 ft. square. Whole horizontal target 36 ft. square. Visible vertical target 31 ft. 6 in. by 6 ft. Effective hits 4 out of 27 rounds. Of these, 3 broke through the magazine sheeting, 2 in front, and 1 on the flank, filling the interior with *débris*. One blind shell broke through the rails, but was deflected into a horizontal line by the baulks, which it damaged. This shell penetrated altogether 20 feet of earth. A single good crater was 14 ft. in diameter and 5 ft. 6 in. deep.

(*b*) The magazine was rebuilt, the overhead cover consisting of 12 in. by 12 in. oak baulks, with a double layer of 36-lb. rails; 1 ft. 9 in. clay; upper layer of 10 in. by 10 in. fir baulks, with double layer of 36-lb. rails; finally, 6 ft. of clay. The upper layer was set forward so that a projectile just clearing it with a fall of 34° would strike just short of the point of the magazine sheeting at the floor level. The projectiles were—10 cast-iron shells, 6 diameter head; 3 steel shells, 6 diameter head; 3 cast-iron service shells. Out of the 16 rounds, 10 hits were obtained. The upper protecting layer was broken through and bared by 3 rounds. One other round, striking halfway down the 45° exterior slope, cleared the upper protecting layer altogether, and blew in the sheeting of the magazine, at the same time displacing the front bearer of its roof. The lower oak and rail layer were never penetrated. It is doubtful whether the magazine would have been fired; but it was rendered useless, and blocked with *débris*.

Deductions.—The experiment was unavoidably barbarous. It was necessary to put up a target which could easily be hit; so that, with a reasonable expenditure of rounds, results representing a possible maximum might be obtained. Under no conceivable circumstances, however, would a magazine of this description, with its 45° slopes, be built up in full view of an 8-inch howitzer. It may probably be accepted that nearly the same conclusion would have been reached in any other soil, however favourable; since the maximum penetration, 20 ft., leaves a margin of reserve. The angle of impact of the shells with the exterior slope was 78° 40′, and the drop of the shells 33° 40′. The shells which give the best results kept fairly on their trajectories after impact, even when striking the flat top of the target; but in one case the angle of descent appeared to be slightly inrceased. In the case of one shell only would the effect have been diminished by substituting a flat exterior slope. The projectiles of the 6-inch B.L., with their much flatter trajectory, would not have been so well held by the clay, and it is probable that the magazine would have been quite safe against single hits from this gun, and that a large expenditure of ammunition would have been needed to injure it. The best results were, in every instance, due to the high angle at which the shells continued their course after impact. Even, with a double protecting layer, the magazine proved unsafe against a single 8-inch shell; but the same amount of protection differently disposed would have sufficed.

No field magazine which could possibly be constructed is safe against repeated accumulative bursts of shells from the 8-inch howitzer. Every magazine, however, is liable to be blown up by a single lucky shell, which, dropping at the mouth of the entrance passage, fires powder at the moment of being carried out. These magazines—especially of the strengthened form slightly amended—would undoubtedly keep out projectiles of many kinds, at many ranges, and under many circumstances; while the probability of successive shells striking at the same spot is not great. What are the real risks of a hit involving the destruction of an unseen magazine? No military operation can be carried on without risks. Are these risks, in the special case under consideration, inordinate? But for the difficulty of obtaining a suitable range, this question might be subjected to experiment. An unseen magazine, the whereabouts of which was indicated by such information as might be expected to be obtained from ordinarily intelligent spies, or by means of a distant balloon, might be fired at. The results of an experiment in this more practical form would possess special interest; since it is evident that, as regards the question of risk, and as a representation of service conditions, the Lydd experiment is valueless.

The only alternative seems to be, either to frankly accept the risk of two shells falling in the same place, and this the most dangerous; or, as Colonel Baylay, R.A., suggests, to give up overhead cover and distribute the store of powder by breaking it up into fractions isolated from each other. It should be noted that a satisfactory delay action fuse seems to have been arrived at.

4. Accuracy of Fire with Reduced Charges for Medium High Velocity Guns, Range 1,600 Yards.

6-inch B.L. gun, common shell filled and plugged. Charge, 6 lbs. R. L. G.^{2} *in place of* 34 *lbs. P*^{2}.—Wood targets, 27 ft. by 18 ft. Out of ten rounds, only two hits were obtained. Mean vertical error 12-ft. Elevation, 12 ft. 10 in.; angle of descent, 14° 2′. Shells reported steady at the target.

