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PREFACE.

THE present volume for 1889, No. XV., contains eight papers dealing with various subjects which lie within the range of interest to the Corps.

Mr. Kinipple's paper on "Subaqueous Foundations" was one of those collected by Major F. J. Day, R.E., for Vol. XIV., but had to be held over for want of space; it explains a new method successfully employed by the author, for overcoming the difficulty of ensuring the proper setting of cement under water.

Major Brown's and Colonel Wells' papers (Nos. 4 and 8) also treat of hydraulic engineering, the former describing the methods that have been successfully employed for many years past in providing for the uninterrupted navigation of an Indian river, where the chief difficulty to contend with has been the unstable nature of the river bed, whilst the latter describes an irrigation scheme lately initiated by the Russian Government in Turkistan, of which the success or otherwise has yet to be proved.

Mr. A. T. Walmisley's paper (No. 6) on "Mathematical and Surveying Instruments" will be found to contain much useful information on several instruments not generally treated of in books on this subject, and its value is much enhanced by the detailed diagrams he has kindly furnished.

The remaining four papers deal with the more warlike side of our character. Paper No. 2, by Colonel Wood, C.B., R.E., gives an interesting account of the multifarious duties that fall to the lot of the Royal Engineers in the field, illustrated by examples taken from the Suakin campaign.

Major G. S. Clarke, C.M.G., in Paper No. 3, contributes his welcome *précis* of the "Lydd Experiments of 1889," keeping us *au fait* with the development of modern artillery; whilst Paper No. 5, by the late Major-General C. B. Brackenbury, R.A., is a treatise on the proper employment of field artillery, by one whose experience enabled him to speak with authority on the subject and the Editor's thanks are due to Major Eden Baker, R.A., for his kind assistance in preparing this paper for the Press after the author's lamented decease.

Paper No. 7, by Captain T. S. Jackson, R.N., is one of the latest expressions of opinion by a naval officer on the much vexed question of the combat between ironclads and coast defences.

W. A. GALE, CAPT., R.E.,
Secretary, R.E. Institute, and Editor

ERRATA.

Page 71, Line 32, after "master" insert "mind."
,, 77, ,, 22, for "beleagured" read "beleaguered."
,, ,, ,, 29, for "limits" read "units."
,, 79, ,, 4, for "pontoon corps" read "pontoon troop."
,, ,, ,, 37, for "reconnaisance" read "reconnaissance."
,, 81, ,, 26, after "have to" insert "be."
,, 84, ,, 24, for "military" read "artillery."

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LIST OF PLATES.

PAPER I.

SUBAQUEOUS FOUNDATIONS.

BY WALTER ROBERT KINIPPLE, M. INST. C.E.

LECTURE I.

(Delivered on the 6th March, 1889).

DURING the last 30 years marked progress has been made in what may be termed the department of engineering science which deals with foundations of structures laid down under water.

New methods of executing work, new appliances, and new materials of construction, have enabled the engineer to successfully execute works, which, a comparatively short time ago, would have been either quite impossible, or prohibitory on account of cost.

In the two lectures I am about to deliver I will endeavour to place before you the most recent practice in subaqueous foundations, illustrated by representative examples of work executed, so as to make the lectures as comprehensive as the limited time for delivery will permit. I will also refer to the ordinary methods of timber piling, and cofferdams, which are so valuable in numerous cases for works of moderate extent, or where exceptional difficulties do not present themselves.

In the lecture of to-day I will refer to works executed in sheltered positions, which may be termed "Inside Works," and in my next lecture, to works executed in exposed positions, which may be termed "Outside Works."

Inside Works.

In cases where a depth of only a few feet of water has to be excluded, no limitations imposed in regard to space occupied, and the foundation composed of sandy or clayey material, then an earth dam formed entirely of clay, or having a central wall of clay, is the simplest and most effective method of excluding the water from the site of the works, and, as regards maintenance, is the least troublesome, care, of course, being exercised to see that a complete clearance be made along the site of the proposed dam of all stones, gravel, shingle, sand, or other materials which would allow water to pass freely.

In a semi-porous stratum a trench should, if possible, be excavated or dredged down to an impervious stratum, or to such a depth that there would be no danger of percolation of water through the strata underneath the dam, which depth would be dependent on the nature of the strata, and the head of water against the dam.

A very thin wall of puddled clay, say from 12 to 18 inches in thickness, in the centre of an earth embankment, is quite sufficient to serve as a watertight wall, provided that care be taken that the clay is of good quality, free from stones or other extraneous substances, and has been thoroughly chopped and well worked before being placed in the dam, in successive layers, each layer being rammed or punned in place, so as to leave no horizontal lines or joints of separation. In practice, however, it is better to carry up a much thicker wall of clay, so as to provide a good margin of safety against the risks of defective workmanship, and the use of inferior materials.

The places where leakages are most likely to occur in such dams, or, indeed, in dams of any kind, are at their ends, or junctions with smooth surfaces, such as the faces of quay walls, paved slopes, embankments, etc., and special precautions should be taken at such places by forming gusset dams, grooves, if possible, in the walls, or by increasing the thickness of the puddle clay, and also by exercising great care with the punning and hard stock ramming of the clay.

I might quote a number of instances from my practice of the importance of such precautions, but one may suffice, which occurred at the eastern entrance of the James Watt Dock at Greenock.

An earth dam was there formed to exclude a head of water of about 14 feet. At one end of the dam, which abutted against the paved slope of an embankment, sufficient care was not exercised by the contractor in making a proper junction of the dam with the paved slope; the result was a heavy leak, which undermined the paved slope, involved a heavy outlay to stop it, and also caused a serious delay in the general progress of the works.

An earth dam, with its slopes, occupies a considerable area of ground, and is seldom used, except in cases where there is ample room.

When the area for operations is limited, a single pile dam, backed up with clay on the outside, and waled and strutted on the inside, such as that erected in 1835 under Mr. James Walker, F.R.S., P.P., Inst., C.E., in connection with the founding of the new stone bridge over the river Lea at Stratford-le-Bow. Sheeting piles, 14 inches square, by 22 feet 6 inches in length, and driven nine feet into the bed of the river, were used for excluding the water from the foundations, and much care was taken in making gusset dams at the junctions, or abutment ends of the dam.

In the construction of quay walls, where half-tide dams are sometimes employed, that is, dams constructed to such a level as to exclude the tidal waters, from half-ebb to half-flood, single-pile dams are most serviceable. I have used them in a number of instances, the most recent being in the harbour of St. Helier, Jersey, last year, in the execution of some harbour improvements there.

In the south-west angle of the Victoria Harbour, St. Helier, a new landing stage (see *Plates* I., II. and III.) was constructed, the quay, or front wall, of which was founded on the rock, at depths varying from 12 to 22 feet below the surface of the bottom of the harbour. The back, or light division walls, of about 25 feet in height below coping, along the side of the inclined roadway, down to the middle and lower landings, were founded on bearing piles from 24 to 30 feet in length, driven down to the rock, or to depths of from 47 to 53 feet below high water level, and although the capsills, longitudinal and cross bearers, and bruised points of piles on the rock were subjected to this great weight of wall and filling, they have not squeezed down, or subsided more than at the rate of about $\frac{1}{32}$nd of an inch per foot in height from quay level to the rock, which is not nearly so much as usually takes place under similar conditions, while the face wall, which is founded on the rock, shows, as a matter of course, not the slightest sign of subsidence or movement of any kind for its whole length.

By founding the division walls on bearers, and bearing piles, instead of on the solid rock, a saving of several thousands of pounds was effected.

To enable the front wall to be founded on the rock, I had a back and a front row of six-inch pitch-pine close sheeting piles, driven at about 16 feet apart, and parallel with the back and front faces of the proposed quay wall. These piles were driven to the rock, or as far down as 25-cwt. monkeys would drive them.

The tops of these sheeting piles were cut off at a few feet below half-tide level, and clayey material was embanked against their outside faces. The material driven through was composed of fine compact sand and clay.

The range of spring tides is nearly 40 feet, and the depth from high water to the rock in the bottom of the trenches was in some places as much as 53 feet, or 33 feet below half-tide.

The rock for the full length of the wall foundations in the trench was successfully laid bare, and the wall founded thereon, at depths varying from 47 to 53 feet below high-water of spring tides.

The trench was cleared in lengths, equal in capacity to about 900 tons of water, on an average, which took about 42 minutes to pump out, by a 16-inch centrifugal pump, mounted on a barge. (See *Plate* II.).

At one end of the trench, the new works abutted against an old quay wall of the Victoria pier, founded on loose stones and sand at about 12 feet above the bottom of the new work, and the foundations of the old work had to be protected by pole-boarding below the feet of the sheeting piles of the trench.

Some trouble was here experienced, in several instances, from "blows" through the fine sand at open joints in the sheeting piles, and under the piles, but the "blows" were promptly dealt with as they arose.

Had prompt attention not been paid to these "blows" the dam would have soon collapsed, as the removal of the sand from the back of the dam would have so slackened everything as to have rendered the sheeting piles, struts, and walings free to float, or rise up, as soon as the incoming tide had filled the dam.

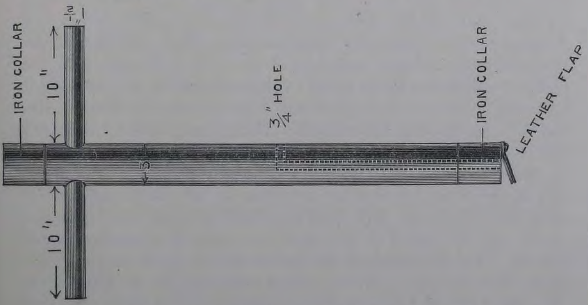
Stock-ramming, often found serviceable in tightening leaky cofferdams, was used at this work in filling up a large cavity under the wall, and also in stopping a heavy "blow" from under the foot of a broken pile which had not stood driving down to the rock.

I may here give you a short description of what is known as stock-ramming. During my practice I have frequently had to deal with most serious leaks, under and through cofferdams, foundations, dock sills, dock sides, and dock bottoms. These leaks, subjected to constant heads of water, had they not been immediately dealt with, would in a very short time have brought about the entire failure of the works.

In such cases any attempts to have stopped the leaks by grouting up with Portland cement would have been futile, for as soon as the grout poured down the pipes had reached the leaks it would have been washed away. Grouting up with Portland cement can only be done successfully when it is possible to equalise the head of water, so as to prevent any disturbance of the grout until it has thoroughly set, and is capable of resisting water pressure.

Sometimes leaks are gauged, that is to say, only so much water escapes as can pass through the interstices of a bank of rubble, rough ballast, fissures, or open joints in masonry, or in sheeting piles, or through hollow beds between the underside of a foundation course of masonry, and the surface of a rocky foundation. Such leaks are not immediately dangerous, for as soon as the puddled clay in the rear of these leaks is washed away, the velocity of the leakage water, owing to the enlarged orifices in the puddle clay, is so reduced as to pass almost harmlessly away. But leaks which are not so gauged, that is to say, those which pass through the puddle and retain their full force due to a constant head of water, irrespective of the size of the orifices, and acting directly and freely on the puddle, soon create a great "blow," and effect a speedy destruction of the dam.

For tightening up dams, dock bottoms, etc., I have used a stock-rammer as per sketch, thus :—



It is about three inches in diameter, $3\frac{1}{2}$ feet in length, and has its head and foot rung with iron. A $\frac{3}{4}$-inch air hole is bored up from its foot for about 20 or 30 inches, and this is covered by a thick shoe leather flap, which serves as a valve to admit air and prevent suction during withdrawal.

In stock-ramming a cofferdam, $3\frac{1}{4}$-inch holes are first bored in the piles, then charges of clay in rolls of about three inches in diameter, and of from six to nine inches in length, are inserted into them. The stock-rammer is then driven by heavy mauls into the hole as far as its length will admit, is afterwards withdrawn and other charges of clay inserted, and so the process is repeated until it is found impossible to drive in more clay.

The action is similar to that of a Bramah press, and by this means heavy leaks in dams have been readily and successfully stopped in a very short time. A cofferdam across the entrance channelway to the graving dock at Greenock, erected in the year 1871, was so badly filled with inferior puddled clay, that, on testing it, it leaked to such an extent as to threaten its destruction within a few days. Stock-ramming as above mentioned was resorted to, and in a week or so it was rendered absolutely watertight, although there was a head of water against it of about 15 feet each tide, during the process of stock-ramming and tightening up. A wooden plug was inserted in each hole, and was removed from time to time as further clay was found necessary. In earth or puddled clay dams, of great width at base, across valleys, it is necessary for stock-ramming purposes to put down bore holes as near as possible to the sites of the leaks and of from three to five inches in diameter, and line the same with wrought iron tubing. Charges of well-puddled stiff clay are then dropped into the pipes, and rammers of wrought iron round bars nearly filling the pipe, and having air holes and flap as in the smaller rammer, are lifted up by a small pile-driving engine, worked by steam or hand, and dropped from a height of 10 to 15 feet down the tube, as the case may require. In this manner the puddle clay can be inserted and rammed hard into any of the cavities or leaks in the bore hole, and the softened and wasting clay may be hardened and tightened up to such an extent as to effectually and securely stop any leak in the dam. In fact, hard ramming may be carried on to such an extent as to almost lift a dam of a hundred feet in height. The positions of the bore holes for stock-ramming such dams would depend upon the section and construction of the work, but, generally, the most suitable positions would be as shown in *Fig.* 1, *Plate* XXVIII.

Single pile dams may be utilized for excluding a very considerable head of water, if sufficient care be exercised in so driving the piles as to ensure close joints, and additional precaution be taken of grooving the piles and inserting iron or hard wood tongues.

Very successful and well-executed work of this class was done in connection with the founding, at $47\frac{1}{2}$ feet below T.H.W, the four piers and two abutments of the new Putney bridge over the Thames. The piles were 14 inches square, having elm tongues, and were driven through mud and clay down to the stiff hard clay, and formed almost perfectly watertight dams. After the dams were completed, the pier foundation caissons were sunk inside the dams to a lower level, and rapid progress was afterwards made with the excavations and the founding and building of the piers within the dams.

The use of a single pile dam, which occupies a minimum amount of space, is an important consideration, especially when the area is limited.

It is essential, however, that very careful work should be done, especially where there is a great head of water against the dam. Where the conditions are such, either from the inexperience of workmen or from the nature of materials through which the piles have to be driven, that it is impossible to make close work, recourse should be had to a double pile dam enclosing a wall of puddled clay; such dams being used for heads of water up to 40 feet, and in sites where it is impracticable to obtain close jointed piling. The dimensions of the timbering and ironwork are of course dependent upon the head of water, and likewise on the conditions of each particular case. In a dam of about 500 feet in length, which I designed for the Esquimalt Graving Dock Works, Victoria, British Columbia (see *Plate* IV.), there were three rows of close piling, the depth of water in the centre of the dam being nearly 35 feet at high water, gradually diminishing towards its ends. Along the side of the dam there was a layer of sand and shells, several feet in thickness, overlaying a bed of clay in the centre portion of the dam, and rock at each end of it.

The sheeting or close piles of the dam were of $12'' \times 12''$ fir timber, the gauge piles $15'' \times 15''$, also of fir timber, as well as the wales, which were $12'' \times 12''$.

The thickness of puddle between the piles was seven feet. At the ends where the dam rested on the rock, special precautions were taken by means of heavy rock shoes on the piles, and by depositing concrete along the feet of the piles to render the dam secure.

The dam was thoroughly watertight from its completion in October, 1879, until the spring of 1887, or just prior to the opening of the dock.

Wherever it is possible in the execution of the subaqueous portions of works to exclude the water from the area of the works by such simple means as dams, and where there is no objection in regard to space occupied, then undoubtedly such a course should be adopted.

The facilities for executing such temporary works are usually at hand, and above all it is most advantageous and economical to carry on the main works within an area laid dry, where work can be executed with rapidity and in the best possible manner, instead of under water, where, even when perfectly satisfactory results are believed to have been obtained, they are generally under disadvantageous conditions.

There are many cases where, owing to considerable depths of mud or soft strata, it would be quite impracticable to exclude the water by means of dams, and recourse must then be had to other methods of founding, such as sinking by means of caissons down to a firm stratum, or of driving bearing piles down to the same, or the foundations may be spread out so as to increase the bearing area (see *Plate* XIII., *Fig.* 2).

Founding on the tops of bearing piles is a very old practice. It is still used to a considerable extent, but not so much as formerly. The general practice is to drive over the area of the foundation piles from 9 inches to 14 inches square, and centred from three to four feet apart. On the tops of these piles whole timber bearers are laid longitudinally and transversely, and covered with planking, the whole being well bolted together, and the masonry structure built thereon.

Timber, when thus completely buried, is preserved for a very long period. I have here a specimen taken from one of the bearing piles of the foundation of the old Stockwell Bridge, Glasgow, a structure built in the year 1345, by Bishop Rae, in the reign of King David, son of Robert the Bruce, taken down in the year 1850, and replaced by the present bridge. The oak timber in the piles and bearers when taken up was as sound as when first laid down. A quantity of the timber taken from these foundations has been converted into tables, cabinets, picture frames, etc., and no appearance of shrinking or drying up has been visible, which is remarkable after having been buried for so long a time. I might give another instance of the durability of timber where so buried. In 1860, the bottom of the

King and Queen Dry Dock, Rotherhithe, was reconstructed, when it was found that the old dock bottom groundways of English elm, which were taken up, were in such a good state of preservation that I had some of the ribs of the new gates to the dock made from them.

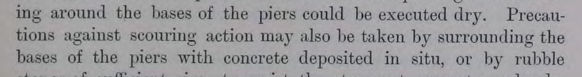
Dock walls almost innumerable exist founded on piles, especially in Holland, where they have been used to a very large extent.

In founding on piles the piers of bridges crossing rivers, precautions must be taken to guard against the risk of any scouring action set up by tidal or other currents removing a portion of the bed of the river next to the piers, thus leaving the piles exposed for a portion of their height, and which, if not protected, would soon result in the failure of the bridge.

Many subsidences of the piers of bridges have been brought about through this cause; for instance, the old Westminster and Blackfriars bridges across the Thames; and recently, to guard against such risks, the foundations of Waterloo bridge have been protected and strengthened, ordinary cofferdams having been used for excluding the water, so that the protection works of underpinning and concreting around the bases of the piers could be executed dry. Precautions against scouring action may also be taken by surrounding the bases of the piers with concrete deposited in situ, or by rubble stones of sufficient sizes to resist the strongest currents, or by depositing the same in the form of rough rubble paving between the piers of the bridge, and for some distance above and below the cutwaters.

The last-named method, however, is highly objectionable in a navigable river, especially if there is only sufficient depth of water for large vessels to pass at the top of the tide. A better course to pursue is to carry the solid foundations down to a firm stratum, or to such depths that no danger need be apprehended from scour.

In some instances, where great depths of soft strata exist, and where very long piles had to be used, it has been necessary to "fish" them, as per sketch, in order to obtain the necessary length; thus,



at the Prince's pier, Greenock, a section of which I have here represented (*Plate* V.), there is a considerable depth of very soft strata, as much as 60 feet in places, below the bed of the river, overlying the firm clay.

An ordinary masonry or concrete quay wall on such a site as this would have been almost impracticable, and a timber structure was therefore adopted, consisting of piles 16 inches square driven down into the firm clay. Many of the piles were upwards of 90 feet in length, each formed of two logs fished and jointed together during the process of driving. So soft was the material overlying the hard clay that the piles by their own weight sank several feet into it before a blow was struck by the monkey. The upper portions of these piles were of greenheart timber from 40 to 50 feet in length, and their lower portions of pitch pine. In driving to such depths considerable difficulties were encountered, but these were gradually overcome as the men gained experience.

The quay is 20 feet in width at top, and the piles are spaced 10 feet apart transversely and 8 feet longitudinally.

At about 2 feet and 15 feet down from the tops of the piles, heavy ties are secured to the back piles of the pier and carried back for a distance of 100 feet to back tie piles, were used for tying back the quay. The filling behind the quay was retained by sheeting piles and back planking.

Subsidences of the backing of clay, which was the material first used for filling, took place to such an extent as not only to cause the piles to bend forward, as shown in *Plate* V., but the bed of the river in front of the quay to rise several feet.

As the heavy material deposited behind the piles was gradually filled in, so the mud in front of the quay continued to rise higher and higher, when, owing to the heavy pressure caused by the backing of clay, the piles became so bulged at about 30 feet down from cope as to subject the lower ties to such a heavy strain that they ultimately gave way; whilst the top ties by the falling back of the heads of the piles became slackened.

At this juncture, in January, 1869, I was consulted by the Greenock Harbour Trust, and the measures I then adopted to prevent further movement of the structure were to dredge a trench 24 feet in width by 8 feet in depth, and 1,000 feet in length, along the front of the quay, below the bottom where the bed of the river was soft, and to fill it up with whinstone rubble, which had the effect of at once arresting the outward movement of the quay and of practically taking off the strain from the whole of the ties. This was so marked that it became quite an easy matter to straighten the line of quay by adopting a few further precautionary measures, such as backing up behind the quay with cinder ashes, depositing extra rubble under and in front of the quay, and also by utilising the bumping of steamers against the quay at the places where it had bulged the most, the ties having been previously very tightly screwed up, and men told off to give an extra screw up just as the steamers bumped. Additional ties were carried back to nearly 250 feet from the front of the quay stone being deposited in front of the tie piles and cinder ashes behind them.

Since the introduction of Portland cement as a building material, it has been used to a considerable extent in the construction of subaqueous foundations. Many devices have been adopted to secure, by means of Portland cement concrete, substantial and reliable work under water, sometimes with the aid of divers and sometimes without, or almost so. In many instances the proportion of materials, and the manner of placing them in the work, have been such that sound work could not possibly be executed. Too frequently the fact has been overlooked, that owing to the particles of the cement being very fine, as compared with those of the sand, gravel, and broken stone with which the cement is mixed, the slightest current of water disturbs the cement, and a very large portion of it is washed away, so that in one part there is an excess of cement, and in another less than there should be, or perhaps none at all. In addition to this, in opening the skip and discharging the concrete a still further displacement occurs. Precautions to a certain extent can be taken against cement being carried off by currents, but there is always a dissipation or loss of strength irrespective of loss by waste, and which has been determined by numerous experiments as being upon an average, as nearly as possible, equal to about one half of its strength out of water, and, therefore, if it be desired to construct subaqueous work equal in strength to eight to one concrete work out of water, it is necessary to use materials in the proportions of at least four to one. It is quite an easy matter for any one to test this, and it will be seen even under most favourable conditions, viz., by filling into a box, out of water, say ordinary six to one concrete and allowing it to set for three months, and by placing some of the same concrete in a similar sized box filled with water, and displacing the same by the depositing of the concrete in the box, that at the end of the three months the under water work will be very much inferior to that of the out of water work, and most likely will be found to be not more than from one-half or, perhaps, even one-third of the strength of the work done out of water.

With due care, such as by the use of facing skips and very fine extra strong concrete, better results might be obtained in regard to the lessening of the separation of the materials used, than by the use of ordinary skips; for by the latter, the stones and other coarse materials roll out from the general mass and lodge in the corners and against the faces of the moulds, and thus exceedingly defective work is obtained.

Portland cement concrete *in situ* for work under water has occupied my attention for very many years, and with all the study and care which has been bestowed on it by engineers to ensure sound work, and although in years past I have strongly advocated its use for monolithic work in subaqueous foundations, from the many indications in recent years that the life of such concrete is not likely to be that of centuries, I am almost led to the opinion that in the construction of all important sea works the use of rubble concrete blocks faced with masonry, and the finest quality of cement, selected from well burned clinkers, used in the body of work, and for grouting up the bed and joints of the blocks, should supersede concrete *in situ*. I will describe what I mean in detail in my next lecture.

In the years 1856 to 1858, when Portland cement was regarded as the newest material of the day for under water work, I made a number of experiments with reference to this, the results of which I laid before the Institution of Civil Engineers in the year 1866. (See Appendix I.).

I there stated that to obtain sound work without loss of cement, it was absolutely necessary to keep the entire works clear of water, for it was not possible to obtain strong and sound concrete work under water, whether the water was quiet or not, that is, if the materials were thrown in dry immediately after mixing. I had ascertained that concrete in the process of being deposited in this manner, and with only one inch of quiet water over its surface as deposited, even in the proportions of three to one, was most seriously weakened by the working out of the finer particles of the cement from the body of the concrete. In the year 1865, in concreting an outer apron of a graving dock between the pointing sill and the cofferdam at low water, I had used Portland cement concrete in the proportions of four of Thames ballast to one of cement. It was all put in at the same time, in the same manner, with the same cement and ballast, and by the same men, in quiet water of not more than an inch in depth above the concrete as it was laid. The concrete was then allowed to remain three months, and at the expiration of that time I had occasion to examine it, when I found that the portions nearest the abutments of the entrance were sound, but in the centre, or rather in the part last closed in, a considerable portion was found to be quite soft; in fact it was ballast which had retained but a mere fraction of cement, and what was retained of the cement had about as much strength as pipe clay.