Common shell filled and fused.—Target, exterior slope of about 8°. Out of ten rounds, six hits were obtained, all in a rectangle 62 ft. by 13 ft.; angle of impact about 22°. The shells were not deflected; craters small.

Deductions.—The results appear to be decidedly unsatisfactory, notwithstanding that the rotation seems to have been sufficient to steady the shells in flight. The importance of being able to use modern guns with reduced charges for high angle fire is so evident that further trials in this direction are eminently desirable.

5. Effect of Gradual Slopes in deflecting Projectiles. Range 1,200 Yards. Fused Common Shell.

6-inch B.L. gun, cast-iron shell, parapet 30 *feet thick, exterior slope* 15°.—Eight effective hits were obtained in ten rounds, four on exterior slope 15°, and four on superior slope 5°. None were deflected upwards; but they appeared to break up rather than burst. The parapet was breached, but still afforded cover. Average breadth of breach, 9 ft.; depth, 4 ft.; angle of descent, 1° 43′.

Slope 8°, *soft clay.*—Shells at first decidedly deflected and scooped up. As the breach began to be formed, they were better held by the parapet. Breach formed in 21 rounds. Average breadth, 14 ft.; depth, 4 ft. 6 in.

8-inch R.M.L. howitzer, 70 *cwt., parapet* 30 *feet thick, exterior slope* 15°.—Out of 20 rounds, 13 effective hits were obtained, and the parapet was breached. Average breadth of breach, 11 ft. 6 in.; depth, 5 ft.; angle of descent, 3° 55′. No deflection observed. Previous experiments with a similar target, having an exterior slope of 45°, showed that from six to nine effective hits were required to form a breach.

Deductions.—The experiment was not altogether satisfactory, clay being an eminently unsuitable material. The cast-iron shells of the 6-in. B.L., being held by the parapet, were broken up. The effect of the decrease of slope in delaying the formation of a breach is, nevertheless, very marked, both in the case of the 6-in. B.L. and the 8-in. howitzer. The effect of one good burst in the Lydd clay is to form a crater with steep sides, so that the succeeding shell finds a nearly vertical target. The effect of an 8-in. howitzer shell fairly burst in loam, as observed this year, was to create a visible indent, but to form no crater whatever. These experiments should evidently be tried again with a different soil, and, as regards ascertaining the comparative deflecting power of slopes, delay action fuses or plugged shell appear to be needed, and steel shell for high velocity guns. Meanwhile, the case for flat slopes appears to be already made out.

6. Number of Rounds required to dismount an Unseen Overbank Gun. Range 2,400 Yards.

The two target guns were behind a 30-ft. parapet, with a screen in front, which hid them from the firing point. A laying mark was put up occasionally.

Gun	No. of Rounds	Result
6″ B.L. . . .	21	Both guns dismounted.
5″ B.L. . . .	24	One gun dismounted; detachment of other gun killed.
6·6″ R.M.L. .	23	One gun dismounted and its detachment disabled.
8″ Howitzer .	23	One gun dismounted and all its detachment killed except one man.

Deductions.—The 6-in. B.L. gun proved its superiority; but the performance of the 8-in. howitzer was very good, and, but for one lucky burst of a shell of the 5-in. B.L. just in front of the target gun, the howitzer would have equalled the 5-in. B.L. It is evident that a siege battery, not itself under fire, would in a short time dismount any overbank guns directly in front of it, as soon as the range was obtained. More definite conclusions cannot well be laid down. If siege batteries concentrate their fire on individual guns with a view to dismount them successively, they will lay themselves open to unreturned fire at known range, and will suffer proportionately. Smoke will exercise considerable influence on the artillery engagement. The observation of the results of individual shells will be of cardinal importance to the attack, which cannot afford to lose time in the operation. The Lydd experiments showed that the best point for the observing party was about 700 yards to the flank, and 900 yards to the front, the observers being raised about 8 ft. above the ground. This position could certainly not be taken up until such advanced works of field type as the defence had been able to construct had been captured. Further, the Lydd range is devoid of all natural features, and rarely could the desired elevation of the observing party be obtained. It remains to be seen how far such observations can be carried on from balloons anchored at a safe distance; and it is to be hoped that experiments in this direction may be made next year. The question is certainly important. These dismounting experiments perhaps serve to show the value of the disappearing system of mounting both for defence and attack. A disappearing target, representing a dummy gun, is to be fired at this year; but the conditions will not be nearly so favourable to it as they might easily be made in actual practice. It should be exceedingly difficult to localise such guns during the artillery engagement.

General Conclusions.