The whole of the defective concrete had to be removed and replaced with new concrete after the water had been excluded.

To avoid such a contingency in future, I resolved that all Portland cement concrete before being deposited under water should, after mixing, be allowed to partially set. The time allowed for the concrete to set before being deposited depends upon the newness and fineness of the cement used, the proportion of the cement to the sand and stone, and the state of the atmosphere. If these conditions be not strictly adhered to unsatisfactory results will be obtained.

By numerous experiments I found I was able to retain nearly the whole of the cement, and obtain a much stronger and better concrete, in proportion to the quantity of cement used, than by the ordinary methods. I referred to several specimens which I then exhibited. One was composed of one part of Portland cement and one of fine river ballast; this was thrown into six inches of quiet water dry immediately after being mixed, was submerged eighteen days, at the expiration of which time it showed the great separation that had taken place even in quiet water. A second specimen, similarly composed, was also thrown into six inches of quiet water, but not until it had been allowed to partly set, after being mixed for about two or three hours in the open air previously to being submerged for eighteen days. This specimen was so hard that it had to be split by a cold chisel and hammer, and had retained nearly the whole of the cement.

Passing dry concrete down shoots, even with their lower ends somewhat buried in the newly deposited concrete, did not prevent separation from the coarser and heavier materials, which descended much more rapidly than the cement; for the cement, if very fine, which it should be for under water work, has a tendency to remain in suspension, and thus the component parts of the concrete become washed or mechanically separated during the process of depositing.

Generally in preparing concrete for under water work it should be mixed with as little water as possible, and where feasible should be rammed solid into the skips, after a small admixture of Medina cement, allowed to remain for two or three hours, and then be gradually or slowly submerged beneath the surface of the water, so as to allow the interstices to become gradually filled up with water, after which the skips may be quickly lowered down to the work in progress.

Since the remarks I made in 1866 as to the use of Portland cement concrete *in situ* under water, I have had considerable further experience in the various harbour and sea works executed by myself, and likewise from the examination of works I have visited, executed by other engineers, and my former opinions have more than ever been confirmed as to the loss of strength and the uncertainty of obtaining sound work under such conditions, except at great cost for extra cement.

As I have before mentioned, in order to guard as much as possible against the great loss of strength, I have in every work allowed the concrete to set one, two, and three hours, before being deposited in the work, or until it had become somewhat pasty or tacky, or just stiff enough to hold together while being passed through the water, but yet soft enough after it is deposited from the skips to fall to pieces, and to unite with the previously deposited concrete, and so form sound work.

At Greenock, Girvan, Wick, Quebec, and elsewhere, I have managed to get admirable work done by using partially-set concrete, where, if the concrete had been deposited immediately after mixing, much larger quantities of cement must have been used to obtain equally good work.

However, under the most favourable circumstances, and where the greatest possible care is taken, there is always uncertainty about works constructed with concrete *in situ* under water, and if there were the same facilities for examination and detection of imperfect work done under water as for work done out of water, I am quite sure that engineers in the future would use it in connection with such works much less than they have done in the past.

I think I cannot do better than illustrate my remarks upon this point by reference to the condition of an experimental block of concrete constructed under the superintendence of General Newton, of the United States Army.

The block weighed over 80 tons, and the object of the experiment was to ascertain if the system of constructing some new quay walls then in progress in the North River, New York, was such as to secure sound work.

The method pursued was to build a caisson, to lower it to the bottom of the harbour, deposit therein concrete in a similar manner and of similar proportions to what was employed in the construction of the quay wall, and when sufficient time had been allowed for the concrete to thoroughly set, the caisson with its contents was raised from the bottom of the harbour, its sides removed and the block of concrete examined.

The caisson was about 10 feet square, closely planked, and had a sloping face in front, corresponding to the batter of the wall, and short ends of piles were erected on the bottom of the caisson, similar to the bearing piles driven into the bottom of the harbour, and upon which the quay walls were built.

After the caisson was completed it was sunk to the bottom of the harbour and filled with concrete, composed of one part of Portland cement to two parts of sand, and four parts of broken stone. The materials as soon as mixed were filled into a skip having a sloping bottom and an opening side, and this was lowered through the water, and the concrete deposited.

Next to the sides of the caisson forming the face of the wall, and at the corners of the caisson, the skips were guided in position and tipped by divers, so as to secure as sound work as possible.

In order to make the block approximate as closely as possible to the quay wall, the caisson was not filled up in one day, but several days were occupied, the work thus being done in layers as in the quay wall.

Five weeks after the caisson had been filled with concrete, it was raised by a derrick crane, placed on shore, its sides removed, and the work examined.

The removal of the sides was done with great care so that the concrete might not be disturbed. Several photographs of the different sides of the block were taken, one of which I have shown on *Plate* VI.

The appearance of the block on the removal of the sides of the caisson was as follows :—

The faces were very ragged towards the bottom of the work, and on the river and south sides the ragged appearance of the faces extended to the top of the block. On the top of each layer of concrete (or day's work) there was a deposit of waste cement, which at the top of the whole mass was six inches in thickness on an average. From this upper deposit a specimen was taken, and kept in a warm office for some weeks ; there was no appearance of setting, and after it had been thoroughly dried, it floated on the surface of fresh water. It would, therefore, appear that the cement had separated in a great measure from the bulk of the concrete, the heavier particles finding their way through the broken stone to the base of the block, and the lighter floating on the top; and this fact was borne out in the mass of concrete even where the setting was very good, the proportion of sand always apparently being in excess of that in which it was deposited in mass. The faces of the block against the planking exhibited very few stones, but there was a coating from $\frac{1}{4}$ inch to 3 inches in thickness of cement, sand, and sewage, having the appearance of stratified deposit. This coating, instead of being hard and capable of resisting abrasion from the rubbing of vessels, was soft and easily removed, and upon its removal strata were exposed of washed cement, sand, sewage deposit, and concrete, with more or less excess of sand. At the corners the defective work was more strongly marked, and in one place there was a cavity, of which the bottom and sides were of loose stones without any cement. An examination by divers of the subaqueous portion of the quay wall, which had been completed prior to the construction of the experimental block, showed that there were defects of a similar character to those in the block. (For further remarks on these works see extracts from report by General John Newton, to the Commissioners of Docks, New York City, New York, February 18th, 1876, Appendix II).

Could the entire face of that quay wall have been rendered visible by the exclusion of the water, the defects exposed would have astonished most engineers, but as these defects are buried under water, only divers can possibly have a knowledge of the actual state of the work.

From a conversation I had with General Newton in New York, on 23rd May, 1881, I was greatly impressed with his remarks on the best method of obtaining sound concrete work under water, and he was strongly of opinion that something should be done, if possible, to prevent the mechanical separation of the particles of cement, etc., under water, and I have, therefore, thought it might be of service to refer at some length to an example such as this, of the uncertainty of obtaining uniformly sound monolithic work by the deposition through water of freshly mixed concrete, and especially as to the difficulty of forming a hard durable facing to the work, and filling up of angles or corners.

Various methods have been adopted to secure a good face to concrete work constructed *in situ* under water, but whatever course may be pursued, it is most judicious to use plenty of cement, and this is an absolute necessity when the soundness of the concrete facing is to be relied upon, for as a rule concrete as ordinarily deposited under water generally requires at least double, and even treble, the amount of cement, to make it equal in strength to concrete made out of water.

At Aberdeen harbour plastic concrete was used in December, 1881, and also in 1882-3 in connection with Provost Jamieson's quay of 600 feet in length, and the quay walls of 900 feet in length, enclosing the site of the graving dock, and which, I believe, has been successful, especially if I may judge from the excellent specimens sent me some years ago, which were chips which had been broken off from a corner of a block immediately after the frame or timber mould had been removed.

Instead of trusting to the formation of a sound facing by the deposition of concrete containing a large proportion of cement, other expedients in many cases have been employed. Thus in the construction of the south-west pier walls of the tidal harbour at the James Watt Dock Works, Greenock—a section of which is shown at *Fig.* 2, *Plate* VII.—I had the under-water portion of the wall from the foundation up to two feet above low water level faced with greenheart piling.

This wall is 46 feet in height, 28 feet of which is under low water. The method adopted in its construction was to dredge a trench over the site of the work, to drive along the line of the face of the wall, and to the batter thereof, 14in. square greenheart gauge piles, at distances of seven feet apart. Between the gauge piles 7in. greenheart sheeting piles were driven, and the heads of the piles were cut off at two feet above low water.

These piles were connected together at their tops by a greenheart waling, with the necessary filling-in pieces. At intervals of about six feet apart vertically $1\frac{1}{4}$-inch bolts of about three feet in length were put through each pile, having tails several inches long, turned down at right angles in order to get a good hold of the concrete and so prevent the piles from bulging out, or separating from the facing concrete.

At the back of the wall ordinary temporary timber framing or shutters were used to retain the concrete in place until it was set. There were two classes of concrete used. Next the facing of greenheart piles, the proportions for three feet in width of the wall were one of cement to three parts of coarse sand and finely broken stone, and for the remaining portion of the wall one of cement to six parts of sand and broken stone.

From the tops of the piles to coping level the wall was faced with granite ashlar, and backed with rubble concrete.

In some instances a facing of cast iron has been adopted; thus, in 1832, Mr. Matthews used cast iron piles in lengths of nine feet by a width of two feet by half an inch in thickness, in connection with the foundations of the north pier-head at Bridlington harbour. After that year other engineers used them, viz., in London at the New River head, and also on the Thames at the Broken wharf. In 1824, in connection with the rebuilding of the return end of the quay wall of Down's wharf, Saint Katherine's, a wharf in the river Lea at Limehouse, another at the sea entrance of the Norwich and Lowestoft Navigation, and in the founding of the pier-heads of the basin of St. George's dock, Liverpool, and other places down to the years 1833-4, when the Brunswick wharf at Blackwall was constructed by Messrs. Walker and Burgess. The main piles of this wharf are 25 feet six inches in length by $11\frac{1}{2}$ inches on face; are pitched at seven feet centres, and driven ten feet. The face metal was $2\frac{1}{2}$ inches in thickness, and the back ribs $1\frac{1}{8}$ inches by $5\frac{1}{2}$ inches in depth. The spaces between the main piles were filled in with five sheeting piles of 22 feet in length, and were driven about eight feet into the ground composed of coarse gravel and Blackwall band or rock, the latter of which occured in patches along the line of driving.

The upper portion of 14 feet in height of the wharf, or between the tops of the sheeting piles and the underside of the coping, was faced with cast iron plates in three tiers between the main piles, which were carried up to coping level, and the whole facing from foundation to cope was backed with one to ten lias lime concrete, and coped with Devonshire granite.

The wharf has a depth of 10 feet at low water against its face, and its total height from the bed of the river is 32 feet. The length of the wharf is about 720 feet, and the weight of cast iron used is about 900 tons. This wharf, although 55 years old, is still in good condition, with the exception of a few broken piles and plates, and certainly up to the present time, even although these breakages have occurred, has answered well the purpose for which it was designed, viz., a passenger landing quay at a moderate cost.

It may be regarded as a very good example of a work having a cheaply constructed face of a somewhat perishable material.

Following this work, some years afterwards the wing walls of the Blackwall entrance to the Victoria docks were similarly constructed.

Structures dependent on cast iron and exposed to the action of sea water, can only be looked upon after from 30 to 50 years as of a comparatively temporary character, and especially is this the case in regard to the very light cast iron pile structures erected as promenade sea piers at many of the watering places on the coast.

The rapidly oxidising action of sea water upon such iron structures would seem to indicate that the time is not far distant when it will become an absolute necessity that an examination by a duly qualified Board of Trade inspector should be made of all the cast iron piers in the kingdom, so as to satisfy the public that such structures can be relied upon during heavy weather.

At the Albert harbour, Greenock, a facing of large slabs of granite between cast iron piles was employed below water.

I have represented a section (*Fig.* 1, *Plate* VII.) of that quay wall. The method pursued was to dredge a trench along the site of the wall, drive at distances of about seven feet apart cast iron double flanged gauge piles, and slip down between the flanges of the piles rough faced granite slabs 7ft. × 7ft. × 2ft. thick, but somewhat reduced at their edges next the piles to fit into the grooves between the pile flanges.

The piles were driven to such depths that projections or ledges in the grooves between the flanges were level with the bottom of the harbour, and these ledges formed a stop or seating for the granite slabs to rest upon, so that the tops of the slabs by this means were kept at an uniform level, or very nearly so.

The piles were tied back with wrought iron tie rods. Behind the granite facing, Arden lime concrete was deposited by skips, and above low water level the wall was faced with sandstone ashlar, and backed with concrete. Many of the cast iron piles, although not much more than 30 years old, are now so soft that they can be easily cut by a penknife.

In the construction of a quay wall at Girvan harbour, I adopted for the portion below low water a facing of small concrete blocks of dovetailed shape, 21 inches in length and 12 inches in depth (see *Figs.* 2, 3, and 4, *Plate* XIV.).

The weight of each block was about 180 lbs. in air, and about 100 lbs. in water, and was easily handled without a crane. The blocks were made of one part of Portland cement to four parts of sand and fine gravel, and their exposed faces and arrises were rendered with a coating half an inch in thickness of one to one Portland cement compo.

Small semi-dovetailed grooves all round the outer or face arrises of each block made (when the blocks were laid in position) complete dovetailed grooves with the adjacent blocks, which, as each course was laid, were caulked or filled up with canvas, clay, or quick setting cement, thus forming the sides of a cement-tight box or dam, within which the concrete backing was deposited up to about six inches below their tops. Thick cement grout was then poured down the centre circular holes and end joints of the blocks, when it flowed into the hollowed-out beds, and the hearting firmly cementing it to the facing blocks. In this manner a solid monolithic structure, with a durable facing of blocks, was constructed without the aid of timber frames or moulds. The divers found no difficulty in setting, or rather stacking, the blocks one on top of the other, as fast as they could be lowered down to them.

In the construction of the quay walls in connection with the recent Quebec harbour improvements, the circumstances under which work had to be carried on differed so much from the conditions in England, that I had to adopt considerably modified arrangements in the execution of these works.

The working season at Quebec is confined to about half the year, viz., from the middle of May to the middle of November, and all plant and temporary work must be removed at its close, as only very substantial work can possibly resist the very heavy abrasion of the sheets of ice, from three to five feet in thickness, rising and falling with the tide from 16 to 18 feet (see *Plates* XI. and XII.). Such being the case, I resolved to construct the 1,250 feet lineal of the tidal harbour wall with cribwork, so formed as to contain a full section of a (concrete-in-situ) wall with the usual counterforts. The cribs were constructed early in the spring of 1879, 12-inch by 14-inch square baulks of timber being chiefly used for the purpose. These baulks were accurately sawn to gauges laid longitudinally and transversely, notched into each other and firmly bolted together at their intersections (see *Fig.* 1, *Plate* XIII., and *Plates* VIII. and IX.)

Between May and November, 1879, the cribs (with the exception of the sawing of the timber) were all built, floated into position, and sunk on to the tops of the heads of the bearing piles at 24 feet below low water.

The cribs were each 120 feet in length, except the last or closing one, which was about 50 feet; they were all 33 feet wide at their bases, 23 feet wide at their tops, and 27 feet high. Their front compartments, which formed the usual and full section of ordinary quay wall, together with the counterforts, were filled from bottom to top with partially set Portland cement concrete in the following proportions, viz., the front 2 feet of four to one concrete, and the remainder eight to one.

The construction of the 1,250 feet of cribwork complete, that is the building (partly aground and partly afloat) of the cribs, dredging for their reception a trench through sand of 28 feet in depth, or to 24 feet below low water, by 40 feet in width at bottom, with flat slopes on each side resembling a wide railway cutting, driving bearing piles at bottom of trench with great accuracy for the reception of the cribs, sinking the cribs on to the tops of the bearing piles, and filling up the compartments in the front of the cribs with concrete, and among the timbers of the cribs behind the compartments with clay, stone and sand, occupied only five working months, being at the rate of about one lineal foot of the complete wall up to four feet above water per working hour, a most exceptionally rapid rate of progress for the execution of such works, and, as far as I know, is without a parallel in subaqueous works.

The tops of the cribs when in position formed part of the quay wall, and were at a level of about three feet above low water. Above this level the wall was faced with ashlar and backed with Portland cement rubble concrete (see *Plate* X.)

This length of wall of 1,250 feet, 48 feet in height, is founded on sand, and forms the southern side of the tidal harbour.

The works from first to last have stood the severest of Canadian winters without damage of any kind. A block of Portland cement rubble concrete, similar in every respect to that which was being used in the harbour works, was placed at about half tide level on the Custom House stairs alongside of a block of concrete in which a Canadian or native cement was used. These blocks were exposed for two or three winters to very severe frosts. The Portland cement block at the end of the test was found to be quite perfect and sound in every respect, while the native cement block had wasted and gone to pieces.

Any of the concrete in the work between coping level and low water mark completed seven days before the winter first set in showed a very slight disintegration, while that executed a fortnight or three weeks before the frost came was found to be absolutely perfect when uncovered in each following spring.

I believe it was the first time any such work, under similar con ditions, had been executed in Portland cement in Canada, and it is now used everywhere with confidence in that country

In cases where a solid structure is required and a firm stratum can only be reached at a considerable depth, it is customary to resort to the use of caissons for sinking through soft strata. Caisson work has been very largely developed within the last thirty or forty years, and especially for founding piers of bridges over rivers and estuaries, where formerly foundations of bearing piles would have been employed.

Brick caissons, however, are well known to have been used in India for well-sinking and similar purposes from time immemorial, and the very modern practice of using concrete cylinders for founding dock walls is simply an extension of that system. Cast iron cylinders have been so largely used for the piers of railway and other bridges during the last forty years, and are so well known, that I hardly think it necessary to refer to them in detail. I may, however, mention that the cast iron cylinders (sunk in 1842) of the Terrace pier at Gravesend were the first, I believe, used in Great Britain, and the next were those of Rochester bridge, in connection with the construction of the piers. The larger class of caissons are usually formed of shells of wrought iron plates, rivetted together, stiffened vertically and horizontally by angle T or H irons, or built beams, or ribs, according to their sizes and the pressure to which such caissons may have to be subjected.

Caissons may also be built of cast iron, timber, brick, or concrete, depending much upon circumstances, locality, etc.

In sinking a caisson it is usually necessary to add considerable weight, in order to overcome the friction of its outside skin against the strata through which it has to pass.

One of the most convenient arrangements for adding the weights required in sinking is by building up a wall of concrete inside the caisson, next to the shell. If sufficient weight cannot thus be obtained, then temporary loading must be resorted to with cast iron stacked on the inside stringers, or by railway bars laid on the top, which weights are removed and added from time to time as the sinking proceeds, and further rings or strakes are added. During sinking, great care is required in order that the caisson may be kept vertical, for if once allowed to get even slightly out of plumb, it is difficult and sometimes impossible to get it back into position, or even nearly so.

At the commencement of the construction of the Thames Embankment, adjoining Westminster bridge, cast iron caissons were employed in the first instance to serve as a cofferdam, so that the embankment works should be executed dry, but these were abandoned owing to the great difficulty of sinking them with the accuracy required for such a work.

Elliptical wrought iron caissons were afterwards tried, and were sunk close to each other; the joint between each end was to be rendered watertight by a timber guide pile, or tongue, driven down a groove half formed in the ends of each caisson, at the points where they adjoined each other. The lower portions of the caissons were to be left in the bottom to form a toe to the wall, and the upper portions above the bed of the river were to be removed on the completion of the wall.

It was found, however, that the caissons could not be sunk so accurately as was expected, and although the depth of strata to be sunk through was less than 20 feet, yet the caissons got so much out of plumb in that shallow depth, that watertight junctions between them could not be made except at great cost and trouble, and the dam of caissons had therefore to be abandoned in favour of an ordinary timber double-pile dam, with a clay puddle wall.

The largest and best known examples of caissons are those which have been recently employed in founding the piers of the Forth bridge. They are upwards of 70 feet in diameter, and have been sunk, compressed air being used, to depths of more than 70 feet below high water level. Greater depths than these have been reached in a number of instances with open caissons and cylinders of smaller sizes.

Time will not permit me to enter into the details of the different methods which have been adopted for sinking caissons at various important works, excavating from within, and filling them up with masonry or concrete.

The details which have been found necessary at the several works have been adopted to suit the special requirements of each case, and in a number of instances are most interesting and important, but I must content myself with these remarks, as the subject has a very wide range indeed.

Another application of caissons has been used for founding harbour and dock walls upon soft strata instead of sinking through such strata to a firm foundation. This method is also applicable for obtaining sound facing to subaqueous works, apart from the questions of foundations.

I have represented (see *Fig.* 1, *Plate* XIV.) a design I proposed for some quay walls to be constructed on the Clyde in 1871, where the foundation was soft, and an extended bearing area was necessary.

The method proposed was to dredge along the line of the wall a trench about 25 feet in width, by about six feet in depth, below the bottom of the harbour; to fill up this trench with loose rubble and broken stone to within a few feet of the level of the bottom of the harbour, and the top of this stone filling was to have been sprinkled or levelled up with fine shingle, without the aid of divers, to form an even bed on which to found the caissons. The tops of the caissons would have been about two feet above low water, and above this level the quay wall was to have been built in the ordinary manner.

The caissons were each to be about 40 feet long, 18 feet wide, and 22 feet high, formed of brickwork in Portland cement compo, the sides and bottoms being about two feet thick, divided by partitions, and stiffened at the corners.

These caissons would have been constructed in an adjoining graving dock, allowed to harden for a few months, after which they would have received a thick coat of pitch and tar, been floated out to the site of the works, and sunk into position by allowing them to ground at dead low water, and afterwards water would have been admitted to prevent them from rising. These caissons had sufficient freeboard of themselves to serve the purpose of safe flotation without the assistance of pontoons. After they had been sunk in place, the interiors would have been filled with sand or rough concrete, or each compartment could have been pumped out and the concrete filled in dry. The work, however, was not carried out at the time, and, subsequently, I substituted another and less costly design of greenheart timber.

At Ardrossan harbour, an arrangement similar to this in principle, although differing in a number of details, was adopted in the construction of a portion of one of the piers, and served the purpose remarkably well.

I have already made reference to the manner in which the foundations of the new Victoria landing stage works, at St. Helier's, Jersey, were executed, single pile half-tide dams having been adopted. In another part of the same harbour, an extension of the north quay wall was carried out (see *Figs.* 1 and 2, *Plate* XV., and *Plates* XVI., XVII., XVIII., and XIX.), and in this case a similar method was pursued in sinking down to the rock, and afterwards in the construction of the wall from foundation to cope. In this case, owing to the limited area for carrying on building operations, the depth below the bottom of the harbour to which the foundations had to be carried to reach the rock, and the limited time of four to five hours per tide, during which work could be carried on, the arrangements, both as regards economy and expedition, had to be such that everything should be at hand and ready, so that the work might be carried on in the most expeditious manner possible. For driving the piles, a back and front or double leader pile-driving engine was erected, which travelled on rails laid down on the bottom of the harbour, and had an under trolly frame, so that it could be moved transversely as well as longitudinally, and thus any necessary adjustment of the engine for driving the piles was obtained. The material to be driven through was composed of fine sand, peat, gravel, and clay, with large stones interspersed. After the experience of the use of various classes and thicknesses of timber, and forms of shoes, it was found that good sound pitch pine piles, 6in. in thickness, and 9in. to 11in. in width, with heavy cast iron shoes, having stout wrought iron straps, gave the best and most economical results.

Piles of less thickness, or of greater breadth, did not stand the heavy driving through the hard, compact sand and clay.

Thicker piles, or hard wood piles, could have been used, but the cost of the work would have been increased. The inner and outer rows of the sheeting piles were waled and strutted, as the excavations proceeded, with whole timbers, 12 to 14 inches square, and the frames were spaced from five to three feet apart vertically, according to the depth below the surface of the ground and the pressure to which they were subjected.

For draining these trenches of water, two pulsometer pumps were used, throwing jointly about 400 tons of water per hour, steam for which was supplied from boilers on board a barge grounded near to the trench. The pumps were suspended from a cross beam over the trench, and were shifted by the crane from one trench to another as the works progressed.

The excavation of the trenches was chiefly done by pick and shovel, the material filled into skips, and raised and deposited behind the finished end of the wall by a 10-ton crane, seated on the last built portion of the work constructed. Excavation by grabs was tried, but owing to the limited space for working between the struts and the danger of laying hold of and pulling out or disturbing some of the timbers, work could only be done in the middle of the trench without touching the sides and corners, and it was found, upon the whole, that the excavations could be done more cheaply and satisfactorily by hand labour than by crabs.

When the rock had been laid thoroughly bare, a levelling of fine concrete up to a fixed height corresponding with the bed of the first concrete block was laid down, and on the top of this the wall was built up to the coping with blocks of rubble concrete three feet by three feet on face and varying in length from four to eight feet. These blocks were built in a work-yard near to the works, allowed to set until thoroughly seasoned, then placed on trollies and run on a line of rails laid on the top of the completed portion of the wall, out to its end where the work was in progress.

The face blocks had a facing of granite ashlar 11 inches in thickness, with headers from two feet to two feet six inches long, and set in $2\frac{1}{2}$ to 1 Portland cement mortar. The hearting blocks were built of granite rubble and five to one Portland cement compo. The blocks were firm enough to bear handling when three days old, but were allowed to become thoroughly seasoned before being placed in the work. They were laid header and stretcher in the wall, and bedded in three to one Portland cement mortar about three-quarters of an inch in thickness.

Vertical joints of one inch in width were kept between all the blocks, the outside ones were then stopped with Medina or quick-setting cement, and all joints filled up with mortar, composed of three parts of coarse sand and one of Portland cement.

A single course of blocks of three feet in height by $18\frac{1}{2}$ feet in length of the wall was built in a few hours, and the rate of progress of the whole was such that a 37-feet length of wall, of an average height of about 47 feet, was built regularly per month, including pile-driving, excavating to a depth of 20 feet below the bottom of the harbour, and the building up of the wall from foundation, to cope at an inclusive cost of £27 10s. per foot linear of the full section of the wall.

The wall was built in lengths of 18 feet 6 inches, which were so solid the day after the last course was laid, that the 10-ton travelling crane used in the construction of the work, and weighing over 22 tons, was moved on to the new work as each length was brought up, and not the slightest disturbance of the work was occasioned thereby.

As the wall carried the two lengths of moveable platforms of 18 feet 6 inches each and crane, the trouble and expense of erecting ordinary staging were avoided. The crane, at each shift forward, lifted from its rear and laid down in front of itself one of the 18 feet 6 inches lengths of platform and staging complete, in about half-an-hour, and was then travelled forward to its extreme end, ready to command another length or section of the wall. Each length contained a counterfort, which was found of great use in carrying the shifting platform. The gauge of the rails on which the crane travelled was 12 feet.

A system such as this of executing work is highly preferable to the deposition of concrete through water, as there can be no doubt in regard to the soundness of the whole of the work, for a hard and perfectly durable face, either of granite or other material, can be obtained, and the work can be expeditiously carried on with but little plant, and, in the majority of cases, at an exceedingly small cost.

The blocks, instead of being brought up in vertical courses, as shown in *Figs.* 1 and 2, *Plate* XV., might be built in sloping courses, but this, as also the sectional lengths of the wall so brought up at one time, must necessarily depend upon the outreach of the crane.

In the wall I have just described the length of section was covered by a clear outreach of 18½ feet from the end of the last finished portion, or 26 feet from the centre of the crane.

On the 22nd March, 1869, I reported to the Greenock Harbour Trustees (see Appendix III.) on the best method of founding the proposed north-west pier of the western tidal harbour at Garvel Point, when I recommended a method of construction such as that shown by *Figs.* 3 and 4, *Plate* XV., and which consisted of blocks formed for the full width of the wall (see *Figs.* 11 and 12, *Plate* XXVIII.), the joints at *a a a a* being vertical and quite close from foundation to cope. The guides *b b* (see *Figs.* 3 and 4, *Plate* XV.) were to have been of iron, pointed at their feet, and having parallel bars or rungs, so that by raising one leg the other easily followed, when both would have been removed; and the spaces C C C would then have been filled in with stones and grouted up, or filled with fine concrete after the outside vertical and bed face joints had been caulked.

I have now given in as concise a form as possible a summary of the methods pursued in founding what I have termed Inside Works under water, with as much detail of the principal features in each case as is sufficient to show the object of adopting such a method, or the advantage which it possessed.

I have endeavoured not to introduce anything in the shape of formulæ, as it has been my wish to deal with the subject from a practical, rather than a theoretical, point of view.

My engineering experience has extended over a period of more than 42 years, and during that time I have been actively engaged in the designing and construction of harbour works especially. I thus know the value of what frequently, upon a cursory glance, seemed trifling modifications of detail, but which have been the means of ensuring success all round, where, had they been disregarded, the opposite result would have ensued. And so in regard to this question of subaqueous foundations, more, perhaps, than any other with which the engineer has to deal, his mathematical knowledge is called much less into requisition than his knowledge of what has been successfully done under similar, or approximately similar, conditions. He has to consider the methods which have been successfully pursued, and the appliances used, and to exercise his ingenuity in adapting, modifying, or improving, such methods, to suit his own particular work. In pursuance of this purpose in my lecture, I have referred more frequently to works executed by myself than I probably should otherwise have done, for I have felt that I could thus speak from actual knowledge of the works to which I have made reference.

In concluding this lecture, I would reiterate what I stated at the commencement, that wherever it is possible to shut out the water, having due regard to cost, and to execute work dry instead of in water, or by blocks of concrete laid under water and grouted up, it should be done, for much more satisfactory work in every detail can be obtained, and the usual doubts as to the soundness of concrete *in situ* works executed under water are avoided.

LECTURE II.

(*Delivered on the* 14*th March*, 1889).

In my former lecture I dealt with subaqueous foundations so far as they related to "Inside Works," that is, works executed in sheltered positions.

I now propose to treat of works constructed under water in exposed positions, which may be termed "Outside Works."

The character of such works is dependent on their site, the object they have to serve, the force of the waves and currents they have to resist, the depth of water, and the nature and configuration of the sea bottom. These vary so much that there are, perhaps, not two sea works existing subject to precisely similar conditions.

The practice of engineers in regard to the construction of breakwaters differs very much, and this is largely due to the fact that the forces which have to be dealt with are not ascertainable with the same accuracy, or approximate accuracy, as in the majority of other engineering works, and, therefore, the experience and judgment of the engineer have to play a much more important part to ensure economy and safety than in almost any other branch of engineering. Many observations and experiments have been made in regard to the height and force of waves, and also with respect to the "fetch" or uninterrupted distance over which they have travelled, and formulæ deduced from these observations. Such formulæ, however, have not, so far as I am aware, been called into practical use for the designing of breakwaters.

In designing such works, the engineer proceeds rather by analogy, reasoning from works successfully executed by himself or other engineers, observing the points of similitude or difference, and modifying the design accordingly.

The tendency is, and upon the whole it is judicious, to provide ample strength, and whenever the designer is in doubt, to give a very wide margin indeed.

In the opinions of engineers, this margin varies so greatly that I am not saying too much in stating that of two engineers, both experienced in the construction of breakwaters, one might produce a design at least twice as costly as that of the other, for a breakwater upon the same site, and to serve the same purpose.

In short, the designing of breakwaters is purely empirical; useful experience has been gained from numerous failures, and a step by step process has been pursued, leading up to the designs of the present day.

I will give a short resumé of the principal features of some designs of breakwaters, concluding with the most recent, one of my own works, which embodies some novel features, viz., the Hermitage breakwater, which is now in course of construction at St. Helier's harbour works, Jersey.

Where the exposure is somewhat limited, an inexpensive class of work may be adopted, consisting of a mound or embankment formed of roughly quarried stones, and faced with heavier stones closely laid, or with a covering of concrete blocks, of such sizes or weight as may be found necessary to resist the seas to which they may be subjected.

Numerous examples of this class of work are in existence round our coasts, and recently I constructed in this manner an embankment (see *Fig.* 1, *Plate* XVII.) forming the outer arm of a large tidal harbour at the James Watt dock works, Greenock. This embankment is 3,300 feet in length, 200 feet in width at top at its widest part, and was founded in depths varying from 0 to 18 feet at low water.

Over a considerable portion of the site of the embankment, the material on which it was founded was very soft, for a depth of more than 100 feet below low water.

The method of construction was as follows, viz. :—

Along the sites of the inside and outside slopes of the embankment, trenches were dredged down to a depth of 23 feet below low water, or 33 feet below high water, for the reception of waste stone from the rock excavations of the James Watt dock works, which was deposited by end tip wagons in the form of ordinary railway embankments, up to eight feet above high water mark, and the space between these embankments was filled up with a hearting of clay, stone, etc.

During progress, the bank had to be made up from time to time, as it gradually sank into the soft material on which it was founded, the depth to which it sank being about 50 feet below high water, or 40 feet below low water. On one occasion, simultaneously with a very low water of a spring tide, when the embankment had nearly reached coping level, about 450 feet in length from the tip end suddenly sank from seven to about twelve feet. This was due to the increased weight of the embankment, brought about by the base being uncovered some two or three feet more than usual.

After the embankment ceased to subside, the slopes were faced below low water with heavy blocks of stone, and above low water with rubble pitching 2 feet 6 inches in depth, the joints of which were filled with fine Portland cement concrete. The top of the embankment, for a width of 10 feet back from the coping, was pitched with rubble 18 inches in depth, laid on a bed of broken stones.

In some of the iron-making districts, the slag from the blast furnaces has been run out and tipped in the form of embankments for sheltering purposes, and which have answered well as breakwaters. On their inner or sheltered sides, timber wharfings and jetties have occasionally been erected, and useful berthage accomodation obtained.

Works of this class, even although exceedingly cheap to construct in the first instance, are sometimes very costly to maintain, especially if there is much wasting of the slag, or if there is a concrete covering to keep the slag intact; for, probably, in the long run, it may be found that the annual cost for up keep may equal the interest on such a sum as would have paid for the erection of a good substantial breakwater, which would have needed no such repairs. Generally, it is better and more economical to build a solid head to a slag or rubble mound breakwater, than to attempt to protect the slopes by a covering of concrete, the toe of which is so easily undermined unless it be well protected with heavy blocks of concrete.

Such works, even under the most favourable conditions, are only suitable for very moderate exposures; but where works are completely exposed to the Atlantic, Indian, or Pacific oceans, they should be of the most solid description, and the arrangements for their execution such that at almost any stage of their progress they, together with the plant employed, should be capable of resisting any storms that may arise.

In the earlier breakwaters of any magnitude, such as Plymouth, the method adopted was an extension of the rubble mound system; but the magnitude of the work, compared with any work at that date of similar construction, rendered it of great importance that the utmost care should be bestowed on the design and construction of the work, and that the materials should be arranged to give the most effective results. This was done by depositing them in layers according to their sizes, and on the outside of the mound a coating or covering of very large sized stones was laid down.

The Plymouth breakwater (see *Fig.* 2, *Plate* XXVII.) is 5,100 feet in length, founded in a depth of 33 feet at low water, and is carried up to two feet above high water. The range of tide is 15½ feet at springs. The slope on the sea face is paved with heavy blocks of granite set in cement, from low water up to the top, and all are firmly cemented and cramped together.

The cost of the works appears to have been about £300 per foot run, but there is a constant annual expenditure for maintenance.

I have shown (see *Plate* XXVII., *Fig.* 3) a section of Port Said breakwater, founded in a depth of about 25 feet of water below ordinary sea level, and which consists of a base or mound of rubble deposited up to a level of about 18 feet below sea level; and on the rubble, up to 12 feet above sea level, it consists of a mound of 20-ton concrete blocks, partly launched from the decks of barges, and partly deposited by sheers mounted on a barge.

The employment of a mound of large concrete blocks, is a decided step in advance of the protected rubble adopted at Plymouth, resulting in a reduction of material employed; in increasing the stability of the upper portion of the work, which is subjected to the greatest force of the waves; in being executed for a smaller first cost; and in greatly lessening the expenditure for repairs.

A still further development is shown in the section of the Madras breakwater (see *Plate* XXVII., *Figs.* 4 and 8), which consists of a vertical wall of large concrete blocks founded on a rubble mound, the surface of the latter being at a level of about 22 feet below low water.

The total depth at the outer end is 45 feet at low water, the rise of tide 3 feet 6 inches, and the total height of the work from foundation to coping, about 50 feet.

The widening of the rubble base, the mound of large concrete blocks against the sea face, the concrete bags on the inside, and the capping of concrete, are the additions to the ordinary section of the work as proposed for the new outer arm.

At the Manora breakwater, Kurrachee, the sloping concrete block system was first adopted in 1870 by Mr. Wm. Parkes, and has opened up a new era in concrete block laying. The system of sloping courses, although excellent, is not new, for it was formerly used in connection with the building of ordinary dry stone harbour walls and sea piers. It avoids the cost and trouble in connection with the bonding, levelling, and the making of the beds and joints fair, as in horizontal coursed work (see *Plate* XXVII., *Fig.* 9).

Dover breakwater (see *Plate* XXVII., *Fig.* 5), 2,100 feet in length, was built at the rate of about 90 feet linear per annum, between the years 1847 and 1871, and cost upon an average about £323 10s. per foot run, exclusive of engineering and other expenses, but inclusive of these about £360.

Such a work as that at Dover is the best example extant of the vertical wall type of construction. The solid stratum of chalk on which it is founded was dressed down to an even surface, for the reception of the first or foundation course of concrete blocks, at about 59 feet below high water, or 40 feet below low water.

From foundation up to within a few feet of high water mark, it is wholly built of concrete blocks in horizontal courses, laid dry. From these blocks up to quay level, it is built with concrete *in situ*, and from low water up to coping, it is faced with granite.

The parapet is carried up to about 25 feet above high water mark.

The width of the breakwater at quay level, or at about 10 feet above high water, is 47 feet, and the width at foundation level 65 feet. The total height from foundation to quay level is 69 feet, and the top of the parapet stands about 15 feet above quay level.

This method of founding on a solid bottom, at 40 feet below low water, owing to its great cost, and the comparatively slow progress made during construction, has not been repeated. The work, however, is a masterpiece of engineering, and when designed in 1847, was very far in advance of any method then in use.

A work of a similar vertical section can now be constructed on an absolutely monolithic system, from foundation to coping, with rubble masonry blocks, faced with granite ashlar, having every joint and bed, both above and below low water, filled up with neat cement, for less than half its cost, and in 10 instead of 24 years.

Wick Bay, owing to its great exposure to the North Sea, the deep water outside, and its bell-like form, is subjected to very heavy and destructive seas, which, on entering the bay, are gradually heaped up, or contracted, by the narrowing of the bay landwards, and so their forces are almost wholly spent vertically by rising to great heights, that is, their reduction is not much influenced, as in most cases, by the gradual increase in width and reduction of depth of water landwards.

When I gave evidence in Aberdeen on the 6th August, 1883, before the "Sub-committee appointed to investigate the question of the most suitable place for a harbour of refuge on the east coast of Scotland," I alluded (see Appendix VI.), among other things, to the failure of the Wick breakwater.

This work was commenced in 1863, and after being in progress for about nine years, a severe gale, which occurred in December, 1872, carried away about 150 feet of its seaward end, which included the 1,350-ton block at its head, to which so many engineers have from time to time made reference.

At the end of June, in the year 1880, and again in March, 1881, I made examinations of the ruins of this breakwater, which at the latter date had, through succeeding heavy gales from the year 1872 down to that of the 11th and 12th of March, 1881, extended from its head shorewards for a length of 500 feet, leaving little more intact than the shallow water portion or shore end of the work.

The mass of 1,350 tons, which was moved entire, was not one block cast *in situ*, but consisted of a block, 26 feet in length, by 45 feet in width, by 11 feet in depth, of cement rubble work built *in situ*, and weighing upwards of 800 tons, and this was connected by

$3\frac{1}{2}$ inches diameter wrought iron rods to a course consisting of 80 and 100-ton blocks immediately below it, weighing some 550 tons.

All the blocks under water were laid dry, that is without any attempt being made to fill up the open joints with cement.

Had each of such blocks borne its fair share of the weight of the concrete-in-mass superstructure, or, better still, had the breakwater been a monolith from foundation to cope, no such accident as that described could have occurred, for the breakwater was of ample section or weight to resist the forces it had to encounter, but being of compound construction, composed of a loose rubble mound, with blocks of concrete laid dry on top thereof, and again on the tops of these blocks a monolithic superstructure of cement rubble concrete built *in situ*, the stability of the work, as a whole, was dependent upon that of its weakest component part, so that if by any means the rubble base or concrete blocks, laid dry on top thereof, that is having open joints and beds, became disturbed, and the weight of the concrete-in-mass superstructure thus no longer borne uniformly by the whole of the dry blocks, one or more of such blocks would soon get dislodged, and an opening or breach once formed would extend very quickly.

In the rubble base of a breakwater, such as that at Wick, the outer margins are much more liable to subside, or are more easily affected by storms than the central portion, and, further, the faces of the slopes have a constant tendency to flatten and assume an angle or section of repose. From this it may be concluded that the commencement of the failure at Wick was principally due to one or more of the outer blocks B B B′ B′ (see *Plate* XXVIII., *Fig.* 2) becoming loosened, probably from subsidence of the rubble, and thus the 1,350-ton upper block, being almost wholly supported on the central blocks A A, and rocking on them, under the action of the waves, still further punched down or loosened the lower outer dry blocks in their beds, until, finally, they were dislodged, leaving the 1,350-ton mass (or 980 tons in water) resting upon the blocks A A, upon which it was slewed round as on a pivot, and deposited inside the breakwater.

The shelter afforded to a portion of the bay and to the old Pulteney Town harbour works, by this breakwater during its short life, was of great service, but its gradual destruction by successive gales, down to the beginning of 1880, once more subjected the harbour works to the exceptionally heavy seas to which the Bay of Wick is exposed.

During a heavy gale on the night of the 15th February, 1880, the head of the old south pier (*Plate* XXII., *Fig.* 1) was seriously damaged, over 2,000 tons of stone facing blocks of from three to four feet in depth from the slope, and rubble from the parapet and mound, being washed down, and on the 18th of the same month I was called in to advise as to the best course to pursue to repair the damage in the shortest possible time.

The steps taken were first to pin and cement up the loose ends of the stonework, and then to cover up the mound of rubble as quickly as possible with concrete *in situ* up to the original slope line, and to restore the parapet.

The work of restoration was in hand and progressing rapidly and well, when on the 4th April, 1880, a heavy gale carried away 30 feet of the damaged head, down to nearly low water mark, seawards of the portion which had just been repaired, and which stood the gale exceedingly well.

Beyond a few planks, barrows, and flat bar rails, it was impossible to obtain suitable plant for carrying on the work. I, therefore, resolved to cast blocks of concrete *in situ* in compartments, having frames formed of stools of six to eight feet in height of flat bar rails, bent into an A form (*Fig.* 3) to serve as trestles, which were placed six feet apart, and carried heavy flat bar rails, which were used as rafters, to which $1\frac{1}{8}$th ploughed and tongued flooring boards were lashed, by $\frac{1}{2}$-inch diameter ropes to centre-bit holes, to the under-sides of the rafters, and to the legs of the trestles. Along the junction side of the block to be cast, with that of the succeeding block, heavy bags of shingle D D (*Fig.* 2) were stacked, to form a temporary wall during the casting of the block in the compartment. To prevent wash, old sails were nailed to the roofing and end boarding, laid over the side walls of sacks of shingle, and on the floor over open rubble. The whole of the framing, boarding, and covering with sail cloth was easily completed as the tide receded, and immediately it left the compartment the concrete (which had been allowed to partially set for two or three hours), amounting to from 70 to 145 tons per compartment, was laid in in a couple of hours, and its top surface under the roofing rammed in solid with a strong fine concrete. The heavy seas, as the tide rose, had no effect on the newly-cast blocks, and after two or three days the framing was removed, when in every case sound work was obtained; and, as far as I can learn, no disintegration has taken place in the plastic concrete, although it is now nine years old.

The work was carried out in accordance with an original sketch, which was laid before the Pulteney Town Harbour Commissioners on the 7th April, 1880, and approved of by them (see *Plate* XXII., *Figs.* 2 and 3).

In executing the concrete *in situ* work down the slope, considerable difficulties—owing to the few hours men could work at spring tides—were encountered in founding the lower portions of the slope and the toe blocks at about low water mark, several of which were successfully cast, but at a considerable expenditure of time and money, and, therefore, I advised that as soon as possible sheeting piles should be driven well down into the clay to form a toe, to be backed with concrete, grouted up rubble, and coated with Medina cement, and so prevent undermining, which I believe has since been done.

During the progress of the work, some of the concrete facing was damaged by the exposed rubble being washed out from under the concrete, before it could be covered up.

Figs. 1, 2, 3, and 4, *Plates* XX. and XXI., show plan, cross section elevation, and longitudinal section of the proposed 840 feet extension of the South Pier, dated February, 1880, illustrating the use of concrete caissons for founding facings of concrete made out of water up to a few feet above low water, so as to prevent disintegration, as concrete work out of water in the form of blocks, and allowed to harden, seldom gives way. In this case the outer skin of the caisson next the sea takes the place of facing blocks.

Figs. 5 and 6, *Plate* XXI., show cross section and plan of proposed groyne or pier of 800 feet in length on the opposite side of the bay to that of the proposed extension of the new south pier, also using concrete caissons, as for the south pier and the groyne.

Fig. 7 shows section of method of floating and sinking the concrete caissons, and levelling the beds for the reception of the same.

These drawings I prepared in January and February, 1880, for the Wick Harbour Commissioners, in support of their application to the Treasury for the remission of the debt or loan of £60,000, so as to enable them to proceed with the extension of the south pier and other works.

Fig. 1, *Plate* XXIII., shows a cross section of the repairs to the head as executed (dated 21st April, 1880).

Figs. 2 and 3, *Plate* XXIII., show elevation and cross section of the 40 feet length of the proposed extension of the south pier prepared in March, 1882, as a modification of the design for caissons, dated February, 1880, and show the work to be carried out by the use of small dovetailed concrete blocks, such as were at that date being so successfully used at Girvan, after the abandonment of the costly and troublesome timber framing and moulds. These small blocks were readily and easily laid when there was a good splash on, formed a most excellent and durable face and a cement-tight mould for the reception of the concrete *in situ* backing, which was thoroughly united to the dovetailed blocks by neat cement grout poured down the holes in the centres and joints of the blocks. The backing was brought up in layers with the blocks, and finished off at each tide's work at half way up the last course of blocks, so as to form a good junction with the succeeding tide's work.

Generally upon these designs—omitting the caissons or small dovetailed blocks—a length of about 150 feet of the extension works has been carried out; that is to say, the concrete *in situ* system of depositing within frames, from foundation to cope, has been adopted.

This system I had for many years strongly advocated, as a means of avoiding the many risks to which sea works otherwise constructed have been subjected. But even with concrete *in situ* so laid under water, other and, perhaps, worse troubles are likely to arise, such as those which have occurred more or less in connection with several works of comparatively recent date, viz., at New York, on the east coast of Scotland, and elsewhere, and which are likely to occur again, unless special provisions are made for preventing the softening or disintegrating of the concrete by a lasting and durable face, composed of neat cement in a plastic state packed with rubble under water against the faces of the moulds, or, in the absence of rubble, by dovetailed blocks of strong fine concrete, or, by what makes the best of all faces, rubble concrete blocks faced with ashlar, and their beds and joints grouted up below and above low water, such as I have used at Jersey, and which I will presently describe.

I believe disintegration has so far been confined to works where concrete has been mixed dry, and then laid under water, or where it has been mixed in the ordinary manner, and deposited immediately thereafter.

During the storms of the 6th February and 10th March, 1883, a portion of the south pier at Aberdeen was seriously damaged, and when visiting Aberdeen in July and August of that year, in connection with the proposed harbour of refuge there, I examined the breach and concluded that it was a similar example to that at Wick, of the dangerous practice of surmounting a stack of dry blocks laid under water by a rigid girder superstructure of concrete above low water, more especially if the blocks are founded on a yielding bed, or on a bed that would be likely to be undermined, that is, on any stratum short of solid rock, for a subsidence of an eighth of an inch, or even less, would be sufficient to loosen or leave the blocks free to be acted upon during heavy weather.

In this instance, after the blocks had been carried away, the superstructure for 23 feet in from the sea face, out of a total width of the pier of 35 feet, became a girder of concrete *in situ*, weighing about 2,500 tons, and spanning an opening of 90 feet in length, by 23 feet in width, by 12 feet in height.

Some of the blocks of the harbour face had been punched out into the harbour, while those in the sea face had been pulled out and strewn on the bottom of the sea for some 20 yards outwards from the face of the breakwater (see *Plate* XXVII., *Fig.* 6).

The girder was a very remarkable example of the strength of concrete *in situ* work, chiefly out of water, and of the resistance it successfully offered to the waves, which dashed with such great force into the cavern-like breach.

After the withdrawal of the blocks, most engineers would have believed that an unsupported girder of 90 feet span, subject to such heavy seas as those which made the breach, would have readily given way; but such was not the case, for it remained intact until the 22nd June, when it was cut through at its ends, and dropped down on to a level bed prepared for its reception in the breach.

Now, had the joints and beds of the dry blocks under water been grouted up with neat cement, the blocks would have been in place at the present time, and any undermining of them at their bases could easily have been filled in with large rubble and shingle, and grouted up solid with neat cement.