For many reasons siege experiments conducted under the conditions inevitable at such ranges at Lydd are most unfavourable to positive deductions. They are useful mainly as comparative determinations of the powers of different guns. It is greatly to be regretted that we cannot place the Lydd results by the side of those of identical experiments carried out with the German siege train of 1870, or the American guns of 1863. We know that it required 1,000 rounds of the 15-centimetre gun to effect an easily defensible breach at Soissons, and that 122,233 lbs. of iron failed to open up the provisional sand-covered bomb-proofs of Fort Wagner; but there is here no common denominator, and comparison fails to do more than indicate that the Lydd results must be heavily discounted. Certain general deductions, however, may perhaps be made.

There is no apparent reason to expect that the defence will rush into armour. No expenditure on turrets or cupolas, such as is ever likely to be accepted, will greatly avail. The cupola will be a beautiful target to shoot at, and, with modern guns, it is evidently a question of time only to cut through any intervening mass of earth and concrete protecting the turning gear. Apart from this, however, such a gun as the 8-in. howitzer, with ordinary luck and good observations, would, after a certain number of rounds, drop a shell between the cupola and its glacis, which would probably prove fatal. This experiment is to be tried at Eastbourne, and ought not perhaps to be prejudged. Cupolas, though they might otherwise be expected to prolong the life of guns mounted in them, do so at the price of providing a good upstanding target which may neutralise their benefits. In any case, the balance of advantage is not so evident as to cause their great expense and other drawbacks to be readily accepted.

For the artillery of the defence, the importance of the earlier stages of the bombardment is great. At the start, the defence possesses some slight but definite advantages which must be utilised to the utmost, as any considerable destruction of siege material would tell heavily on the attack. Fortresses must be liberally armed, and should have some guns and howitzers of heavier nature than any that the attack is likely to be able to bring into the trenches. Besides the permanently mounted guns, the defence must dispose of a large number of guns of siege type on travelling carriages, and also of field and quick-firing guns. Such guns will serve not only as the armament of the advanced works, destined—as was shown at Belfort—to play a very important part in future sieges; but, used as counter-attack guns, moved about in or in rear of the intervals of the forts, they may serve to disconcert the plans of the besieger to an unexpected extent. It is only by such an armament so used that the defence can prevent the initiative from passing at an early stage into the hands of the enemy.

Perhaps the most important lesson is that the defence must employ howitzers to a much greater extent than has been hitherto contemplated. In a howitzer duel, if the howitzers are behind the line of forts, the defence possesses definite advantages. If the howitzers are placed in the forts, the uncertainty as to their position at once ceases to exist. Their position is known to be within an area of greater or less extent, bounded in front by an eminently visible rampart. Having disposed of the direct shooting guns of the fort, the besiegers have only to pile shells on to its cramped area in order to make the service of howitzers practically impossible. Howitzers outside the forts, concealed by the ground, having no visible parapet in front of them, presenting no conspicuous target, and having their fire directed by observers stationed in the advanced works, and later in the forts themselves, ought to be able to approach more nearly to the Lydd standard of shooting, and to inflict great damage on the siege works, the direct shooting guns of which must at least be visible to the observing parties. To shell a fort is one thing, to fire at an indefinite cloud of smoke rising behind a low hill, and only somewhat accentuated at intervals, is quite another matter. And it is to be remembered that the defence is by no means limited to siege conditions as to the weight of howitzers, but may use large calibres and very heavy shells.

It is remarkable that, as regards coast defence also, the value of howitzer fire is coming more and more into prominence. At present the Italians have the lead, and howitzers form a principal feature rather than a mere accessory in the armaments of all their more important coast defences. In due time we shall doubtless follow suit, and before very long no coast defence armament will be considered complete without a large proportion of howitzers. When we had mortars which could not shoot, we freely mounted them in coast defences. Now that we have howitzers which shoot with remarkable accuracy, and position-finders by which the position of a ship in motion can be ascertained in advance, the enhanced power of curved fire is certain to receive full recognition. The deck of a first-class ironclad is its most vulnerable part; and large howitzers, with shells carrying some nitro-glycerine compound, are probably capable of putting any ship out of action with a single hit. A concealed group of howitzers, working with a position-finder, will be able, if necessary, to go on shooting all day; and anything more heart-breaking for the ship than to remain under a fire to which she is unable to give any effective reply, cannot well be imagined. Except as regards the probable value of howitzer fire, Lydd affords no teaching with respect to coast defences. Ships cannot hope to effect breaches in parapets unless they are at anchor and not themselves under effective fire. For them it is a question of dismounting a gun by a direct hit, or of bursting common shells or shrapnel with such exactitude as to kill the gun detachments or disable the carriages, and the excellent breaching results obtained with the 6-in. B.L. point no moral. They serve, however, to bring out the accuracy of this gun, which, as on board ship it will not be mounted behind thick armour, tells entirely in favour of the shore battery.