The sketches of the breach (see *Plate* XXVIII., *Figs.* 9 and 10) are from the *Minutes of Proceedings of the Institution of Civil Engineers*, Session 1886-87, p. 159.

I think it is conclusive that the local subsidences, or inequalities in the foundations, or underminings, caused some of the piles of blocks to be here and there relieved of the weight of the superstructure, and thus were free to be acted upon by the sea, which soon displaced them, while other blocks were heavily pinned down and held in position by the great weight of the girder, such as the blocks under the ends of the girder, which actually became the abutments or supports of the concrete girder of 90 feet span.

At Dover, the whole of the dry block work is accurately founded on the solid chalk, and, therefore, there is not the same risk of the blocks settling down and leaving the superstructure locally without support, as there is where the blocks are founded on a rubble mound or on material that is either compressible or easily removed by undermining.

The next step in advance, in forming subaqueous foundations, was that of the bag system, which for rough work not subjected to such very heavy seas as those at Wick, has answered upon the whole fairly well, and I believe was first adopted at Aberdeen by Mr. W. D. Cay.

With this system it is almost impossible to carry on important works continuously and economically, and I fear, as far as my knowledge serves me, that, as a whole, it is not only more costly than even the best class of grouted up block masonry, but it retains some of the evils of the old dry block system, such as crevices and disintegration of concrete *in situ*, although covered by bagging, and, therefore, it cannot be regarded as permanent, which all public works of this class should be.

With the grouted up block system, the works can be carried on almost continuously, for when the divers and others at the scar-end of the work are thrown idle, their labour can largely be utilized in the block-yard and elsewhere, but not so with the bag system, which cannot be economically carried on except in localities where there are comparatively long periods of fine weather; and, further, after long experience, I find in the former system most excellent and durable blocks can be formed with one ton of cement to 11 tons of rubble, dressed ashlar, and coarse sand. With these proportions, blocks of 9 and 12 tons weight have been made in large quantities, and lifted from their moulds within four days, but with the bag system it is necessary to use more than double the cement in order to obtain work of similar strength.

Most of the structures to which I have referred may be taken as representative examples of the gradual progress in the construction of breakwaters during the last 60 or 70 years.

As to disintegration. In order to obtain sound work under water, and to make a good face, it is far better to dispense with the ordinary concrete *in situ* for the face work, and to use slightly moistened and partially set neat cement, with or without an admixture of Medina cement, depositing the same by facing skips next the timber face of the mould, and afterwards for a diver to pack as many rubble stones into it as it will take, pushing their flat faces hard up against the timber mould, or in the event of stone suitable for facing not being at hand, then substituting small strong blocks of fine concrete for the purpose. The ordinary five to one backing of partially set concrete could be carried up simultaneously with the facing work.

This facing work of say 12 or 18 inches in thickness, although somewhat costly, would add but a small percentage to the entire cost of the work, in cases where there is considerable width of backing, or in the case of a pier of great width.

Facing work in these materials may be classed next to grouted up block work, but it is immeasurably inferior, as frames are required, and it is only in moderately fine weather that such work can be done successfully. As to whether the rapid deterioration of Portland cement concrete, from a few feet above to a few feet below low water, is due to bad cement, insufficient quantity of cement, or bad workmanship, has not yet been satisfactorily answered. Let me give an instance or two.

Prior to 1877, a large number of from 70 to 90 ton blocks for the Hermitage breakwater works, at St. Helier, Jersey, were made *in situ* in the Victoria harbour at about the level of low water of neap tides. These were covered at each tide, and subjected to a wet and dry action from the time they were made down to the year 1885, when, as they were found to be utterly useless for building purposes, they were broken up, and the debris filled in behind the new north quay.

What took place in Jersey is by no means the exceptional case, for something very similar has occurred in connection with the New York harbour quay walls, as described in my first lecture, Maryport dock, the graving dock at Aberdeen, and at other places on the east coast, and I have no doubt that if many of the recent concrete *in situ* works were examined by divers, enough would be revealed as to softened and disintegrated concrete face work as to shake the confidence of most engineers in the further use of concrete *in situ* for first-class works.

In one case which came under my immediate notice, viz., at Girvan, I found that in a portion of the north pier or groyne, which was executed with every possible care in 1882, the outer face of 12 inches in thickness, which was composed of four parts of coarse sand and fine shingle to one part of cement, and the hearting of six parts of coarse sand and shingle to one part of cement, with as many large sized rubble blocks as could be placed in the mortar without touching each other, had become most seriously disintegrated within about 12 months after its completion, and ultimately it wasted away, until there was a breach of the form shown in *Figs.* 2 and 4, *Plate* XXVIII.

The concrete was mixed and put into the frames at the same time, in the same manner, and by the same men; not allowed to partially set for a few hours before being deposited in a plastic state, but as ordinary concrete for dry work is mixed and deposited for work out of water. The base was founded at low water mark, and the compartment was filled up to coping level within five hours, thus keeping about an hour or two in advance of the rising tide.

On examining the cause of the breach, I found the portion (see *Figs.* 3 and 4, *Plate* XXVIII.) at A as soft as garden mould, at B soft, C just hard enough to crumble in my hand, E hard, F to G very hard and excellent work which resisted a heavy blow of a hammer. Probably the cement used was a portion of a cargo which contained a large percentage of unburned cement.

Recently I have made some enquiries of the Harbour Engineer at Aberdeen, as to the plastic concrete used in the quay walls there in the year 1882, and I learned that it is still tough, and in good condition.

Some of the advantages of the subaqueous grouted block system, are, that the rubble blocks, which are shallow grooved and flat tongued on all sides, can be made in the usual manner in the block yard, in almost all weathers, by the cheapest of labour, and when it is impossible to carry on block setting and grouting at the scar-end, the labour thus thrown idle being utilized in the block building yard in aiding the ordinary workers.

In block building, the best and most suitable of material can be used with every advantage and economy, and under thorough inspection.

At the Hermitage breakwater, where the blocks were of two sizes, viz., 9 and 12 tons, and averaging $10\frac{1}{2}$ tons throughout the work, the average weight of cement used per ton of rubble and ashlar built into these blocks, was about 200 lbs. or $\frac{1}{11}$th of the weight of materials cemented together, but a good job could be made with $\frac{1}{12}$th, that is $\frac{1}{13}$th of the weight of the block, being cement. (See block yard, *Plate* XXV.).

The mortar for the rubble jointings was composed of four to five parts of coarse sand to one of cement, and the mortar in the joints of the facing ashlar, and at any corners or arrises where extra strength was required, was two of sand to one of cement. The face joints were raked out for an inch in depth, and pointed with neat cement.

I have in the sea works for which I have been engineer, carried on the monolithic system; thus at Girvan harbour, Ayrshire, where I constructed a sea pier and a groyne, together about 1,200 feet in length, and both were solid throughout. On *Plate* XXVII., *Fig.* 7, is shown a section of the South Pier founded at 17 feet below high water, or seven feet at low water.

The portion below low water was first constructed within a piled trench, the concrete for which was deposited *in situ* after being allowed to set for a short time. Owing to the great trouble experienced in keeping the joints in the sheeting piles and the lining of flooring boards, even when covered with canvas, cement tight, and preventing the mould from vibrating during heavy seas, I abandoned timber framings altogether, and used handy-sized dovetailed concrete blocks (see *Fig.* 2, *Plate* XIV.) which answered exceedingly well, and these, together with the backing and grouting up, were all executed without further trouble or risk. A fine concrete of three to one was used to back up the blocks, and the hearting was of four to one fine cement concrete, with as many blocks of stone, or broken boulders, as could be inserted into it, having joints of fine cement of a few inches in thickness between each block.

In Mr. Vernon Harcourt's work on *Harbours and Docks*, 1885, under the head of "Construction of Superstructure," see p. 114, it is there stated—"the lower courses of the superstructure, being laid below low water, cannot be cemented together;" and again, at page 115, that—"below low water no means could be used for filling up crevices, and the waves rushing caused a compression of the air inside them;" again, at page 126—"When the bottom is several feet below low water, it entails both the cost of building under water, and also the weakness of uncemented blocks;" and at page 127—"the weakest part of an upright wall founded below low water is close to the level of low water, where the uncemented blocks are liable to be forced out by the waves compressing the air through the joints;" and, on the same page, as to the "limits of application of the upright wall system," "the enhanced expense would preclude the erection of an upright wall in deep water." "The greatest depth in which an upright wall has been founded is in 40 feet of water at Dover, and the great cost in this instance does not furnish an inducement for imitation elsewhere."

From these quotations it would appear that no attempt by other engineers than myself had, up to 1885, been made to cement blocks together under water.

Now, in the system I have inaugurated at the Hermitage breakwater, Jersey, not only has the upright wall system been executed in *sixty* feet at high water, and *twenty* feet at low water, at extreme springs, but the whole of the rubble foundation bed, for several feet in thickness, has been cemented into a solid mass, in addition to the whole of the blocks having been cemented together under water from the foundation upwards, and, further, the whole of their faces have grooves and projections, which render it next to impossible for any of the blocks to become dislodged, even should they not be cemented together.

These improvements have, in fact, put an end to most, if not the whole, of the risks of failure which hitherto seem to have been, from some cause or other, almost inherent in every method of construction yet used, more especially where blocks have been laid dry under water.

In order to make sure and to give confidence, if possible, to those who, up to 1882, had doubted my system of grouting—and I am sorry to say almost every engineer I know still doubts it—some experiments were carried out, under my direction, by Mr. William Smith, Harbour Engineer, at Aberdeen, in July, 1883 (see Appendix V.); and also by Mr. G. H. Spencer, at St. Helier, Jersey, in November, 1884, to ascertain whether the system of grouting I had adopted for the bed and joints below low water of the face blocks at Girvan, might be advantageously extended. At Aberdeen, a timber box, $6\frac{1}{2}$ feet long, 12 inches wide, and 4 feet deep, was filled with round smooth shingle, and pieces of whinstone, from one to four inches in diameter, and was lowered to the bottom of the tidal harbour in a depth of 18 feet at high water of spring tides, and having a wrought-iron pipe three inches in diameter, the lower end of which was inserted into the box for about 12 inches, and long enough for its upper end to stand a few feet above the water level.

At high water a very thick grout, composed of four parts of neat fine Portland cement and one part of Sheppey cement, was poured down the pipe in sufficient quantity to fill up the whole of the interstices. After twelve days the box of concrete, which weighed nearly two tons, was actually lifted out of the water by means of the $3\frac{1}{2}$-inch pipe alone, which, although only inserted for 12 inches, had become so firmly cemented into the concrete as to admit of this being done.

On removing the sides of the box, the concrete was found to have a smooth surface, and to be perfectly solid throughout.

At Jersey,* two experiments were made by Mr. G. H. Spencer, in November, 1884, under my direction. First, a box of about six feet cube was filled with shingle, and a gas-pipe of $1\frac{1}{2}$ inches diameter was inserted 18 inches into it, and when the tide had risen 20 feet above the box, thick neat Portland cement grout was poured down the pipe. On opening out the box, its contents were found united into a solid mass, with the grain of the rough-sawn timber of the box imprinted upon the surface of the concrete, so completely had the grout filled up all the interstices of the box.

Second, a box of two feet cube, filled with shingle, was suspended in a depth of 60 feet of water in the strong tide-way just outside of the Little Roads. A thick grout of Portland cement was poured through a tube reaching nearly down to the bottom of the box, which united with the shingle into a concrete block. The block † is here on the table, and is really the parent block of my new system of constructing subaqueous foundations in great depths of water, and, as far as I can judge, it can be done with equal success in 200 or 300 feet of water, as in 60 feet of water.

The block (see *Plate* XXIV.) is not so perfect as in the first experiment, owing to the bottom zinc tubing being crushed by the weight of the iron tubing above, which allowed the grout to escape; the failure, however, was only partial, for one-half of the block was thoroughly solid, and had sharp arrises.

These experiments confirm those I made in 1856–8, in endeavouring to prove the feasibility of cementing shingle together in foundations at great depths, grouting up fissures, and repairing structural works undermined, or wasted away by the action of the sea or scour.

It is somewhat remarkable that, although it is now nearly a quarter of a century ago since I described some of these experiments at the Institution of Civil Engineers, in 1885 Mr. Vernon Harcourt should have published the statements that the bed and joints of courses of concrete blocks laid below low water cannot be cemented together, and also that below low water no means could be used for filling up crevices. Again, that those engineers who took part in the discussion on "Concrete as applied in the Construction

* See *Minutes, Inst. C.E.* Vol. lxxxvii. 1886-87. p. 166.

† Mr. Kinipple has since presented this block to the authorities in charge of the Royal Engineers' Museum at Chatham.

of Harbours," at the Institution of Civil Engineers, Session 1886-87, should doubt or condemn the system without making such enquiries as would enable them to conduct experiments in such manner as would ensure success.

In 1882, I succeeded in stopping considerable leakages at an old graving dock (see Appendix IV.), in the west harbour at Greenock, which had given so much trouble for years, as to lead to proposals for re-constructing or removing it altogether. Bore-holes were made one foot to two feet apart, through the masonry behind the heel-posts, down into the sandy foundation for several feet below the masonry foundations, and also down through the inner and outer aprons near the pointing sill, in which latter holes stand pipes were set up. A thick grout of neat Portland cement was poured down into these holes and permeated the various fissures and open joints to a distance, in some cases, of 18 feet from the bore-holes, virtually joining the bore-holes together, and thereby forming a watertight sheeting of neat cement. The quantity used in grouting up these holes was about five tons.

The grout was only poured down the stand pipes when the water was at the same level inside and outside the dock. The level of the grout inside the pipes during the grouting operations was several feet below the water level outside of the pipes, and this varied with the tide.

Before these operations were carried out, an 18-inch pump was constantly working to keep down the leakages, whereas subsequently only one hour's pumping was required in forty hours.

Jersey.

As chief and consulting engineer for the Hermitage breakwater and other works at St Helier, Jersey, I had to consider very carefully what design should be adopted to meet the requirements of the locality.

In a report, dated 9th May, 1877, to the committee appointed to enquire into the actual state of the new harbour works at Jersey, Sir John Coode stated :—

"That during the gale of 3rd December, 1876, railway metals standing less than six inches above the surface of the Hermitage breakwater, and firmly spiked down to the masonry, were twisted and thrown out of line to such an extent as to stop the traffic."

"I know of no port where the elements to be contended with as to force of sea, rise of tide, and irregularities and difficulties of foundations were of so formidable a character as at St. Helier's."

This was the picture drawn by Sir John, when the works were stopped in 1877, of the locality in which I was about to continue the Hermitage breakwater in 1887, for 525 feet seawards. The end of the work, in 1877, was on rock a little beyond low water mark.

The breakwater is exposed to the Atlantic, and subject to heavy southerly and southwesterly gales, and, therefore, during progress, should always have a reliable scar-end, if possible, equal in strength to the finished end of the breakwater.

The depth of water in which the works have been founded at high water of spring tides is 60 feet. The range of a high spring tide being about 40 feet.

Over about two-thirds of the length of the foundations the rock was exposed at the bottom of the sea, and over the remaining portion there was an overlying deposit of sand and clay, varying in thickness from a few inches to about $8\frac{1}{2}$ feet. The rock on which the work is founded is granite, the surface of which is very irregular.

The system of construction I adopted was to make the work as nearly a monolith as possible throughout, from the very irregular surface of the foundation on the solid rock up to cope, and instead of founding on such materials as sand and clay, along the portion of the site where these occurred, I had them entirely removed down to the solid rock, so that the whole of the work should be founded on it. The levelling up of the irregularities in the rock, in order to form a perfectly level bed or base upon which to found the blocks, was a work which required great care in execution, but ultimately it was very simply and expeditiously effected by the system of grouting to which I have already referred, and which has been further and most successfully used in grouting up the beds and joints of the blocks, and making solid work from about low water level of neap tides down to the levelled surface of the foundation on which the first course of blocks was founded, or for a height of nearly 30 feet.

Various expedients were tried, shortly after the commencement of the works, as to the simplest and most efficacious methods to be pursued in the construction of the subaqueous portion of the breakwater, but that which I will now describe proved to be the most useful in practice, and ultimately became the ordinary routine pursued during the execution of these works.

The sand, clay, gravel, etc., overlying the rock were dredged by means of a digger grab, worked by a steam crane mounted on a barge.

The foundation trench dredged was about 50 feet in width at the bottom, and the portions of the soft materials in the irregularities and crevices of the rock, which could not be dredged by the grab, were removed by divers, so as to ensure a perfectly reliable foundation on the surface of the cleaned rock throughout the entire length of the breakwater.

When the rock was thoroughly cleared, the trench was filled in with rubble and shingle, which were thrown overboard. Sometimes when there was a moderately rough sea on, and when it would have been quite impossible to have properly deposited ordinary concrete from a barge into the trench, the top surface of the filling of the trench was levelled off at a fixed height.

The levelling was done by divers by means of stiff timber straight edges, with spirit levels let into their upper surfaces, and smaller and similar straight edges were used for transverse levelling between the larger straight edges. The work was advanced in lengths or sections of 12 feet 6 inches, so that three courses of the sloping layers of blocks were brought up at once, see sketches (*Figs.* 5, 6 and 7, *Plate* XXVIII.). The reason for such advance being that this length, together with that of the slope of the blocks, suited the outreach of the block-setting crane. The excavation in the foundations, the filling in of the trenches with rubble and shingle, were likewise carried out in similar lengths. When the rubble and shingle bed had been brought to the proper height and levelled off, it was then grouted into a solid mass with neat Portland cement grout; but in order to prevent the escape and consequent loss of cement from the filling up of each 12 feet 6 inches length or section, it was enclosed by bags of concrete on three of its sides, and made cement tight all round. This was effected in the portion of the work where excavation had to be done by simply placing across the end of the section a wall composed of bags of concrete of about 7 feet 6 inches by 4 feet by 2 feet, piled one on the other and levelled to the same height as the rubble and shingle, and, further, by stopping up whatever crevices or spaces might exist between the large bags by small bags, or by canvas, according to the size of the crevices. The sides of the excavation prevented the escape of cement at these places, so that bags were not required; but along the portions of the site where there was neither sand nor clay overlying the rock, the bags had to be placed along the two sides of the work as well as across the end, in order to enclose an area for the foundation bed, and to prevent the escape of the cement.

At such places the levelled grouted rubble and shingle stood above the bed of the sea, instead of in a trench below it.

When the rubble and shingle of a section had been placed in position and levelled off, and all the crevices in the end and side walls formed of bags of concrete, the filling was grouted up with a thick cement grout, which was passed down through a 3-in. stand pipe, the funnel mouth of which was placed above high water level, and the lower and perforated end inserted by divers well down into the mass of loose rubble and shingle.

The cement was worked into a thick grout on a platform or box, suspended from the jib of the block-setting crane immediately over the site, or nearly so, of the area to be grouted. This platform was of sufficient size to hold from 20 to 40 bags of cement, and to enable a gang of from six to eight men to work on it. It was always hung (see *Fig.* 5) at a fixed height of a few feet above high water so that the pipe was of a fixed length, and thus avoided the adding to or shortening of the pipe according to the rise or fall of the tide, as would have been necessary had the grouting been done from a barge. In preparing the grout and passing it through water very great care was required, and the workmen had to be trained before they could be entrusted to do the work properly without supervision. Cement grout may be so prepared or so passed through water into the work as to be utterly useless; I am assuming that the cement is fit for the purpose. To be reliable it should be very finely ground, the test for fineness being at least 90 per cent. to pass through a sieve of 6,400 meshes to the square inch.

Cement of a greater fineness, from 8,000 to 10,000 meshes to the square inch, has been used experimentally in the work, and it was found that the finer the cement the better the grout for making solid work.

It should be manufactured from picked, well burned clinker, and as free as possible from extraneous matter, such as magnesia, excess of lime, etc., and used as new as possible. If the cement be not finely ground, the coarser particles will deposit much more rapidly than the finer in the lower end of the stand pipe, where they will remain and give trouble; but as far as the setting or cementing properties of the coarser particles are concerned, they are practically as inert or useless as sand. If the cement be fresh it will set, after being deposited in the form of grout in the foundation, in a couple of days or so, sufficiently hard for the foundation course of blocks to be laid on the newly formed foundations ; sometimes it takes very much longer to set, and the rate of progress of the main work is, therefore, much hindered.

In mixing the cement to form grout, the practice of preparing it by placing in a mixing tub a quantity of water and adding and stirring in cement until a certain degree of consistency is obtained, must be carefully avoided, as this process effects a mechanical separation of the particles, whereby the cement is rendered almost useless for the purpose intended, and if in this condition it is simply poured down on to the top of the shingle and rubble to be cemented together, it is still further washed or dissipated.

I believe that experimental grouting has been done in this manner by some engineers, and other engineers have added sand to the cement grout, but failures only could be expected as the results of such departures.

The proper course to be pursued is to mix the cement on a flat surface or platform to the consistency of stiff paste, place it in a tub, and then slightly thin it down by adding water in very small quantities, and stirring until the paste is reduced to a thick grout, or just soft enough to leave the bucket from which it is to be poured as rapidly as possible into the hopper or funnel attached to the head of the pipe. The finer the cement and the quicker it is poured down the pipe to keep up a continuous flow or column, the better will be the results obtained. The only drawback to thick grout is that sometimes the pipe gets choked at its bottom end, that is if sufficient attention is not given by the men ; but even this can be avoided to a considerable extent by simply pouring some water down the pipe as soon as there is any appearance of an obstruction. The lower end of the pipe, which is open and also perforated with $\frac{3}{4}$-inch holes for twelve inches up, is placed by divers well down into the mass of loose materials, and the grout is forced into the interstices of the rubble and shingle filling by the weight or column of grout in the pipe, which is equal to about half the depth or head of water in which the grouting is being done.

It has been observed that, generally, half a column of cement balances a full head of water—that is, a column of 30 feet of cement grout is balanced by about 60 feet head of water. Any greater height in the cement column represents the amount of pressure necessary to force the cement upwards through the interstices to the surface of the filling. As the grout descends in the pipe it rises in the rubble filling, and so the water is displaced or driven out. This displacement may extend to a distance of 15 feet from the pipe, as ascertained by work done.

It is much better, however, that the distance travelled by the cement from the lower end of the stand-pipe should be as short as possible, and in the bed of the Hermitage breakwater it was not allowed to travel more than five or six feet. When the divers saw that the grout from the stand-pipe had forced its way up through the mass of materials to the surface, he then had the pipe shifted to another position, by which a similar area was grouted, and so on, until the entire mass was filled up. The grouting is first carried on all round by placing the stand pipes close to the sides and ends of the section of foundation in progress, and the central area is afterwards completed. One diver was generally sufficient to attend to the pipe in having it shifted from place to place as required, and likewise to stopping up the crevices in the enclosing walls of bags of concrete, whenever he observed cement escaping.

When the grouting had partially set, any irregularities on the top surface which may have been caused by the grout rising in some places considerably above the general level of the surface, and especially at the places where the stand-pipe had been inserted, were removed by the divers, who used straight-edges faced with iron, which were passed over the excess of grouting, and thus planed off or dressed them down to a true and perfectly level bed. The whole surface was then allowed to set into a solid and compact mass of concrete, free from all crevices or openings, which, in other methods of founding, are chiefly the direct cause of most of the foundation failures in connection with sea works, especially where dry blocks have been founded on an unreliable bed and surmounted by a heavy superstructure.

The time occcupied by the divers in preparing and grouting up a bed of the full width of the foundation, and for a 12ft. 6in. section, or length of breakwater, was from a week to 10 days, and the cement used in grouting up the loose materials, to form a solid mass, was about one-ninth of the weight of the rubble and shingle cemented together, but with larger blocks of rubble stone with shingle between them it would have been less.

When the grouting of the bed had become firmly set, block-laying on top thereof was proceeded with, the first, or foundation course, being composed of blocks, two sides of which were sloped corresponding with an angle of inclination of 68 degrees with the bottom.

All the blocks above the foundation course were four feet square, in section and in nine feet and 12 feet lengths, being equal to about 9 and 12 tons respectively.

The foundation course of blocks, and three or four courses on top of the same, were laid by divers; the level of the upper surfaces, or bed joints, of the topmost of these blocks is about half-way between low water level of spring and neap tides. All the blocks above this level up to coping were set in position by ordinary masons, at such times of tide as enabled work to be done, and laid dry, one on top of the other, for two courses in height, and after the outer vertical and horizontal joints had been stopped with quick setting cement, or caulked with canvas, the open beds and joints between the blocks in the two courses were filled up with thick neat Portland cement grout; two more courses were then added and grouted up in a similar manner, and so on up to coping level.

For caulking up joints below low water a different arrangement was required, consisting partly of Portland cement, enclosed in calico cases or stockings, and partly of jute sacking rammed or caulked into the joints of the blocks. In caulking the joints below low water by divers, proper arrangements had to be made to ensure its being carried on expeditiously and economically. Grooves were first cut in the joint faces of the granite ashlar at a few inches in from their exposed faces, after the blocks had been moulded and allowed to set and be well seasoned. The form of the groove in each block is semi-circular, so that when the blocks are laid in position complete circular grooves are made in the joints.

The diameter of these grooves is about three inches. The calico cases or stockings are, when completely filled with Portland cement, a trifle larger in diameter than the grooves formed in the upper and lower joint meeting faces, and as the blocks are lowered on to their beds, so the stockings become tightly squeezed into the half-grooves, and the joints are rendered perfectly cement tight.

For the purpose of caulking the vertical, or rather sloping outside face joints, a tin tube is used of about five feet in length, and of somewhat smaller diameter than the grooves. The tube is filled with slightly damped neat cement, and inserted into a rather loose stocking, and, with the stocking on it, is lowered down to the diver, who inserts it into the joint groove. A plunger is then rammed into the tube, and the cement is forced out into the stocking, and in escaping forms a most effectual, well-filled, hard, cement-tight joint.

The vertical and horizontal joints across the scar-end of the breakwater are, as the work progresses, caulked with canvas, which, for temporary joints, is found to be very useful, more especially as the canvas can be pulled out of the joints as each section of the breakwater is built up, and so enables the open joints left by the removal of the canvas to be grouted up. When the caulking is complete, the beds and joints between the blocks are then filled up solid with thick neat cement grout, in a manner similar to that which I have already described for the foundations, the stand-pipe through which the cement is passed being placed successively (see *Fig.* 6) in the lewis holes formed in the various blocks for the insertion of the lifting rods.

Not only is the work rendered monolithic from foundation to cope by cementing the whole mass together, but, in order to increase the security of the work, an arrangement of grooves and projections on all the surfaces of the blocks, save the outer or granite faces, has been adopted, whereby each block fits into, or is, so to speak, keyed on to the adjoining blocks (see *Fig.* 7, *Plate* XXVIII.).

In the 42-feet width of the breakwater, there are four blocks, viz., two, each of twelve feet in length, and two of nine feet, weighing respectively twelve and nine tons.

In each layer or course, break-bond at the joints is neither resorted to nor required, the omission of which effects a very great saving in the cost of diving time, and very greatly facilitates the execution of the work.

The blocks are laid, or piled, one on top of the other, and any irregularity in the setting of a foundation block is simply repeated, block after block, until the finishing work built *in situ* at coping level is reached, where all irregularities are easily worked out. This can be done in the top of each pile of blocks without the slightest detriment to the work, for between each sloping layer, or course of blocks, there is a minimum cover, or break-bond, of at least three feet at its joint, with the last layer.

This arrangement of stacks, or piles of long and short blocks, with a break-bond of three feet, makes most excellent work.

The maximum weight of 12 tons for the blocks was adopted to suit the appliances on the works. The blocks were built of granite rubble masonry, set in Portland cement mortar, composed of four parts of clean coarse sand and one of cement; the outside, or facing blocks, were faced with granite ashlar set in two to one Portland cement compo. The blocks were hard enough to be lifted in the summer season at three days after being built, and in the winter season from five to seven days, according to the state of the weather. After being lifted out of the block-building pit (see *Plate* XXV.), they were allowed to harden well in the stacking yard before being placed in position in the breakwater.

This system of constructing a breakwater presents considerable advantages, as regards economy, expedition, and reliability.

The Hermitage breakwater was executed, when everything was going at full speed, at the rate of about 300 feet per annum.

Its width is 42 feet, and total height from foundation to coping 65½ feet. During progress, there was not the slightest mishap of any kind after the blocks were grouted up, although very heavy seas had sometimes to be resisted almost immediately after the blocks were set and grouted up.

The cost of the 525-feet extension of the Hermitage breakwater has averaged about £100 per linear foot run complete.

Seas, indeed, have been experienced at this breakwater such as no ordinary dry block work system could have successfully withstood for many years, for had even one of the blocks been removed, others would have soon followed, and to repair such damage by underpinning with bags, or dry blocks, in such an exposed locality, would have been almost a physical impossibility, or at all events could not have been permanently and well done. The experience in connection with the failure of the dry block system at the south breakwater at Aberdeen in the year 1883 is well known, and at Wick some years before this time, when almost the entire breakwater failed, and became a mass of ruins.

Had time permitted, I could have made reference in detail to other examples of works executed, which go to show the gradual development in the system of construction of sea piers, from the rubble mound up to the solid vertical, or nearly vertical, wall.

However, I think I have given sufficient examples to indicate the tendency of engineers at the present time towards vertical walls as largely monolithic as possible, and founded either on the natural sea bottom, or if on the top of a rubble mound, at a considerable depth below low water.

My own opinion, which I have endeavoured to express as clearly as possible, is, that breakwaters should be entirely monolithic from foundation to coping, and that the foundations, except in cases of extreme depths, should be carried down to the natural sea bed if rock, or if soft material, to a sufficient depth below such bed as the circumstances of the case may demand, besides taking further necessary precautions to guard against scour along their bases. The system of grouting, which I have introduced and used so successfully at many sea works, large and small, when taken in conjunction with concrete blocks or granite-faced blocks, as in the works executed by me at Girvan and Jersey, shows what can be done with small blocks in securing solid work with a durable face, and with a very moderate amount of plant. Frequently the item of plant is most important, and bears a large proportion to the entire cost of the work. Especially is this the case in sea piers, for small fishing harbours in exposed positions, where funds are comparatively limited, and the cost of plant and temporary works must be kept at a minimum. The system of grouting with small or moderate sized blocks meets cases of this description exactly, but is also equally suitable for the construction of breakwaters in a site, such as that at Alderney, where the depth reaches to as much as 71 feet at low water, or 88 feet at high water. In such a case as this a rubble mound could first be deposited, having its top levelled off at from 25 to 30 feet below low water, and on the top of this a superstructure formed of blocks weighing 10 to 15 tons each, and grouted together with neat Portland cement. The weight of blocks to be adopted in any particular case is, of course, dependent on the amount of work to be done, sum to be expended, time for execution, and various local conditions.

As the inventor of the grouting system, I may be inclined to attribute more importance to this method of obtaining sound and substantial subaqueous work than in reality is due to it, but knowing from experience the excellent work which I have done by this means, without accident or loss of cement, sometimes under the severest conditions, and always at a low cost, I do not think that I can speak too highly in its favour, or that I can make it too widely known, for I feel sure that it only requires to be known and thoroughly tried to be adopted in the majority of cases in lieu of the dry block system

APPENDIX I.

EXTRACTS FROM MINUTES OF PROCEEDINGS, INST. C.E., "ON THE STRENGTH OF PORTLAND CEMENT." BY JOHN GRANT, M. INST. C.E., SESSION 1865-6, VOL. XXV., p. 125.

"Mr. Kinipple remarked that the author had stated that 'Portland cement concrete, made in the proportions of 1 of cement to 8 of ballast, in some cases, and of 1 to 6 in others, had been extensively used for the foundations of the river wall, piers of reservoir, and foundations generally, at Crossness and Deptford, with the most perfect success.' Now, to have obtained such perfect success, it must have been absolutely necessary to have kept the entire works clear of water, for it was not possible to get good concrete under water, whether quiet or not, if it was thrown in dry immediately after mixing. He had ascertained that in only 1 inch of quiet water, concrete made in the proportions of 3 to 1 was endangered by the working out of the silicates, or the best of the cement, from the ballast; those silicates resembled slime on the surface, and with the slightest motion or run of water were lost. In concreting an outer apron, just inside a coffer-dam at low water, he had used Portland cement concrete, in the proportions of 4 of ballast to 1 of cement. It was all put in at the same time, in the same manner, with the same cement and ballast, by the same men, and was allowed to remain in quiet water for three months. When he had again occasion to examine it, the concrete nearest the abutments was sound and hard, but in the centre, or rather in the part closed in, it was quite soft; in fact it was ballast, with a mere fraction of cement retained in it. This was executed in about two inches of quiet water, and had to be removed for the insertion of fresh concrete. To avoid this for the future, he had resolved that all Portland cement concrete should be mixed on the surface and allowed to set for several hours; the length of time for setting to be in proportion to the quantity of the cement used, and when set to be used in a crumbled condition. By experiments he found that he was able to retain nearly the whole of the cement without any loss as to strength.

"He then referred to several specimens which he exhibited. No. 1 was composed of one part of Portland cement, weighing 114lbs. to the bushel, and one of fine river ballast; this was thrown into 6 inches of quiet water, dry, immediately after being mixed, and was submerged eighteen days, at the expiration of which time it showed the great separation, even in quiet water, which had taken place. Specimen No. 2, similarly composed, was also thrown into 6 inches of quiet water, but not until it had been allowed to set, after being mixed, for five hours in the open air, previously to being submerged for eighteen days. This specimen was so hard that it had to be split by a cold chisel and hammer, and had retained nearly the whole of the cement. Passing dry concrete down shoots would not prevent the separation, as the larger stones rolled out and set the cement free. If mixed and allowed to set a day or so, it would without doubt be a success. As to the mode of executing brickwork free from a current of water, he agreed generally with the author, but he did not think that all bricks should be thoroughly saturated with water. For tidal work, such as wharf walls, river wings, etc., Roman cement stood the 'wash' best, lias lime next, and Portland cement last. A joint was seldom lost in Roman cement compo. brickwork, in lias lime mortar now and then, but in Portland cement compo. there was great difficulty in preventing sometimes six or more courses being destroyed in one tide, from loss of the joints. Portland cement brickwork, covered twice by water in twenty-four hours, should be made with compo. as stiff as it was possible to use it. The bricks should be perfectly dry, cleansed from the maker's sand, the face joints raked out for a depth of 1 inch whilst green, and pointed, temporarily, with Rochester yellow clay. The clay joints would last many days, and by the time the clay joints were washed away, the cement work would be perfectly set, and could then be pointed in neat cement. Work executed in the manner described seldom failed, and was free from many of the consequences of the running of the joints. Complaints were often made of the badness, or rather of the irregular qualities, of Portland cement. He believed, in many cases, those complaints were chiefly due to the manner in which it was applied to uses so varied in their character.

He would recommend, for all brickwork executed under water, that the joints of compo. should be dispensed with, that the bricks should be coated with compo., and be allowed to set out of water some hours, and then be rubbed together in position under water. Specimen No. 3 showed nine bricks moulded, or coated, in neat Portland cement. of an average thickness of 3/16ths of an inch, allowed half-an-hour to set in the open air, rubbed together into the present form in agitated water, and kept submerged for eighteen days. Specimen No. 4 showed a better result. Nine ordinary stock bricks were coated as before, in neat cement, then allowed five hours to set in the open air, afterwards rubbed together under agitated dirty water, and kept submerged for eighteen days. Both these experiments went to prove that jointless work in almost any working depth of water, whether clear or muddy, or where there was a great current, could be executed with perfect success. The specimens were not disturbed from the time they were submerged until they were taken out, when the work was found to be thoroughly sound.

"The statement as to the making of a joint to a mining pump pipe under water at a considerable depth, was interesting, and proved what might be done with Portland cement under water. Joints might be caulked under water with cement nearly set, and broken in pieces about the size of a pea. *He had frequently made use of neat cement for grouting between sheet piles, with perfect success; in one case under water, the cement, in its descent or settling down, drove out the clear water and filled every crevice; within ten days it was hard enough to resist a chisel point.* Model No. 5 showed blocks of concrete coated with compo. in the same way as the specimen bricks, guided into position by rods or chains, built on a concrete foundation, the face joints caulked with cement or soft wood wedges, and the chains or light rods grouted in with neat cement.

"Mr. Kinipple added that the concrete out of which the cement had been washed was mixed in the ordinary way. He suggested, in order to ensure success, that the proportions should be accurately measured in the usual way, mixed together dry, and water added by means of a common watering-pot; the mass then turned over, and afterwards separated and allowed to remain for some hours in layers of 3 inches or 4 inches thick, exposed to the open air; and when it became so tough that it would not receive an impression from the hand, it was ready to be turned over again and passed into the water. By working it in that way he had retained the whole of the cement."

APPENDIX II.

Examinations of the Concrete, "en masse," of the King Street and Canal Street Sections, as made by Divers and others on Feb. 18, 1876, and reported on by General Newton.

General Newton quotes from Mr. Grant's paper, 1865-66, as follows, adding some remarks as he proceeds :—

"The lower, or foundation, layer of concrete is the worst of the three or four layers, because the concrete has to fall through a greater depth after discharge from the bucket, and the heavier parts of the mortar are lost in the interstices of the rubble. It is also clear that the pile-heads should have been cut to a level, and an impervious bed, or platform, provided to receive the first layer.

"From the mode of depositing the concrete, as, likewise, from the peculiarities of this slow-setting cement, a considerable wash has also taken place in the layers above, although not so much as in the lowest one.

"Owing to the want of unctuosity of the cement, and its slow setting, the disintegration of the mortar continues some time after deposit, and these portions, at the sides of the wall exposed to the water, show this action more than the interior mass, which has been better protected. It is also evident that the mode adopted of depositing the concrete in long successive layers was injurious, because of the large surfaces unnecessarily exposed to the action of the water.

"It would have given better results had the full height of the concrete mass been deposited in sections of limited length, such as to have ensured their completion by a continuous operation.

"It is not intended to assert that there is no concrete of fair quality contained in this wall ; but, from the causes mentioned, the results are so uncertain that serious defects have appeared in places where the wall was required to be of unimpaired strength. As a monolith it is imperfect, if not essentially a failure ; and besides the defects already cited, attention should be called to the fact that the front row of piles intending to have good bearing, particularly against the thrust of the earth backing, can give no support to the wall, because the angle, or toe, of the wall, against which the piles abut, has fallen away, or is too weak to answer the purpose.

"At one period Portland cement was used with much misgiving because of the ignorance and selfishness of manufacturers, and the want of systematic experiments calculated to explore the subject fully, or to classify the properties of the several varieties. The lengthened course of experiments of Mr. John Grant were conclusive in their effects to remove prejudice, and to demonstrate the excellence of the heavier and slow-setting brands.

"Mr. Henry Reid states, in his work on the manufacture of Portland cement, that 'much of the clamor against heavy cement is caused by its slowness in setting, and, doubtless, great waste and loss is occasioned by many using this quality of cement for purposes to which it is unsuited.' (Edition of 1868). But since that period the thorough endorsement of this quality, by experiments and actual construction, has rather changed the risk to the other side, and induced waste and loss by its application to purposes for which it is not suited.

"The instances given of the application of Portland cement in hydraulic constructions are often vague and inconsequent of the details.

"One instance is taken from the work just referred to of the construction of the foundations, inside of cylinders, of a bridge across the Thames, at Windsor. The cylinders were sunk through the gravel without pumping, and, of course, were full of water. Through that water the concrete was passed, and it set well and hard in eight or ten days. The proportions were one of cement to nine of ballast, increased afterwards to one to six. On pumping out they tested the concrete by drilling nearly three feet, and no amount of drilling consistent with reason, could make any further impression. They were so encouraged by this essay that they applied the same process in cylinders, through depths of water from 50 to 70 feet.

"At first sight all this sounds well, but when the question comes how, by penetrating three feet into the top surface of the concrete, it is possible to certify concerning the quality of concrete at greater depths, the fallacy of the reasoning becomes apparent. Had such mode of investigation been relied upon, we should probably have found no defect worth mentioning in the Canal or King Street sections. If the foundation upon which the cylinders rested was gravel, an investigation there would show that the bottom courses had lost their cementing portions, which had fallen into the gravel. It made very little difference, in fact, to the security of the pier, whether the concrete was good or bad at all depths, because it was confined in cylinders; but *the inference, that the concrete was good because the piers stand, is too gratuitous to need refuting.* The effect of such loose modes of presenting a subject is simply to mislead engineers who are not experts in concretes, by the sanction of high authorities, into the commission of grave errors. Mr. Kinipple, on the other hand, quoting from the same book, states that he had ascertained that in one inch of quiet water, concrete of Portland cement, made in the proportions of one to three, was endangered by the working out of the silicate, or the best of the cement, from the ballast; and he furnishes an instance in point from his own experience. He says, further, that, to avoid this for the future, he had resolved that all Portland cement concrete should be mixed on the surface, and allowed to set for several hours, the length of time for setting to be in proportion to the quantity of the cement used; and, when set, to be used in a crumbled condition. By experiments, he found that he was able to retain nearly the whole of the cement without any loss as to strength.

"The two examples cited show conspicuously the differences of statement between an engineer who knew something of the subject, and was possessed of a logical mind, and another who did not enjoy such advantages.

"The practice of the Imperial Austrian engineers, and of the Italians, in the use of concrete made with puzzolana and fat lime, is worthy of mention, as it proceeds on the principle laid down by Mr. Kinipple. The mixture is made two or three days before being deposited in the water, for fear, if used in a green state, the lime would be separated by the water from the other ingredients. After the interval cited, the mass is shoveled or dumped into the water without further precaution, and makes excellent concrete, because there is no separation of the constituents of the mortar.

"We have seen that Rosendale cement, and hydraulic limes which possess unctuous properties, can be relied upon to hold together in water until setting takes place, and Mr. Kinipple recommends for Portland cement of the heavier varieties, which do not possess that property, to allow a partial setting before deposit in water. This would be worthy of trial by the Commissioners in a series of experiments calculated to test it severely."

APPENDIX III.

Extract from W. R. Kinipple's Report on New Works to the Greenock Harbour Trustees, 1869.

Materials and Cost of N.W. Pier.

Sixth.—The class of construction I consider best to recommend for works similarly situated to those of the north-west pier is as follows: —If the bottom is soft sandstone or hard "till," a trench of sufficient width to take the entire foundation is blasted or dredged out to a depth, say, of three feet below the finished level of the bottom of the harbours; and so long as the heads or points of the rock or boulders do not rise to the level of the underside of the foundation course, it matters not how roughly the blasting or dredging may leave the surface to take the cement concrete, on which the first block of masonry is to be founded.

When the trenches are ready, the irregularities are filled in with Portland cement or other hydraulic concrete and levelled down; this process is carried on as block after block of rubble masonry is lowered into place; the bed is not kept level throughout, but may be stepped up and down into any of the hollows.

The joints are all uniformly vertical up to low water mark, but the horizontal ones are irregular in accordance with the levels of the foundations. Blocks of masonry are built up with hard freestone ashlar facings and rubble backing on a selected and convenient spot for future removal, are then allowed to remain exposed for months in the open air to harden up before they are submerged into position.

A model of a piece of the wall is handed in, with this report, for the purpose of better illustrating the beds and joints, which are so arranged that not one block can force forward without others moving at the same time, thus obtaining an almost homogenous monolith without any tendency to separate; forming a wall even of greater strength than one of equal thickness, although similarly erected in the open air, but of the ordinary facework and rubble backing.

When the blocks are laid, the joints are open for at least 12 inches, except at the face and back ashlars, where they meet, and are quite close as shown by the plan and cross sections; after the blocks are laid the joints are carefully filled up to half the height of each course, so that even the fine Portland concrete jointings or keys break joint horizontally as well as the rubble blocks.

As the rubble blocks are carried up, they are backed below low water either by quarry refuse broken up to small sizes, first rolled in a grout of Portland cement, allowed to remain in the open air some four or five hours, and then thrown in behind the walls through any depths of water, or with concrete lowered in the usual way by skips or otherwise.

APPENDIX IV.

Extract from "Engineering," of 24th Feb., 1882, on "Novel Method of Checking Leakage in a Graving Dock."

"The following brief description of some experimental work recently made on the old graving dock in the west harbour at Greenock may be of interest to many of our readers, as embodying some feature of novelty in a practical attempt to overcome leakage. For some years past, in consequence of the very leaky condition of the entrance works of this dock, a question has been pending with the Greenock Harbour Trustees, as to whether or not these works should be re-constructed at an outlay, probably, of £4,000, or to remove the dock altogether. Constructed, it is believed, from the designs of James Watt about the year 1785, this graving dock is one of small dimensions, namely, 223 feet in length by 50 feet in breadth, and having an entrance of 34 feet in width, with about 10 feet of water on the sill at high water spring tides. Before determining that the Trustees should be recommended to adopt either of the two courses already mentioned, their professional adviser, Mr. W. R. Kinipple, M. Inst. C.E., resolved to try what could be done by putting down 3-inch boreholes, at from one foot to two feet apart, through the masonry behind the heelposts down into the sand for several feet below the foundations. He also had several boreholes put down through the outer and inner aprons close to, and at a few feet from, the pointing sill. All the holes were sunk well down into the foundations, so that when a thick grout of neat Portland cement was poured down the holes, it would permeate through the various fissures and open joints, and virtually join the boreholes together, and thereby form, in fact, a water-tight sheeting of neat Portland cement. Stand-pipes were set up in the various holes about the aprons, and the grout was run into them only when the dock gates were open, or when the water was at the same level inside and outside the dock, which prevented any disturbance of the cement grout by runs of water until it was set. The thick grout carried down the level of the water in the stand-pipes to six feet below the level of the water outside of them. These experiments were carried on during the month of January with some four or five men, and about five tons of cement were used in grouting up the holes. The result of the operations is that, while formerly it required an 18-in. pump to keep the leaks down, the dock can now stand for 40 hours without the necessity of more than one hour's pumping during the same period. The leakage which now exists is almost entirely due to the defective meeting-faces of the gates and sill."

APPENDIX V.

Description of Experiment as to running Cement Grout through Stones in Water at Aberdeen Harbour. 1883.

On the 7th July a timber box (six feet six inches by one foot by four feet deep) was filled with round smooth stones of basalt and whinstone, from one inch to four inches diameter, and lowered to the bottom of the tidal harbour, at the south entrance to Victoria dock. The depth of water covering the box at H.W.O.S.T. was 18 feet. A wrought-iron pipe, $3\frac{1}{2}$ inches diameter, was inserted among the stones, opening 12 inches below the top of the box.

At high water a grout, composed of four measures Portland cement to one measure Sheppy cement, liquified with water, was poured through the tube, filling the interstices between the stones.

On the 19th of July the box was lifted out of the water, and the grout was found to be so firmly set that the weight of the box and contents was suspended on the wrought-iron grouting pipe in attempting to withdraw the pipe.

The timber framing was then removed, and the surface of the concrete found to be smooth, moulded exactly to the sides of the box, and perfectly solid throughout.

WM. SMITH.

Aberdeen, 19th November, 1883.

APPENDIX VI.

ORAL STATEMENT MADE BY MR. KINIPPLE, AT ABERDEEN, ON THE 6TH AUGUST, 1883, BEFORE THE SUB-COMMITTEE APPOINTED TO INVESTIGATE THE QUESTION OF THE MOST SUITABLE PLACE FOR A HARBOUR OF REFUGE ON THE EAST COAST OF SCOTLAND, AND ON THE EMPLOYMENT OF PRISONERS.