The great command too frequently given to land works will certainly be reduced. This command may have been necessary when indirect fire was in its infancy, and the main object was consequently to bring the largest possible area into sight. The great advance in the accuracy of indirect fire—an advance by no means ended—has changed the conditions, and it will probably be sought to assimilate the forts in appearance more nearly to the siege works with which they are intended to compete.

Flat slopes in the earthwork of forts are unquestionably advantageous. The Lydd clay with its steep-sided craters was specially unfavourable to the differentiation of results due to angle of slope; but even here the advantage was pronounced. Moreover, an abrupt change of angle is the surest way of making a work visible, and this alone should constitute a powerful argument in favour of flat slopes.

No fort should be without an available supply of earth for repairs. It is not sufficient that earth can be carted in from the outside, and it is desirable that there should, if possible, be a surplus of earth in interior traverses, which can be turned to account for making good damages. Failing this, the defence will be handicapped in the important work of restoration. In night firing the better mounted guns of the defence should beat those of the attack, while the electric light confers advantages which ought to be turned to the utmost account.

The occupation of positions in front of the line of forts by strong works of field or provisional type will play an important part in well-conducted defences. Such works will keep the attack at a greater distance to begin with. It is possible that the besieger may have to devote his siege guns to them, in which case the guns and howitzers of the defence will gain a respite, which they should be able to turn to valuable account. Thus it may be practicable to inflict severe damage on the besieger's siege-material before the forts are even attacked. Till captured, the advanced positions will be the observing stations for the heavy howitzers and guns of the defence. The disadvantage entailed by the loss of *morale* caused by the abandonment of these positions will doubtless be accepted in consideration of the benefits they confer.

It must be confessed that the Lydd experiments give rise to gloomy forebodings as to the efficiency of our older land defences. Short of reconstruction it is not easy to see what could be done with them to render them fit to resist a modern siege train. They may be said to exist on sufferance, therefore, and it is fortunate that the prospects of a regular siege are excessively remote. Against a mere field army they are still sufficiently formidable.

As regards siege works, the Lydd results afford useful hints. Provided that the defender's observation of his fire is well carried on, an artificial screen in front of a siege battery probably affords little real advantage. Natural cover will be anxiously sought for by the attack. Siege disappearing carriages will prove extremely advantageous. There is no reason to increase the section of parallels where they are merely covered communications or infantry trenches. Special portions will, however, need to be strengthened. The chances of ordinary sapping are limited. If the ground is very favourable or the defence very weak, such modes of advance may be carried on; but it will rarely be possible to prevent field or quick-firing guns from being brought to bear on a saphead; and if so, work will be altogether stopped till the siege guns have found out their positions and converged their fire upon them. Under ordinary circumstances deep sap alone is practicable, and this was fully recognised by the Germans ten years ago. Field magazines must be either concealed, strengthened, or abolished. If visible from the front, or if the besiegers possess observing stations which embrace them, they are unsafe as at present constructed.

The above are some of the conclusions arrived at from a careful study of the Lydd experiments. They are open to discussion and criticism; but it is only by attempting to formulate them that either process is possible.

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Since the above was written, a comparative experiment has been carried out at Lydd with two parapets of similar section—one built of the Lydd clay, the other of loam, the exterior slopes being 1 in 2. Three rounds of Palliser shell, plugged and weighted, were fired from the 9·2″ B.L. gun at each, at a range of 1,200 yards. The clay parapet was cut half through, very nearly to the ground level. The loam parapet was practically uninjured. In the latter case, the shells all failed to penetrate, and appeared to scoop up at once, scarcely affecting the parapet. Similar results were observed in the sand parapets at Alexandria, and, as was expected, the projectiles from the high velocity gun appear to have exhibited the tendency to mere deflection in an even greater degree.

Judging from this experiment, it seems that parapets of sand or light loam will not hold such projectiles at all, and that little or no penetration can be obtained if slopes only are exposed to fire. In any case, it appears probable that the thickness of parapet which it is customary to prescribe for coast batteries may be materially modified in many cases. Unless the experiment above referred to proves to be altogether abnormal, a thickness of 40 feet of sand is evidently quite unnecessary.

October 5, 1885. G. S. C.