"My system is out of the general run. I prefer not to give a description of it in detail at the present time, for although I have been working at it for many years, a good deal of what I have done has been of an experimental character. Up to the present time I am happy to say I have been successful in almost every instance, and quite recent successes give me confidence as to what to recommend or not to recommend as regards the construction of a breakwater of such magnitude as that under consideration. I may say I have never had a harbour of refuge to construct—of course there are few to construct—but I have had considerable experience in connection with smaller harbours, and I think the methods adopted at some of these works, or somewhat similar methods could be well applied in the construction of larger works. For the last 28 years I have been endeavouring, if possible, to do away with staging and expensive plant in connection with sea works, for it is well known that sometimes 40 per cent. of the cost of such works—the half of the cost, indeed, in some extreme cases—goes for unsaleable plant, plant that realises very little more than the value of old materials when the works are finished. I may mention that one of my first experiments was simply to throw overboard a quantity of coarse shingle in a depth of about 25 feet of water, and pass neat cement grout into it by pipes, and I found that the shingle was permeated by the grout for a distance of from 20 to 30 feet from the pipes, and united into a solid mass. By a method such as this, I think that the ordinary rubble mound or base of a breakwater, instead of being kept at the great depth of 24 or 26 feet for safety, might be brought up to a considerable height—in fact to within 10 or 15 feet of low water, and secured by grouting at a small cost. The structure above the rubble mound is frequently built with large blocks of concrete laid dry or loose—that is, not cemented together, but I have never regarded this dry block system favourably, nor ever reported or even suggested that it is a proper system for the construction of sea works. When at Wick, where I was engaged for about three years, I had some opportunity of examining a work of this class—Wick breakwater. This breakwater was formed of a rubble mound brought up to what was considered a safe height; on top of the rubble a pile of loose or dry concrete blocks was placed, and these blocks were surmounted by a superstructure of concrete *in situ*. As is well known this breakwater failed, and I think the reason is evident, for the bottom course of blocks would not be resting uniformly on the rubble base, nor would the weight of the superstructure be uniformly borne by the top course. Thus many blocks would be bearing but a small part, if any, of the weight of the superstructure, and so oppose little more than their own individual weight to the force of the waves, and having free or open joints on all sides they would soon get dislodged, and when one went, others would quickly follow. In fact, the strength of a breakwater of this class of construction may be said to be measured by the resistance of one block; and if a failure of one block takes place, the structure soon comes down like a pack of cards. Most of the breakwaters constructed in this manner, both at home and abroad, sooner or later fail in the manner I have indicated. From such failures I consider it absolutely necessary, so as to ensure success, that the dry blocks be altogether omitted, and that either the rubble mound be brought up to a greater height and grouted into one mass, or that the monolithic portion of the breakwater be carried down to the rubble base. Probably something between these two systems would be the method of construction for breakwaters. I, therefore, propose a system which I have employed in the construction of Quebec harbour works, where we had only four or five months in the year to work, or a similar working season to what may be expected for the breakwaters here. In Canada, work has to be done in a very great hurry, and staging cannot be used, as it would be carried away by the ice. I was, therefore, driven to consider what was best to be done under the circumstances. There was a sandbank in front of Quebec, the top of which was four feet above low water, and the harbour walls had to be founded at 24 to 28 feet below low water. The sandbank was dredged out to a depth of 28 feet, forming a wide trench for the reception of cribwork caissons of timber, each of 120 feet length, by 30 feet in breadth at bottom, and 28 feet in height. These were made partially on shore during the winter, and completed afloat during the spring; were floated out into position when required, sunk and filled with concrete, and in this way the works were finished without hitch or difficulty. I have here some designs for breakwaters which are the outcome or development of the experience I have had. What I propose is to build a light framework of angle-iron, and line this framework outside with a shell of concrete, leaving the internal portion hollow. This would form a caisson similar to that for an ordinary dock entrance, with the exception that the sides and bottom would be formed of concrete instead of the ordinary iron plating. These caissons I propose to build on a slipway or launching way, and a sufficient number of them could be in progress at one time to construct, say, 600 or 700 feet of the breakwater—one block being always ready for launching, and the others in various stages of progress. Each block would be launched down the slipway on to a circular pontoon and floated out to deep water. A porthole in the side of the pontoon would then be blown out and water instantly admitted into a sinking compartment, which would cant the pontoon and launch the caisson into the sea. The caisson would then be hauled into position over the rubble mound, sunk by admitting water through a hole in the bottom, and then filled up with concrete. In this way it would be possible to make a block of concrete of several thousand tons weight, or, in other words, to form at once a full section of the breakwater from the top of the rubble mound to several feet above high water. By this method about 1,000 feet of the breakwater could be constructed per annum, all risks of blocks giving way would be avoided, little or no diving would be required, and the only plant would be the ordinary cranes, rails, locomotives, sheds, etc., and a large circular pontoon, which latter could be constructed so that it would carry several thousand tons of rubble, and be used in forming the mound. In fine weather during the summer season, one caisson, or, perhaps, two, could be placed in position daily, and in the course of a few days of calm weather a considerable length of breakwater could thus be constructed. The materials for the concrete shell of the caissons could be brought by a tramway on the top of the staging at the sides of the launching ways, and mixed there into concrete to form the caissons. As Mr. Rendal has said, the system I have adopted of using concrete three or four hours after it has been mixed would also permit a part of the concrete mixing to be done at quarries, and thus the concrete for the hearting of the caissons could be sent down in trucks and tipped by free labour into the caissons, so that there would not be a single convict on the breakwater. The handling of the caissons, such as launching and sinking, would also be done by free labour, but no other free labour would be used, so that the expenditure for free labour would be a very small percentage of the outlay. The statement I have made to-day is merely an indication of the direction in which I have been working during the last twenty-eight years, but I feel that I ought not to be bound to every word I have said. I may just add that I do not wish to cast any reflections upon any of my brother engineers, who have, as we all have been, trying to solve a problem surrounded by not a few difficulties. I hope that further light and experience will lead to a solution of all our difficulties. I trust you will pardon me if I have digressed somewhat in the course of my statement."

APPENDIX VII.

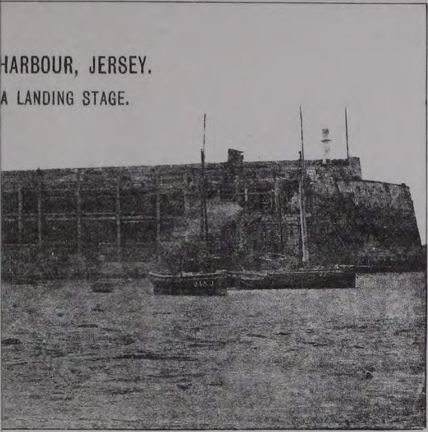
Extract from "North British Daily Mail," 22nd November 1883.

"Since Sunday, our Girvan correspondent says, a furious gale has been blowing, accompanied with blinding hail showers, thunder and lightning, and raising a heavy sea on the coast. On Tuesday the gale culminated in violence, the north breakwater was completely submerged, and the waves and sea-spray were driven furiously against and over the new south pier, but the harbour works have suffered no damage. Mr. Kinipple's, C.E., block system of building, by which the prepared blocks are dovetailed into each other, adopted in the construction of the new works, has been severely tested, and has satisfactorily sustained the full force of a most furious storm."

EXTRACT FROM "SCOTSMAN," 22ND NOVEMBER, 1883.

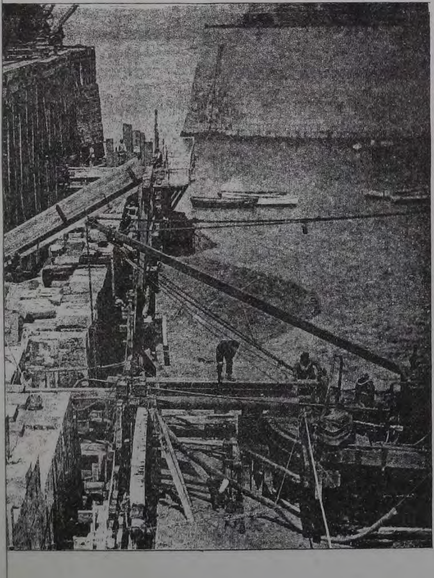
"Since Sunday a severe gale has been blowing at Girvan, accompanied with blinding hail showers, thunder and lightning, and raising a heavy sea on the coast. On Tuesday the north breakwater was completely submerged, and the waves and spray were driven furiously against and over the new south pier, but the new harbour works have suffered no damage."

PLATE I.



HARBOUR, JERSEY.
A LANDING STAGE.

PLATE II.



PAPER II.

THE DUTIES OF ROYAL ENGINEERS IN THE FIELD.

By Colonel E. Wood, C.B., R.E.

It was with some hesitation that I accepted the invitation to deliver a lecture here, for having never before lectured on any subject, I could hardly do so with a light heart, especially as this subject—"The Duties of Royal Engineers in the Field"—is so large, and is treated of in so many textbooks at the School of Military Engineering, that it appeared difficult to discuss it profitably in one lecture.

However, I trust that what will be said may prove of interest and value to young officers just entering their profession, who will see how necessary is the varied training they are now receiving.

Of course, the limited time at our disposal must necessitate a great deal being left unsaid that should otherwise have been touched upon, and that, especially, from the Indian point of view. I trust, ere long, we may hear in this hall that view put forth, embracing, as it must, so wide and varied a field of actual experience.

The duties of the Royal Engineers in the field may be classed as follows:—

1. Works in connection with landings, water supply, hutting, etc.
2. Making and improving roads and communications.
3. Developing the defensible conditions of positions.

4. Demolitions.
5. Siege of fortresses.
6. Bridging.
7. Constructing and working telegraphs.
8. Constructing and working railways.
9. Ballooning.
10. Surveying.

In most of the great armies in Europe the duties of Engineers in the field differ but little from the above. In France, Germany, Russia, and Italy, surveying is omitted, and in the case of France, bridging also; but the working of the pigeon post is added to the list, both for France and Germany.

Besides, there are also the defence of fortresses and submarine mining. These are subjects requiring the deepest study, and upon which the constant advances in arms and science have the most powerful and immediate influence; but, at the same time, they hardly come within the scope of this lecture. The study of the defence of fortresses, however, is absolutely necessary in order to know how best to attack them, and also to foresee, during the progress of the siege, all the possible expedients that may be adopted by an active and intelligent enemy. It is also possible to conceive conditions in which it might be desirable to make a base in a harbour more secure by means of submarine mining; but this duty would not be carried out by the Royal Engineers, except under very exceptional circumstances.

We have thus to consider the subject under 10 heads; and though duties in connection with landings have been put first on the list, as that would be the first operation in an expedition, yet it will be more convenient to discuss them in a different order. The five duties last in the list, in connection with bridges, telegraphs, railways, balloons, and surveys, are dealt with by bodies of men specially trained in each subject.

Of *Surveying* but little will be said, for this subject has lately been exhaustively discussed by Major Talbot in the paper on "Military Surveying in the Field." In future expeditions from England, parties from the ordnance survey would be appointed to carry out any requisite military survey which, being distinct from ordinary military sketching, demands the employment of trained surveyors. In recent expeditions surveys have been executed by parties from the survey of India, using the plane-table, and interpolating from previously fixed trigonometrical points, so that each day's work on the plane-table is at once available for the use of the staff. For carrying on such work, as the troops advance in a hostile country, it is evident that boldness and enterprise are requisite.

Here, perhaps, before proceeding further, we may with advantage consider a few principles, by the observance of which we shall the better carry out our duties in the field.

Before everything else we must fully realize that we are soldiers first and engineers afterwards. I want you to get hold of that strongly, and then you will be prepared to help other branches of the service in all possible ways, both in the camp and on the battle-field. I do not mean to say that we should instantly promise to do everything that everyone asks us to do, over and above the clear work that lies before us. In such cases we may be somewhat chary of promise, but should attempt to do more in performance.

Be prepared to assume responsibility on many and varied occasions, and, therefore, in preparation for such occasions endeavour to develop your judgment by experience and reflection.

Keep your eyes and wits open to see what can be done in the various circumstances in which you may find yourself placed.

Whenever you have stated that a certain work will be done by a certain time, do it at all costs.

You may find many things going on not quite as you arrange, but still be cheerful—cheerfulness will help you out of most difficulties.

We will now return to the consideration of our duties, taking those first which are of comparatively recent growth, and are due to the march of science, at the head of which we may place *Telegraphs*, a subject requiring, of itself, more than one lecture fully to deal with.

The value of the telegraphs in war was established with absolute clearness in the Franco-German War, when by its means one master could direct different armies to one end. But not only for great combinations is it all-powerful. Its influence is felt in the daily work along the whole line of communications from the base to army headquarters, and thence, laterally, to the headquarters of army corps, divisions, and brigades, and even to those of the cavalry brigades, so that information may be received and orders given with a rapidity formerly impossible.

When an army is to proceed into the field a Director of telegraphs is appointed, who takes his orders from the chief of the staff. With each army corps would be a division of the telegraph battalion, each of whose four sections carries 20 miles of line complete, and has a reserve of 80 miles, which would be brought up as required, so that one army corps could lay 400 miles of telegraph line.

Here it may be mentioned that in the Bechuanaland Expedition 350 miles were actually constructed by one section, extra stores being forwarded as required. In the Nile Campaign 160 miles of new line were laid; but the Royal Engineers had also to work the existing permanent line from Cairo to the advanced base, making a total of 1,200 miles. Over this great length important messages were actually passed straight through from end to end. In that campaign the telegraph practically took the place of the post, and the initial difficulties in getting the Egyptian lines to carry the sudden press of work were very great.

In advance of permanent lines may be semi-permanent field lines, generally along the main line of communications; and, again, beyond these will be advanced lines, either of cable, or of light air line.

It is possible to lay a line in open country as fast as infantry marches, and as an instance may be mentioned the case of Tel-el-Kebir, when, by means of the field telegraph, the general was immediately in telegraphic communication with England. Such results can only be obtained by thoroughly drilled men, working with a well ordered equipment.

In an enclosed country the difficulties are far greater, and a good eye and judgment are especially needed to lay a good line rapidly.

Cable is, of course, much more rapidly laid than air line, and more rapidly picked up, but is, at the same time, liable to early destruction by traffic of every description.

The laying of the lines is, however, by no means the most difficult part of the business, for the maintenance and working thereof entail great labour in patrolling daily by mounted men; also in discovering and repairing faults due to damage by traffic, or, as in the Eastern Soudan, by the enemy; and in the general work of the offices, carried on under very different conditions to those of peace.

It might weary you were I even to enumerate the various instruments and detailed duties with which the telegraph battalion must be thoroughly conversant; but the necessity of keeping well in the front of the science of telegraphs is apparent when we see how, in recent expeditions, the use of the latest developments in instruments admitted of work being performed which would otherwise have been impossible. To give one instance amongst several: by means of the vibrator sounder communications were maintained through heavy faults, and through bare wire lying on the ground, at times when a breakdown (as must have happened under old conditions) would have caused grave trouble.

We have no reason to suppose that we have by any means attained a perfection of equipment, good as it undoubtedly is; lighter forms of wire, etc., may be manufactured, rendering it possible to carry many more miles of material than at present, and it is just possible that, eventually, our system may be carried beyond headquarters of brigades.

I have by no means exhausted the duties of the telegraph battalion, for although signalling, generally, is carried out by another branch of the army, yet heliographs are used by it, and also telephones.

In the future the telephone will probably play a much more important part than heretofore between camps and along positions.

Railways.—The importance of railways in war in all civilized countries can hardly be over-estimated. By their means great masses of men can be rapidly concentrated and supplied with food and ammunition from a far distant base; while sick and wounded can be moved back out of the theatre of war with a regularity otherwise unattainable.

In our army there are two R.E. railway companies. Their work would be on the line of communication, under a Director of railways on the staff of the general officer commanding communications. These might be able to maintain and work about 50 miles of railway.

For working a railway, especially under war conditions, men thoroughly, that is *practically*, trained in the locomotive and traffic departments of railway work are absolutely requisite. Bookwork will quite fail to qualify men for such business, in which practical training is more needed than in the engineering department.

These three departments are worked independently of each other, that is to say, the men are specialised, and the stores, too, should be classed according to departments, to avoid confusion in work.

The engineering department deals with constructing, repairing, and maintaining the line.

In the case of a new railway the preliminary survey is of great importance as regards choice of the best line, so as to give the shortest route consistent with reasonable gradients and curves, moderate cuttings and embankments, and a minimum of bridging. For upon the happy balancing of all these generally conflicting requirements may depend the possibility of completing a certain line in time to be of practical use to the army.

The necessary material, if brought by sea to the base, should be loaded in ships in complete sections as far as possible. In order to avoid an unnecessary crowd of ships at the base and a block on land, these various sections should be delivered successively as required, and not all at once; for the latter course means confusion on all sides, and serious interference with the ordinary services for the army.

The railway, as it is pushed forward along the line of communications, should be utilised to some extent in supplying the troops. This is possible if the work be intelligently organised, time tables prepared, and an able traffic manager appointed.

When time presses there will be a strong temptation to omit sufficient precautions against damage by storms, and in so-called desert countries to forget, in their present waterless appearance, the fact that storms may shortly tear up the surface with deep furrows, and sweep away embankments all along the line, if numerous culverts be not provided. A case in point may be instanced in the line across the Suakin plain.

In the Nile Campaign 60 miles of new line were laid under especial difficulties in respect of water supply, etc., and worked with a very indifferent and motley assortment of engines and rolling stock. Indeed, special fittings had to be devised for one class of engine to enable it to couple on to both single and double buffer rolling stock. Probably, however, no better instance can be given of difficulties that may have to be overcome in utilizing an existing railway than that of the advance from Ismailia, in 1882.

The line had been cut and rolling stock removed, and though some was shortly seized, yet for three or four days the supply trains were worked with one indifferent engine, which was then supplemented by two additional small ones, and later on by others. As the whole native staff had deserted, men were required as pointsmen, signalmen, greasers, engine cleaners, carriage examiners, guards, drivers, and firemen; but the want of duly qualified men for shunting and marshalling wagons was especially felt.

The difficulties in watering, owing to want of arrangements, were very serious, but were eventually reduced by the loan of fire-engine pumps from the ships.

The line was a single one, and to work it properly a telegraph wire should have been reserved for its use, but this could not be arranged at first, when most required. Then, as the line was also used as a road by troops, guns, and wagons, the points were being continually broken, and the rails blocked by sand, so that wagons were not unfrequently thrown off the line.

Thus an overworked staff, in a trying climate, had to carry on a press of business with feeble engines and ricketty wagons on an imperfect line, with a continued water difficulty, and under conditions of sand and dust peculiarly unfavourable to locomotives, so that for working the first 20 miles one railway company was found insufficient.

It must be borne in mind that in such a case as we have been considering there is no chance of quietly developing the arrangements. The pressure is all at once, the necessities are most urgent. Everything is wrong, everything is wanting, and it requires energy and clear heads quickly to produce order out of such confusion.

We will next consider *Ballooning*, that branch in which, by means of persistent thoughtful research, such conquests, so to speak, have been won of late years here in your very midst.

Some years ago it was contended by men of science that the practical difficulties of retaining hydrogen gas in a light envelope, and storing that gas under great pressure in metal cases, were insurmountable. But what do we now find? Envelopes of great lightness and strength retaining hydrogen admirably, and that same gas carried into the field under a pressure of 100 atmospheres, whereby the practical application of balloons to war purposes is enormously advanced.

By the employment of so light a gas we obtain greatly increased portability, smaller balloons offering less mark to the enemy, and less resistance to the wind in captive work, which is very important; and we can carry our gas in light steel tubes wherever carts or camels can travel. Moreover, great improvements have been devised in the matter of valves, whereby, amongst other advantages, the loss of gas has been minimized.

The general use of balloons is to observe the disposition and movements of the enemy; and also in the attack of fortified positions or fortresses, to discover the trace of the works, the site of retired and concealed batteries, main magazines, and interior retrenchments; and, further, to observe the effect of artillery fire on the enemy's works, and the steps that may be taken to repair the same.

The value of balloons will be increased in consequence of the introduction of smokeless powder, for the difficulty of fixing precisely the positions of guns and firing lines will be far greater than formerly, unless balloons be available.

From the balloon the country is spread out as a map to the observer; hollows and reverse slopes of hills are seen which would otherwise afford concealment; orchards and scattered bush, which, as seen from the ground, form an effectual screen, appear open from above; and, finally, on a plain the front lines of the enemy's troops will no longer screen those in rear. Hence, the information obtained by means of the balloon should be far more accurate and comprehensive than that obtained by ordinary reconnaissance, which continually fails to pierce the screen, as appeared on many notable occasions in the Franco-German War, even on the part of the German scouts. Indeed, seeing that knowledge of the enemy's movements, dispositions, and force is all important, it is difficult to over-estimate the advantage of military balloons, even if there must be many occasions, under present conditions, in which the weather will prevent their use.

The observer being, as a rule, in telephonic communication with the party below, can at once deliver information, and also issue instructions as to the necessary movements of the balloons. If under enemy's fire, the position would be continually changed, so as to render it difficult for the range to be obtained; but even if struck a balloon will take considerable injury without coming down rapidly.

One or more balloon sections, each self-contained, will accompany our future expeditions. The observers must be men physically qualified for work as aeronauts and trained therein; and they should also be thoroughly skilled in the duties of reconnaissance, and possess full knowledge of the formation of troops. These qualifications will not necessarily limit observers to officers of Royal Engineers, though it is absolutely necessary that with the balloons should be some officers of high scientific acquirements, having practical knowledge of the various processes involved in their manufacture, and in that of the gas; and, therefore, competent to deal with the practical difficulties which will be met with in the field.

And here you should be reminded that in every branch of the duties we are considering, ingenuity must be exercised, and expedients quickly improvised to adapt insufficient means to the necessities of the moment. The strain of war must create unforeseen necessities, which can only be satisfactorily met by the man of well stored, practical knowledge—the man of resource. One such instance may be mentioned in the Bechuanaland Expedition, where, on arriving up-country, it was found that owing to the great heat experienced on the journey, and the dryness of the atmosphere, the balloons had become harsh and liable to crack; whereupon a process was immediately devised, and with the best results, for restoring the envelopes to a supple condition.

This balloon detachment, when not employed in its special work, assisted in putting posts in a state of defence.

Shortly after the despatch of the above to Bechuanaland, another balloon detachment, not quite so well equipped, was sent to Suakin; but, unfortunately, owing mainly to want of transport in its establishment, no balloon was out on a certain occasion when its services would have been invaluable, as the country was most unfavourable to cavalry scouting.

I have said nothing about free ballooning. This would be especially useful from a beleagured fortress; but a balloon, indeed, might also be sent into such a place from beyond the lines of investment, for since 1870 some advance has been made in the power of travelling in a desired direction, by using the different currents of air to be found at different levels.

We have quickly glanced at certain branches of our work demanding high attainments in modern science, in which progress is rapid, and which, though dealt with by special limits, will yet be of general use to the army in almost every theatre of war.

We now come to yet another special unit—*the Bridging Battalion*—which does not stand on the same scientific platform as the others, and the necessity for whose special employment may not occur in every campaign.

Here we have a body of men of special physique, drilling continually for one distinct end, viz., that of being able to throw bridges rapidly, from which you will infer how important must be their action when the necessity shall arise. Yes, the passage of a river, or the failure to accomplish it, may mean the gain or loss of a campaign; and the passage may depend not only upon the presence of a bridge train, but upon the possibility of a bridge being formed with extreme rapidity, so as either to forestall the enemy, or even to get across under opposition. Unless men are thoroughly drilled it would be impossible in the noise and confusion of an action to accomplish such a task rapidly, if indeed at all.

A few instances in past campaigns will illustrate the value of such an unit.

In the great wars at the beginning of this century the French had an admirably equipped bridge train, by means of which they achieved great things; while, on the other hand, the English were miserably deficient, and in 1813 Wellington writes: "I shall have sad work with this bridge throughout the campaign, and yet we can do nothing without it;" and some months later he says: "We are waiting for the movements of the pontoon train, without which we can do nothing."

Contrast this with the French establishment. Note how, in spite of all the horrors of the retreat from Moscow, the bridge train was yet in such an efficient state as to be able to throw trestle bridges over the Beresina, and so save the wreck of Napoleon's army. Or, take the passage of the Rhine below Stein. Here the French had brought row-boats overland by night, and had carried them to the water's edge, and in spite of the Austrian musketry fire, troops were rowed across under cover of the French artillery, and established themselves on the far side. Then the bridge train was brought down to the water, which was 130 yards wide, and the river bridged; so that in a very short time three divisions and a large body of cavalry were established on the other side. This may be considered a type of the way in which to surprise a passage, viz., by rapid movement, and throwing the bridge before the enemy has time to offer effective resistance. For this well drilled men, with a very mobile equipment, are requisite.

The Federal disaster on the Rappahannock was chiefly attributable to delay in the arrival of the pontoon bridges; but the importance of bridging operations needs no further illustrations, though most striking ones could be furnished from Indian campaigns.

It is also apparent that an army might also operate with safety on both sides of a stream, if provided with efficient means of bridging, and would thereby be in a position to secure marked advantages.

In recent operations in Egypt no bridging on a large scale was requisite, owing to the sudden collapse of resistance; but the pontoons proved most useful for carrying supplies by canal to the front.

With an army corps would be one pontoon corps, carrying about 100 yards of bridge. Its mode of operation, as a rule, would be, first to establish communications across a river by using pontoons as boats or flying bridges; then to throw a pontoon or trestle bridge; and next to replace the same, if requisite, by bridges of material procured locally, so that the bridge equipment may again proceed to the front for use elsewhere. The semi-permanent bridges might be formed by means of trestles, piles, etc.

The bridging battalion might also have to form bridge heads, and execute works other than bridging.

The remaining duties are carried out by the companies generally, under Divisional Commanding Royal Engineers, who take their orders from the general officers commanding these divisions.

The Commanding Royal Engineers, as well as the directors previously mentioned, are authorised to hire labour and purchase materials for Royal Engineer services; and then it is, when dealing with large amounts of labour and materials, that practice on large works in peace will be found to give most valuable experience for works in war.

Siege of Fortresses.—The most arduous of all Royal Engineer duties are those connected with the siege of fortresses, in which the demands are so heavy that all the existing field companies, eight in number, might not suffice for the attack of one important fortress; so that in such a case fortress companies in addition would be required in the field.

Our many little wars may lead some to forget that in our next European war, as in our last, we may have to concentrate our whole strength on the attack of some arsenal, and in such an attack will be found full occupation for every branch of our corps. We shall require bridges to complete communications on the line of investment; railway, telegraph, and telephone lines must be constructed, and existing ones repaired. Balloons will then, more than ever, prove themselves of value from the earliest stages of the preliminary reconnaisance to the very end; giving information otherwise unobtainable; guiding the fire of the artillery; and discounting the value of all sorties except, perhaps, those made by night.

The siege of a well-found modern fortress, intelligently and bravely defended, will offer problems of the greatest difficulty, and will entail the expenditure of vast labour and stores.

Let us briefly glance at the points in which the power of modern artillery has chiefly affected the question.

It has induced a great extension outwards of the works of the defence, in the form generally of strong detached forts, armed with heavy guns, protected, it may be in some cases, by iron. Hence, we must have a very extensive line of investment running probably at a distance of about three miles from the line of forts. This line must be put in a state of defence, and every class of problem will present itself—how best to treat villages, woods, gardens, railway cuttings and embankments, etc., so as, with a minimum of labour, to enable a minimum of force to hold that line, upon which question an intelligent development of inter-communications will have the most powerful bearing.

One of the earliest decisions to be made is in respect of the site of the main Royal Engineer Park, and the use of balloons by the defenders will render it difficult to find a suitable site within long range artillery fire for such easily destroyed and bulky stores.

The positions for the siege batteries must, if possible, be sought where the folds of the ground admit of concealment; where, for instance, they may be cut out of the reverse slopes so as to offer practically no mark above ground to the enemy; though even here, as indeed throughout the siege, will be experienced the searching effect of the fire of modern howitzers and mortars.

The practice of availing ourselves of accidents of the ground for sites of batteries merits more attention than is generally given to it; few exercises are more valuable than that of examining ground with varied characteristics, and tracing out with tape and pickets batteries for assumed objects, and at the same time roughly estimating the depth to which excavation should be carried. The type of battery that shows to the enemy an exterior slope of $\frac{1}{1}$ is hardly possible now-a-days.

I am only able to touch on one or two questions in siege work chiefly affected by modern advance in arms.

Magazines, unless mined out, will with the greatest difficulty be rendered proof against heavy howitzer fire. Hence it may be best to make many small magazines, for these, if they be of the same height as the large ones, will only present, on the whole, about an equal area to be struck, while the effects of an explosion will be proportional to the size of the magazine.

The question of the near advance may in future present almost insurmountable difficulties. It may be impossible to prevent quick-firing guns opening on sap-heads, which could not advance under such conditions without adopting even a deeper form of sap than that now practised ; but this would involve greater labour, so that it might be best to take to mining. If, however, rock or water be near the surface, advance might be impossible, as deep sap and mining would alike be impracticable.

Assuming that mining be possible, and that the fortress will not yield to close investment or to bombardment, we must prepare for an underground contest, when coolness, nerve, and rapid decision will, as formerly, be in constant request. There will be need for accurate mapping, resolute work, careful listening, cool judgment when to fire, and occasional dash and reckless boldness to snatch an advantage ; and this contest, the most trying of all, will be going on in many galleries over a considerable front. Here and there we shall experience the most startling rebuffs, but still we shall push on to ultimate success if sufficient men and stores be provided for the work.

Demolitions.—Large provision for this service is now made, as each field company carries with it 450lbs. of guncotton, while the mounted Engineers recently formed will also carry about the same, so as to be able, on a cavalry raid, to destroy railway and other bridges, and thereby hamper the enemy's movements.

In the attack of a position, gates, walls, and stockades may have to blown down ; and in street fighting many occasions will present themselves for using explosives when it may be impossible to bring guns to bear on the spot required. In such cases the difficulty, however, of placing the charge will in future be greater than ever, owing to the use of magazine rifles, for one loophole which cannot be silenced may pour out a continuous stream of bullets. The necessity, then, for steel shields will be apparent, and failing the provision of such in time of peace, they might be extemporized in the field, being fixed temporarily to the back of carts, which the demolition parties would push on in front of them.

In a retreat, the demolition of a bridge may gain time that will save the force. But effectually to destroy a bridge with the limited time or means that may be available, will demand, amongst other things, a knowledge of construction ; for one man will utterly fail to accomplish results that would be achieved by another working under precisely similar conditions in respect of time and means. Probably this will apply with greater force to the destruction of iron bridges than to that of masonry or wooden bridges.

Defence of Positions.—Under this head will come such a variety of work that we can only touch on a small portion of it.

In the first place, the ground must be carefully studied under the view that tactical requirements must govern everything, and the works should be adapted to the conditions that may be presented, care being taken to consider the position from the enemy's point of view as well.

It is very easy to say that the first thing is to obtain the fullest possible effect for your own fire, and, therefore, the ground in front must be cleared; but in practice the time and means at disposal will continually compel you to do less than you would wish, and, therefore, it is essential to decide aright what should be done first. While you are opening out the front, the question of *obstacles* must be borne in mind, otherwise you may have cause to regret that a hedge, for instance, was cut down, which, if standing, might check the attack and yet not practically obstruct the fire of the defenders.

You will next consider the questions of cover for your own troops, and also of inter-communication; but in all that is done simplicity should be aimed at as far as possible. The cover for the firing line will frequently, in the first instance, be shelter-trenches, executed by the infantry. When practicable, Engineer officers should help to trace the line, for a well considered one is very important, especially if the original trench has to be developed into a more substantial breastwork. Whether to put the trench somewhat down a slope so as to see the steeper parts of it, or to retire it back from the brow, will depend on the particular circumstances of the case as affected by the conditions presented by the collateral portions of the line. No positive rule can be given.

Certain portions will be occupied by hasty, or semi-permanent, redoubts, and here, as everywhere, endeavour to keep all your parapets as low as possible, and that for many reasons—they will be the more readily made, less easily seen, and far less easily hit. Again, the long modern shell of high velocity will ricochet harmlessly if not caught in a steep exterior slope, and the fire from the low parapet may be more effective because it will probably be more grazing. The high parapet might be required to see down a slope, but, as a rule, it would be better to sweep that slope by works retired in the re-entering angles of the ground; or it might be required more effectually to screen the ground in rear, but this end may frequently be sufficiently attained by excavating out the terreplein and throwing up low parados and traverses.

For ordinary conditions, when as usual it is important to economise time and labour, *Plate* I., *Fig.* 1 represents a convenient section. The ditch obstacle has been proved to be very formidable, while the parapet is hardly distinguishable at a short distance from the front, covered as it is by the glacis, whose surface, together with that of the parapet, should be made to resemble, as far as possible, the surrounding ground. It will be seen that shells of high velocity would have practically but very little chance of effect. After the first relief, all the earth from the ditch would be thrown into the glacis so that the movement of it is easy, and the glacis practically increases the size of the ditch to a width of fully 16 feet and a depth of over 10 feet.

In addition to many obvious advantages of the V-shaped ditch, one may be mentioned that is rarely considered, viz., that it is easier for men to get out of a ditch six or eight feet deep, with vertical sides, than with slopes of about $\frac{2}{1}$.

Leave no berm, for that would greatly facilitate a crossing, but cut away at the last the ledge you may have retained for convenience of work.

The objection that men standing on the crest of the glacis should not be able to see into the work, has little practical value until the defenders have run away from their parapet and from the trench immediately in rear thereof, while the objections now-a-days to a lofty parapet are very distinct. If a high parapet be adopted shells will be caught and held by it; moreover, in firing down the steep superior slope, in the close attack, men must lean over and expose themselves more than they otherwise need do, so that the instinct of self-preservation may increase the common error of firing high. In future, too, the defenders of a lofty parapet will probably be exposed to machine gun fire over the heads of the attacking line. So accurate is this fire that, as soon as the range be obtained, it might be maintained even when the attack be close to the work, if the defenders be raised above the others, especially during the periods when the attackers are lying down.

Provide inside your work a supply of sods or filled sandbags to maintain loopholes on the parapet to the last, which will greatly increase the power of the defence.

With some European armies we shall find quick-firing guns mounted in iron cupolas for defence of positions. For these and for machine guns, however, efficient cover can be easily secured on the ground against shrapnel, while effective hits by common shell on so small a mark under battle conditions will only be obtained at a great expenditure of ammunition. Batteries of rifles may also be so covered that it would be almost impossible to silence them, for the introduction of smokeless powder would cause them to be practically invisible to the enemy.

Plate I., *Fig*. 2, shows the section of a rifle battery sunk in the ground so as to offer the least possible mark to artillery fire, and it might be covered with iron rails if available. The rifles, 9 or 12 inches apart, are all laid on required points, and then wedged or bolted firmly in position, so that a man can work two rifles at the same time, one with each hand, quicker than he can work one rifle in the ordinary way, for the cartridges would be laid on a convenient tray. Here there need absolutely be no opening for bullets except a small look-out, which might be closed if required. Such batteries might be constructed slightly in rear of redoubts, communicating therewith by galleries, and trained to sweep the salients of adjacent redoubts, for the fire might be safely trained on the glacis itself.

Such a battery, to sweep a causeway, was constructed recently on service, but not being exposed to military fire the rifles were fixed at the most comfortable height for a man to serve, with the tray for cartridges on the top of them instead of below, as in the section represented. With the new rifle a fixed battery on level or uniformly sloping ground could sweep the same to a distance of about 500 yards, so that its effect should be great.

In providing cover for reserves we must remember that the steep descent of long-range bullets necessitates the employment of overhead cover to be effective, but here the intelligent application of means is very important. Suppose, for instance, you can get a quantity of 1-inch boards, these, if laid with a slope to the rear of about one in six, will keep out bullets at a range of 2,000 yards, for the bullets will ricochet down the slope; but if level, the boards would be easily penetrated.

In respect of obstacles, barbed wire is very formidable, but the value of plain wire entanglements is probably much over-estimated, for troops under great excitement will pass through them in a very different manner to what is assumed when the question is treated theoretically. Moreover, the labour and materials required are frequently prohibitive.

Land mines, though now brought to a considerable state of perfection, would rarely be used except in front of a purely defensive position. In the Eastern Soudan the enemy showed the greatest skill and boldness at night in cutting the wires of electrical mines, their movements being noiseless and impossible to detect. Tread mines were almost immediately choked with drifting sand, and though this was met by putting the mines in sandbags, yet there were objections to this plan. Of course, these mines would have been effective in the event of a hostile rush; but, on the whole, they were not effective in preventing these men quietly occupying certain spots at night which it was wished to deny to them.

In all civilised warfare railway lines will enter largely into the question of preparing positions for defence, and it may not be uninteresting to consider a case that I put to myself on the ground some years ago.

We will suppose an English force, say a division, delaying the advance of the enemy, but with the certainty of having to fall back when the hostile attack is developed.

The general sends the Royal Engineers to prepare a position at a small town some seven miles back, where the railway he is operating upon passes by a tunnel through a range of wooded hills.

The Commanding Royal Engineer has been instructed generally in respect of the ground to be occupied, which extends for about a mile on either side of the railway; he is to make use of two battalions he will find in the town, and will hire such labour as may be possible.

One officer would march with the sappers, the others would ride back rapidly to make arrangements.

The railway and main road run side by side across a small stream, and then in another 300 or 400 yards across a canal just below the town, which lies parallel with the canal and stream (see *Plate* I., *Fig.* 3).

The railway crosses the valley by high embankments and a massive brick viaduct. One officer will superintend the preparation for demolition of the viaduct and road bridge, and will arrange to dam the stream below bridge so as to form a small inundation. He will inspect up and down stream to note for demolition any field bridges that may exist. In order to complete his inspection before the arrival of the sappers, it is of manifest advantage in an enclosed country that this officer be a good rider and well mounted.

He will also have to demolish a mill near the viaduct, so that it will be necessary for him to economise his explosives.

In order to ensure an efficient gap in the viaduct, two piers must be blown down.

In dealing with the viaduct, he should first cut away large portions of the piers near the ground, which his knowledge of construction tells him may safely be done, and with no book to refer to he has to rely on rough-and-ready rules stored in his head in apportioning charges to the various jobs he has in hand.

He himself would finally remain with an assistant, with the dynamo machine concealed in a ditch, to fire electrically the viaduct and road bridge at the desired moment. The field bridges, three of which he has discovered, must be entrusted to non-commissioned officers or sappers to blow up, by means of Bickford's fuze, after the passage of their own troops. We will now see what the other officers are doing.

They find that the railway, in high embankment, crosses a straight length of the canal by two arches, over which is a great mass of earth. These archways, one of which is for a field road, can be converted into strong, roomy casemates for machine guns and rifles, to sweep the canal on either side of the railway.

From the station, just above, truck loads of rails would be run down, and from a neighbouring wharf barges of timber, etc., would be run under the canal arch and then settled, so as to form the ground platform. An upper floor would be formed in this arch, while above the other exists a relieving archway which would hold a machine gun, so that the command admits of firing over a raised bit of road which would otherwise mask the fire on one side. The fronts of the casemates, formed of rails, would be practically secure against artillery fire, owing to the wing retaining walls of the embankment. It is unnecessary to describe details of construction, but one little point might be mentioned. Suppose it be desirable to cut many rails for more convenient building of the front walls of this casemate, this could be very quickly done with guncotton. Four rails can be cut through at one time, if packed round one charge of about four ounces.

As one only of the existing telegraph wires is now required for use, the others would be taken down for binding abattis together, and to render the crossing of the canal (which is only four feet deep) more difficult, posts might be driven into its bottom with wire running between.

This section of work will be in the hands of one officer, who will also prepare for demolition the canal road bridge, which would otherwise somewhat mask the fire from his casemate. Arrangements must also be made for a solid breastwork of rails, or trucks of earth, to close the railway above the casemate as soon as the last train has passed.

The other officers enter the town to obtain labour, and secure tools and gunpowder. The latter is required for demolishing canal bridges and outlying houses; and in deciding what to destroy and what to prepare for defence sound tactical knowledge is requisite. Parties will proceed across the canal to clear the ground towards the brook, and for all this rapid decision and organisation are required.

There are trees of all sizes growing on each bank of the brook; if these be cut down unthinkingly, a hundred crossing places may be provided for the hostile infantry. It might be better not to cut down the trees on the near side of the brook, but to lop away their lower branches, so as to give a clear view under them. Then, again, near the canal is a row of great elms, behind which, owing to the existence of a little bank, the enemy is sure to collect before making his rush for the canal, so that he would be thrown into some confusion if these trees could be cut down at the right moment by charges fired electrically. There is ample wire for leads back to the position on the canal, under which they would pass through an existing culvert, and it may be expected that the dynamo will be brought safely up after demolition of the viaduct. As the wires would be concealed in passing from tree to tree, and as the enemy will gladly avail himself of temporary shelter before passing in front of them, successful results may be reasonably counted upon. In order to ensure, as far as possible, that the trees shall fall in the required direction, the charges should be lodged well beyond the centres of them, so that the sides towards the enemy would be blown out thoroughly.

Good positions for guns would be prepared in the high, wooded ground above the town, to command the lines of approach by road and railway; and communications therewith would be made from the excellent roads which lead from the town to the rear.

In respect of forming inter-communications, I propose to give you one instance of practical work, which is worth remembering. At autumn manœuvres on Cannock Chase there was a deep, soft bog, across which it was desirable to make a road, but as there was no brushwood, and but little road-metalling obtainable, it seemed, at first, that the idea could not be entertained. By making use, however, of heather growing near the bog, an excellent road was made in the following manner:—Two deep road ditches were cut, about 40 feet apart, and narrow trenches, draining into these ditches, were also cut across the roadway about six feet apart; bundles of heather were tightly rammed into all the narrow trenches, and all the earth excavated was piled along the inner sides of the ditches, so as to make footpaths. Heather was then strewn in cross layers over the space between the footpaths, and metalling spread thereon, making a road which stood traffic admirably.

Rushes, reeds, or even straw, might be similarly used in default of better material.

As time is short, instead of proceeding further with general reflections on the various and important duties connected with landings, etc., I will ask you to consider some of the demands which have actually been made on one company in about two years' work in the field, so that you may clearly see what any one of you may be called on to perform.

Doubtless some of you say: "Well, as there are five special branches, we need not, at least, trouble about them at present." Such, however, is not the case, for the company in question was called on for work in every branch, except ballooning; and, therefore, officers should have some knowledge on every subject, in order on emergency to make the best use of the few specialists that will be under them.

We will assume that you are embarked for the seat of war, and that care has been taken to provide supplies of such engineer stores as it is foreseen will be required early, in addition to the ordinary equipment. It is probable that you have had a very busy time, but you cannot afford to be idle on board ship, for the few days at your disposal are most valuable. Some of the officers and men are new to one another, the latter, who may have joined from the reserves, being rusty in their duties, and it will be most beneficial to all that the officers should lecture on various subjects, such as knotting and splicing, signalling, firing mines, etc. For such subjects as the latter small selected classes might be formed of such men as would probably be employed on those duties. Apart from the great advantage of refreshing the memory, there is also that of personal contact between the officers and men, which can hardly be over-rated.

One of the first things that will be required on landing is a variety of notice boards inscribed with names of the various headquarters, offices, stores, and with notices such as "water for drinking"—for horses—for washing—in fact, everything you can think of. If printed notices have not been provided, put your letterers to work painting the same on boards, or canvas, or on tin sheets. This may seem a small matter, but great convenience will result immediately on landing.

Study carefully the maps and plans of the place you are going to, if it be known, so that on landing, instead of asking *your* way about, you may direct others.

We will suppose you land at Alexandria when the enemy in the neighbourhood is in far superior strength to the small force landed; you at once set to work retrenching the breaches, laying fougasses therein, putting the drawbridges into working order, and erecting heavy stone barricades in the streets, etc.

The system of water supply is out of order, and now you recognise the value of your skilled plumbers in putting it right.

A position in advance of the town is prepared and occupied for defence, detached houses are prepared for advanced posts, or breastworks are constructed. Fascines of reeds picketted down with ribs of palm leaves are used for interior revetments.

Wells are sunk in the sand, and the sides retained by sheeting, driven behind light wooden curbs. For the flowing sand chokes the Norton tube pumps so as to render them of hardly any value, even with constant attention to the valves.

Night operations are undertaken, both for breaking up the railway well in advance of the position, and also for repairing it when required for a specific purpose.

A survey is executed by plane-tabling. A light infantry bridge, 120 feet long, is thrown one day over a canal near the outpost line. The water is only three feet deep, but the mud is so soft that a rod can be easily pushed six feet into it. Some old boarded roofing is cut into squares, on which trestles are planted, so that these piers with wide bases do not sink in the mud. The shore piers are formed of stout tables found in neighbouring houses, the legs being placed astride of palm logs laid in the mud and driven right down.

Light canvas-covered pontoons are constructed, and a special superstructure for rafting provided, with strongly braced projecting ends to suit the shallow, muddy sides. The intention is to track the raft up the centre of the canal by ropes on each bank, so as to use it as a ferry bridge when required, the material for shore piers being carried on either bank. But the company is moved to Ismailia before this plan can be carried out, though the want of such an arrangement is strongly felt when a reconnaissance in force takes place on either bank of the canal, across which communication is impossible.

A night march is now made back to Alexandria, and the company re-embark for Ismailia, but the ship runs fast aground at a long distance from the landing stage, and serious difficulties are experienced in landing the mass of heavy stores with the company. Where demands on all sides are so heavy much will depend on personal tact and energy in the matter of getting everything on shore quickly.

The animals are being slung on to a barge, but one of the mules slips out of the slings into the water, and as it promptly makes for the nearest shore the others are all sent after it, and the barge is, therefore, available for other pressing needs.

Immediately on landing at Ismailia the two or three telegraphists in the company are required in the telegraph office, and though, perhaps from want of practice, they are slow operators, they prove most valuable. One party loopholes houses in the suburbs, and another repairs cuts in the railway. An extension of the line from the station to the landing stage is commenced; pumps and watering troughs are fixed; the water in the freshwater canal is husbanded by stopping the leaks in the locks and raising the overflow of the gates by boarding; work on light pontoons is continued; and composite beams of economical section are made for the purpose of crossing the numerous narrow canals in the delta. These pontoons prove invaluable in conveying supplies to the advanced force when the early difficulties of transport are most grave.

Soon the company marches up the canal to remove a dam, in order to permit of the passage of launches, boats and pontoons. This dam has been constructed with layers of sand, and of long, tough reeds tied and matted together, solidly compressed by superincumbent weight, so that pick, shovel, specially constructed hoes, and rakes can make no impression under water, and it becomes necessary to employ repeated charges of guncotton of from 3 to 10 lbs. each.

Further on is a very large dam formed of sand only, and it seems desirable to employ a steam dredge for work below water. There are two dredges out of order, with parts missing from each at different spots in the canal; but one of the company is so excellent a mechanic that out of these two strange machines he soon completes one, and gets it into working order.

Further on a camp is fortified, and here green millet is found most useful for revetments ; fascines are made thereof, and each row anchored into the parapet by means of millet stalks, whose butts are driven into the fascines and ends laid over into the parapet.

Here an almost impossible approach to the canal over a railway embankment of thoroughly loose sand was rendered firm and solid by constant wetting. As a rule, water is not present when such sand is met, so that such treatment is rarely possible.

Arrived at Cairo, every class of sanitary improvement is instantly needed. The dry earth system has to be arranged for the troops, and kitchens, stables, and fittings generally have to be erected or re-modelled. These works are essential to reduce disease, which spreads rapidly after a campaign ; and here the experience gained in works during peace proves of the greatest value.

Ere long it is necessary to prepare landing piers at Suakin for an expedition that may be expected to start directly the proper season arrives. General preparations for a base have also to be made, entailing in this case a considerable variety of work.

Immediately on landing, steps have to be taken for the security of the company camp against night attacks, which only need be considered, as the presence of war ships ensures security by day. As no trench work is possible in the hard coral, a stockade is rapidly thrown up along a portion of the exposed side, behind which men may rally. Sentries are thrown well out to the front, and their reliefs are posted in a small loopholed guard-house, which must be held in case of attack, in the hope of time being gained for the men in camp to turn out.

A great store of timber, including 3-inch deals, has been brought, but instead of stacking the deals till they are wanted for the pier heads, they are used in making a long shelter for the men, as shown in *Plate* I., *Fig.* 4. The arrangement is very simple : none of the deals are cut, those about 22 feet long being selected for the frames and merely spiked or bolted together. The frames are fixed six feet apart. A continuous "kneeling" loophole is formed, and except for this loophole there is no absolute necessity for nailing any of the covering deals.

Of course, such a shelter is not suitable in rains, but otherwise it forms a commodious barrack with a double row of beds, and at the same time protection is given against long-range bullets.

In the meanwhile steps are taken to hire native labour, in which difficulties must be expected, as comparatively few of the natives are accustomed to work. However, as they are at first required chiefly for carrying stones and timber, they will be gradually trained to work. The best results follow from introducing direct daily payments to the men, instead of through their sheikhs; the men show their delight by the wildest demonstrations of joy, and increased numbers present themselves for employment. The sheikhs bring the necessary silver in advance, and also provide food and water, receiving gold in exchange; but the water has to be very largely supplemented by issues of distilled water in order that a reasonable amount of work may be done.

The construction of the landing piers is, of course, of primary importance; and from these an 18-inch railway system is to be carried to the camping ground of the expected force.

The water, for a distance of 100 yards round the shore, is shallow, but then the coral reef begins to fall rapidly into deep water. Across the shallows solid coral piers, over 20 feet wide, are carried to a depth of about nine feet, after which timber is used. Coral is brought from the outer reefs in canoes and dhows, and though for the first few days the delivery is small, yet as fresh dhows come in from outside, it rapidly increases to 7,000 "*stones*" a day, which builds about 200 cubic yards of pier. Men are also procured who can build neatly under water to the above mentioned depth of nine feet; and excellent material for the surface is obtained from the railway cuttings, which are in excessively tough coral.

In the meanwhile trestles of 12-inch spars, with transoms 20 feet long, are prepared for use in the deeper water; but as the treacherous nature of coral bottoms is known, it is decided to test the footings, after they have been actually reported sound by European divers.

To do this a 12-inch spar is rung with iron at the foot, and a solid cross-head fixed so that two gangs with heavy hand monkeys can deliver a blow simultaneously in order to punch the footing. The result is startling, for at the first blow the whole thing goes down bodily five feet and the monkeys fall into the water, though the men are able to stick to the platform. It is consequently decided to continue the work by piling, and while the driving of piles up to 12 inches diameter is proceeding with hand monkeys, a monkey of 10 cwt. is ordered to be cast in Egypt, and on arrival is worked from an 81-ton barge, also obtained from Egypt. Timber, 14 inches to 15 inches square and 30 feet to 35 feet long, is used, some of the piles being driven fully 12 feet into the coral bottom, and by a good system of drill the work progresses rapidly.

The timber sent from Alexandria is very fine. One stick, 62 feet long and 18 inches square, which was brought down slung outside a vessel, is bolted along the front of a pier head at the water level, forming an admirable fender, and in that position will retard the ravages of sea worms on the piles, for these worms chiefly attack the outermost timbers at the water level. A somewhat smaller stick is found useful as a derrick for lifting engines before it is worked into a pier.

The total length of six main piers alone is 1,800 feet, and their total frontage in deep water about 380 feet. Ships of all sizes up to 4,000 tons lie alongside them, and no repairs are necessary to them throughout the expedition. The work for the smiths was constant in making bolts, dogs, heavy rings, etc.

As an instance of the pace that light boat piers may be run out by piling, one may be mentioned made in four days by a party of two R.E.'s and eight natives working with two hand-monkeys. This pier was $2\frac{1}{2}$ feet wide, 200 feet long, in shallow water, terminating in a head for boats in four feet of water.

The 18-inch railway connecting five of the piers is completed for a total of five miles with causeways, culverts and cuttings suitable for a line of ordinary gauge. Considerable trouble is caused in working the line, from the need of constant packing, owing to the extreme narrowness of the gauge; and the engines, too, require considerable and heavy repairs to keep them in working order.

Well-sinking on a large scale goes on; wells, $3\frac{1}{2}$ feet to 4 feet diameter, can be sunk at the rate of one foot per hour up to 20 feet, so that it is manifestly useless to waste time on the Norton tube, which is invariably stopped by a stone before reaching water. Eventually, 30 wells yielding water are completed to depths varying from a few feet to 45 feet, and large concrete or other troughs fixed at most of them; while at the same time some shafts fail to reach water at 50 feet.

Concrete tanks containing many thousands of gallons are constructed below ground, and roofed with timber. A stone hospital is commenced, stone being quarried and lime burnt on the works, as but little can be purchased; but the ground floor only of the building is completed.

As the railway is pushed out from the sea it is necessary to cover it from destruction at night, so redoubts have to be thrown up. *Plate* II. shows the type adopted. The lower floor is of sandbag walling about three feet thick, the upper floor of deals or baulks laid flat, giving a room 21 feet square, having loopholes in the projecting angles of the floor, to command the ditch, which is five feet to six feet deep and 12 feet wide. The materials for this particular redoubt were collected under cover over-night, 1,000 yards in rear of the spot to be occupied, and the redoubt (except roofing the crow's nest) completed in the day and garrisoned the same night by 30 sappers. The total strength of the party was 60 sappers and 150 selected natives, who also completed an enclosing zeriba of mimosa bushes to cover emplacements for two guns to be brought out the following morning.

In making a zeriba, be careful to prevent it being made too high, (as the tendency is), otherwise it would interfere with your fire, but make it as thick as possible, and then, if you have the means, run a couple of wires round the outside of the zeriba, one near the top and the other halfway up. Such an application of wire is most effective.

An extensive area for the proposed camps is eventually enclosed by a line of small redoubts, and a survey of the whole executed.

This briefly describes the chief works executed in preparing this base; but a few words may also be said about advancing from it.

Where there is bush, a track should be cut as you advance; the work is far more simple than it appears, and convoy movements will be rendered easy and secure, besides other military advantages being gained by such a road. One plan is to cut, we will say, a track 100 yards wide, forming the bush into a hedge 25 yards on either side of the centre line; this gives a road 50 yards wide, with clear spaces between the hedges and the bush, so that the enemy cannot close on the road unperceived. The other plan is to haul everything to the edges of the cutting, leaving a wider road. Such a clearing, 100 yards wide and two miles long in moderate bush, was cut in one day by a working party of 350 men, assisted by camels, mules and horses for drawing the bush to the sides.

Each section of four has an axe, a billhook, and rope. Mounted men with flags give the cutting lines, which should be as straight as possible; or, better still, men standing on raised seats on the tool carts mark the lines; these also act as look-out men, for their slight elevation gives great advantage in range of observation in bush.

In case of attack the hedges form a zeriba, for the ends may be pulled in if desired and if time admit.

The camps in such a country must usually be protected either by thorn zeribas, which should be low and wide with one or two wires run round their outside near the top of the hedge, or by dry stone redoubts, such as were also largely used in Bechuanaland.

As regards watering arrangements: when the water is running in the sand a few feet from the surface you should cut commodious trenches, so that animals may walk down and drink as from a pond.

If pumps have to be used and are scarce, it may be desirable to connect deep wells by galleries to form pairs worked by one pump. This arrangement gives a large gathering area, without increasing the diameter of the wells, which might render steining necessary; moreover, it gives facilities for deepening if required.

It seems desirable to say a word about the carrying of tools. In other countries sappers, or pioneers, each carry a tool; but in our service the sappers do not, so it behoves the officers to be most careful to issue tools to the men directly there is a probability of the tool carts being unable to keep up. If this be invariably done, as it should, then our system would appear the better, for the following reasons:—We have special tool carts which can accompany troops almost anywhere, and the sappers will march freer and be fresher for work if they do not carry entrenching tools. Moreover, the description of tool actually needed will be issued; whereas, in the other system, some of the men would have to lay down a temporarily useless tool in order to receive one suited to the requirements of the moment.

And now, in conclusion, let us consider for a moment the men by whom all this work has to be carried out.

You will have noticed that the men in the telegraph battalion, for instance, must not only be highly trained and intelligent, but must be trustworthy in a high degree, seeing the temptations to which they are liable in their various offices, and the confidential and important nature of many of the messages transmitted by them.

Over and above all this, however, you will find that in the field non-commissioned officers and men possess the highest qualities as *soldiers.* Our units are of such a convenient size that officers and men are thrown much together; and, pulling together, they gain a mutual confidence, the source of great strength, which has never been more apparent than in night alarms which occurred both in

South and North Eastern Africa. On such occasions, when men's hearts are apt suddenly to fail them, Royal Engineer companies have shown the most conspicuous steadiness.

The power of going quietly on with work under fire, without betraying a feverish haste to throw down the tool in order to pick up the rifle, requires stern, sober strength, and men who can so act will, when the proper time arrives, use the rifle with equal coolness and effect.

It should be in the power of any of you who may in the future command such a body of men to say confidently: "We can go anywhere and do anything that can be possibly required of us."

PLATE I.

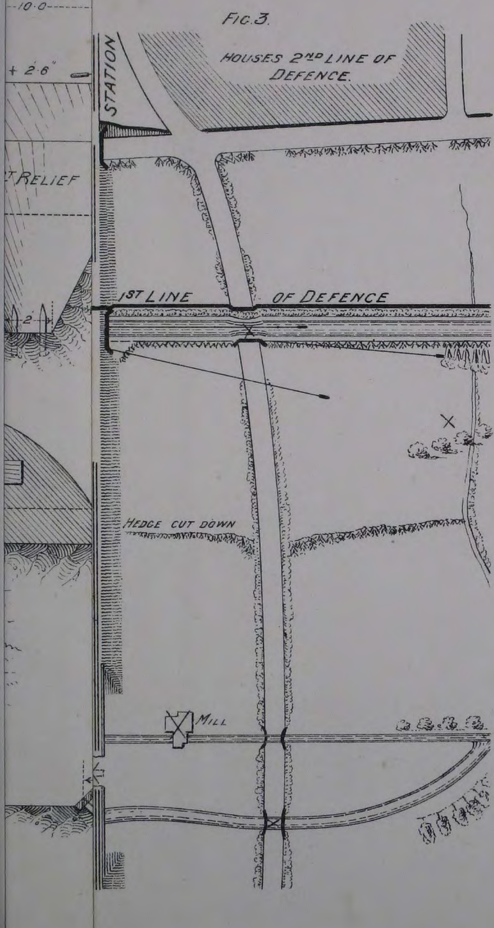


FIG. 3.
HOUSES 2ND LINE OF DEFENCE.
STATION
1ST LINE OF DEFENCE
HEDGE CUT DOWN
MILL
10·0"
+ 2·6"
RELIEF
2

PAPER III.

THE LYDD EXPERIMENTS OF 1889.

BY MAJOR G. S. CLARKE, C.M.G., R.E.

THE experiments carried out at Lydd in 1889 divide themselves into the following principal groups:—

(*a*). Attack of casemates of different forms.

(*b*). Trials intended to afford data as to the comparative effect of the shells of the 10 inch B.L. and 8-inch B.L. howitzers.

(*c*). Practice directed to test the accuracy attainable with high-angle fire at long ranges, "under service conditions as to observation."

(*d*). Comparative trials of "Ripple" form of parapet, proposed by Colonel Richardson, R.A., and siege battery of ordinary type.

(*e*). Practice to test the vulnerability of fortress guns on "blocked-up" carriages and slides when exposed to the fire of field guns.

The experiments were not of a sensational nature; but there is much to be learned from them from the Engineer's point of view. Questions of design are mainly ruled by two sets of considerations, viz.:—(1), the probability of being hit; and (2), the effect of hits when obtained. As to (1), experiment can teach us something, or at least can help to clear our ideas; in regard to (2), the data obtainable are tolerably exact. As, however, the practical significance of (2) depends mainly upon the interpretation placed upon (1), it is evident that there are ample possibilities for disagreement.

One thing at least is certain. No one who does not conscientiously endeavour to understand the meaning of the experimental data available has the smallest claim to speak with authority upon any question of design. Mere speculation, unchecked by facts, may err hopelessly, and what is called "common sense" is of value only when it implies a rational process.

(*a*). Attack of Casemates.

Targets.—See *Plate* I.

The protection was as follows:—

No. 1 casemate	...	7′ 0″ loam. 1′ 6″ concrete. double layer of 56lb. rails; span, 10′ 3″.
No. 2 casemate (in two parts).	(*a*).	3′ 0″ loam. 3′ 9″ concrete arch; span, 12′ 0″.
	(*b*).	3′ 0″ loam. 3′ 0″ concrete. $\frac{5}{15}$″ corrugated steel decking; span, 10′ 0″.
No. 3 casemate (sandwich).	...	2′ 0″ loam. 2′ 0″ concrete. 3′ 0″ loam. 2′ 0″ concrete. double layer of 56lb. rails; span, 12′ 0″.

Nos. 1 and 2 were built side by side, forming a single target. No. 3 was separate and independent.

The practice is summarized below:—

7-inch B.L. Howitzer.

Range.—2,000 yards.
Target.—Casemates 1 and 2.
Projectile.—Cast steel shell filled 15lb. 3oz. powder.
Fuze.—Direct action, with delay.
Line of Fire.—68° to line of front of casemates.

No. of Rounds Fired.	Charge.	Elevation.	Results.
20	3¾lb. R.L.G.[4]	54° 30′ to 60°	One hit on portion (*a*) of No. 2 casemate, which was breached 5ft. by 4ft. One hit on loam short of casemate; shell penetrated 6′ 0″ and burst. No effect.

Cast steel common shell filled 17lb. stemmed Lyddite. Direct action, delay nose fuze.

No. of Rounds Fired.	Charge.	Elevation.	Results.
14	$3\frac{3}{4}$lb. R.L.G.[4]	52° to 60°	Nil.

8-INCH B.L. HOWITZER.

Projectile.—Cast steel common shell filled 25lb. 10oz. powder.
Fuze.—Direct action, with delay, experimental.
Other conditions as above.

No. of Rounds Fired.	Charge.	Elevation.	Results.
10	$5\frac{1}{2}$lb. R.L.G.[4]	26° 50′ to 29°	One hit on No. 2 casemate turned and burrowed along top for 12′ 0″, bursting 1′ 0″ below surface of loam. Crater, 7ft. by 7ft. by 1ft. No damage.

Target.—No. 3 casemate.

No. of Rounds Fired.	Charge.	Elevation.	Results.
15*	$5\frac{1}{2}$lb. R.L.G.[4]	55° to 58° 7′	One hit on top of No. 1 casemate. Crater, 18ft. by 10ft. by 4ft. No damage. One hit on covering mass of target casemate. Crater, 15ft. by 15ft. by 5′ 3″. No effect.

* Includes five rounds of plugged shell for ascertaining range.

Projectile.—Cast steel common shell filled 27lb. 8oz. stemmed Lyddite.

Fuze.—Direct action with delay, for Lyddite.

Target.—Nos. 1 and 2 casemates.

No. of Rounds Fired.	Charge.	Elevation.	Results.
8	5½lb. R.L.G.[4]	57° 53′ to 58° 5′	One hit on portion (*a*) of No. 2 casemate. Breach in concrete 5ft. by 6ft. One hit on earth mass covering No. 3 casemate, not over casemate. Crater, 15ft. by 15ft. by 3ft. No effect.

Target.—No. 3 casemate.
Other conditions as above.

No. of Rounds Fired.	Charge.	Elevation.	Results.
4	5½lb. R.L.G.[4]	57° 40′ to 58°	Nil.

Before considering the measure of protection afforded by the several casemates, it appears desirable to analyse the practice.

The following table summarizes the shooting, the plan of the casemates only being counted as the target :—

Howitzer.	Rounds Fired.	Size of Target (square yards).	Hits Obtained.
7-in. B.L.	34	223 (Nos. 1 and 2 casemates).	1
8-in. B.L.	18	do.	1
do.	19	88·8 (No. 3 casemate).	Nil.

Counting the plan of the total earth mass, together with the excavation in rear, as the target, the above table must be altered as follows :—

Howitzer.	Rounds Fired.	Size of Target (square yards).	Hits Obtained.
7 in. B.L.	34	$584{\cdot}\dot{4}$ (Nos. 1 and 2 casemates).	4
8-in. B.L.	18	do.	1*
do	19	$444{\cdot}\dot{4}$ (No. 3 casemate).	3

Considering that the above was deliberate peace practice at a range of only 2,000 yards, the shooting appears to have been most indifferent.

The following table shows the results obtained by different fuzes :—

Shell.	Nature of Bursting Charge.	Fuze.	No. of Rounds	Results.
7-in. B.L.	Powder.	Direct action with delay, experimental.	20	Burst without delay ... ... 19 Blind 1
do	Stemmed Lyddite.	Direct action with delay nose fuze.	13	Detonated ... 1 Exploded ... 2 Blind ... ... 10 (Delay occurred in one case only).
8-in. B.L.	Powder.	Direct action with delay, experimental.	20	Burst without delay ... ... 14 Burst after ricochet ... 3 Blind 3
do ...	Stemmed Lyddite.	Direct action with delay nose fuze for Lyddite.	3	Blind 3
do	Stemmed Lyddite.	Direct action nose fuze (Elswick).	9	Detonated ... 7 Partially detonated ... 2 (No delay in any case).

* Two hits, obtained when the other target was being fired at, are not counted.

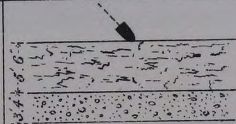
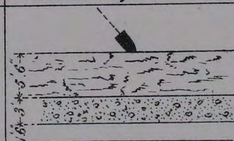
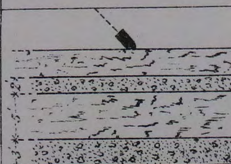
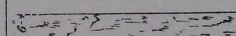
Thus of 40 powder-charged shells, 36 burst with delay and 4 were blind; but of 25 Lyddite shells, only 8 detonated (with delay in a single case), 4 exploded, and 13 were blind. Judged by these results, we appear to be barely within a measurable distance of being able to use Lyddite, and our powder shells are at present infinitely the most effective.

The results of the practice being, as usual, quite insufficient to provide the data sought to be obtained, it was necessary to lay shells in the desired position and fire them by electricity.

The following table gives the results obtained :—

No.	Shell.	Charge.	Casemate.	Position.	Results.
1	8-in. B.L.	27lb. 8oz. stemmed Lyddite.	No. 1.	On top of concrete; 5ft. of loam over shell.	Rails bulged down 1ft. 9in. over a length of 4ft. Loose concrete fell into casemate; side walls broken at top.
2	do.	do.	No. 2 (Portion *b*).	On top of concrete; 3ft. of loam over shell.	Roof broken through, and casemate blocked by débris; side walls less damaged than in case 1.
3	do.	do.	No. 3.	On top of concrete sandwich; 2ft. 6in. loam over shell.	Upper concrete layer breached 5ft. by 5ft., lower layer untouched. No effect in casemate.
4	do.	do.	No. 3.	Shell point down, and 3ft. above lower layer of concrete.	Lower concrete layer cracked. No effect in casemate.
5	7-in. B.L.	17lb. stemmed Lyddite.	No. 1.	On top of concrete; 5ft. of loam over casemate.	Effect of (1) somewhat increased. Rails bulged, and more débris fell into casemate.
6	do.	do.	No. 2.	On top of concrete; 3ft. of loam over shell.	Corrugated roofing bent down 2ft. and split. Interior of casemate filled with débris.

The experiments of three years (1887-8-9) against casemates can

Nº	Year	Shell	Burster	Range	Section of Casemate.	Result.
1	1887	8 in RML.	18½ lb. Powder.	2100		One hit on top Casemate uninjured
2	1888	8 in RML.	22 lb. 12 oz. Gun Cotton	2000	 Double layer of Rails 12 lb.	No satisfactory hit obtained
3	do.	do.	do.	do.		do.
4	do.	do.	do.	do.	 Single layer of Rails 12 lb.	do.
						Rails "slightly

now be brought together for comparison, and it may be convenient to give the various sections, shell actually fired being distinguished by showing a portion of their trajectories (see table).

It will be seen from the table that the greater part of our knowledge as to the relative strength of overhead cover of different kinds, is derived from experiments made with shells buried and fired electrically. The large amount of ammunition required to ensure obtaining the precise hit needed, and the possibility of vitiating the conditions by previous rounds, render this inevitable.

Although data thus obtained cannot be regarded as wholly satisfactory, there is much to be learnt from them. Howitzer or mortar shells are weak in proportion to the weight of bursting charge carried. The long, drawn $4\frac{1}{2}$ and 5-calibre shell, manufactured in France for mélinite, cannot possibly be expected to pass through any considerable thickness of earth, even if delay fuzes were perfectly reliable, which is by no means the case. Nor could they carry a bursting charge through a layer of two feet of concrete.

It may apparently be accepted that the sandwich casemate, No. 10 (see table), provides ample security against any projectiles of any siege train in the world. Four or five shells, falling exactly in the same spot, would probably breach it; but risks have to be run in war, and this risk is relatively insignificant.

Casemates 5 and 8 would probably withstand any single fired projectile. The trial, in case 8, in which a shell containing 27lb. 8oz. of Lyddite was detonated on the top of the thin (one foot six inches) layer of concrete, with a tamping of nearly five feet of earth, was extremely severe; but the roof was not breached. It is highly doubtful whether any *fired* shell carrying a larger charge could do more than fairly reach the concrete and burst upon it. The margin of safety is, however, insufficient, and the concrete roof is too thin.

The comparison afforded by casemates 12 and 13 is interesting, as showing the superiority of the rails to steel decking. No. 12 casemate, although shaken previously, stood better than No. 13. This proves that one foot six inches of concrete on a double layer of 56lb. rails is stronger than three feet of concrete on $\frac{5}{16}$-inch steel decking. The point is of importance, since it will usually be an advantage to keep down the total thickness of overhead cover as much as possible, and the employment of rails enables this to be done.

Again, case 11 should be compared with 8 and 5. The results show that the interposition of three feet of loam between the detonated shell and the concrete roof (in case 11) acted as an effective buffer. The difference of result must be attributed to this rather than to the extra six inches of concrete in case 11. If the interposition of a layer of earth between the bursting shell and the concrete can be ensured, a less thickness of the latter may evidently be employed.

Finally, cases 5 and 8, where the other conditions were nearly the same, afford a comparison between bursters of 22lb. 12oz. of powder and 27lb. 8oz. of Lyddite. The effect of the latter was certainly superior, but not more so than is accounted for by the increase of charge. Clearly, Lyddite possesses no miraculous power of destruction, or the casemate in case 8 must have been easily breached.

In estimating the significance of the data above tabulated, it is necessary to remember that the shell used do not approach in capacity those of which Foreign Powers have made trial. Thus at Kunersdorf and Malmaison, 5 and 6-calibre shell were fired from 21 and 22-cm. mortars, carrying bursting charges of 48·4lb. cotton powder and 72·6lb. mélinite. In Continental sieges, where railways are available to bring up *matériel*, a certain proportion of these exceptional projectiles may, perhaps, be employed; but the heavy cost, and the difficulties of transport and handling, will impose considerable limitations on their use. On the other hand, the armament of a Continental fortress may well contain a proportion of mortars equipped with these powerful shell, and the destruction of siege *matériel* which they are capable of effecting ought to be sufficiently serious.

So far as our own defences are concerned, the heavy siege trains of the Continent may be left out of consideration. For some years, at least, 360lb. projectiles will certainly not be fired into Quetta. No siege train will be landed in Great Britain until the British navy has been effaced, and with that effacement all conceivable necessity for transporting siege artillery across the Channel will have ended. We may safely, therefore, deduce a rational maximum of overhead protection from the data here given, and either of two forms will fully suffice for our requirements.

(*a*). Judging from case 8, ample protection would be given by—

Sand or loam	4 feet.
Concrete	3 feet.
56lb. rails	2 layers.

(*b*). Judging from case 10, the sandwich form would also give complete security, viz. :—

Sand or loam	3 feet.
Concrete	2 feet.
Sand or loam	3 feet.
Concrete	2 feet.
56lb. rails	2 layers.

If the rails are omitted, the concrete would require to be strengthened in either case, probably to four feet six inches in (*a*), and to three feet (lower layer only) in (*b*).

As against high-angle fire, it would probably be undesirable to give a quarter thickness of sand in earth on top. It is well to smother splinters, but not to increase the tamping which shells provided with good delay fuzes would obtain from a thick earth covering.

In the case of shelters, or cartridge stores in coast batteries, the conditions are somewhat different; the single concrete layer would probably be best, and an arch three feet thick under seven feet of sand or loam will amply suffice.

It is desirable to increase the thickness of sand in order to turn up heavy unburst projectiles from high velocity guns. Delay action fuzes will not help the ship against any properly designed works. The whole question of protection against the fire of modern vessels much needs discussion, which cannot be undertaken in the present paper.

In conclusion, it may be stated that our own experience does not appear to bear out the estimate of requirement which General Brialmont has put forward, or to show that three mètres of concrete are necessary anywhere. Nor does he adduce any evidence which supports his views. The much dreaded *obus torpilles*, fired at Bourges at an elevation of 60°, gave—he tells us—craters only twelve inches deep in concrete. He points out that to breach concrete 1·5-mètre thick, from six to eight shells would have to fall successively upon an area from one mètre to two mètres square; but he fails altogether to grasp what this implies under siege conditions.

(*b*). Trial of Shell Effect of 10-inch B.L. Howitzer for Comparison with 8-inch B.L.

Howitzer.—10-inch B.L.

Charge.—12lb. R.L.G.^{4}.

Projectile.—Cast steel common shell, 360lb.

Fuze.—Direct action percussion, with delay.

Target.—" Field magazine of latest type."

Range.—3,000 yards.

Twenty rounds were fired at elevations from 28° to 28° 25′, giving one hit. The shell fell about eight feet short of the top of the magazine timbering, and burst with a delay of about one second, doing no damage in the interior. Most of the shell were noisy in flight.

The shooting of the 10-inch and 8-inch howitzer is compared in the following table; the target, taken as the square formed by the crest-line of the covering mass, was about 34 feet by 34 feet in both cases.

Year.	Howitzer.	Range.	Rounds Fired.	Hits.	Percentage of Hits.
1889	10-in. B.L.	3,000	20	1	5
1888	8-in. B.L.	3,000	30	3	10

The accuracy of the 10-inch B.L. howitzer was, therefore, inferior to that of the 8-inch.

In the following table the shell effect of various howitzers is compared :—

No.	Year.	Howitzer.	Burster.	Fuze.	Elevation.	Soil.	Craters.		
							Ft.	Ft.	Ft.
1	1889	10in. B.L.	44lb. powder	Delay	28°	Loam	17	15	$4\frac{1}{4}$
2	,,	,,	,,	,,	28°	Clay	$16\frac{1}{2}$	$14\frac{1}{2}$	5
3	,,	8in. B.L.	25lb. 10oz. powder	,,	27° 45′	Earth & Shingle	16	15	$2\frac{1}{2}$
4	,,	,,	,,	,,	29°	Medium Shingle	15	$14\frac{1}{2}$	4
5	,,	,,	,,	,,	57° 53′	Clay	18	18	4
6	,,	,,	27lb. 8oz. stemmed Lyddite	,,	58° 5′	Shingle	13	13	$2\frac{1}{2}$
7	,,	,,	,,	,,	58°	,,	14	14	
8	,,	7in. B.L.	15lb. 3oz. powder	,,	54° 30′	Medium Shingle	15	15	3
9	,,	,,	,,	,,	55° 30′	Shingle and Loam	15	14	$2\frac{3}{4}$
10	,,	,,	,,	,,	54° 45′	Shingle and Turf	13	13	2
11	,,	,,	17lb stemmed Lyddite	,,	52°	(?)	18	18	3
12	1888	8in. B.L.	25lb. 1oz. powder	Directaction	6°	Loam	18	17	$5\frac{1}{2}$
13	,,	,,	,,	,,	6°	,,	22	21	6
14	,,	,,	,,	Delay	27° 20′	Shingle	18	18	3
15	,,	7in. B.L.	15lb. 13oz. powder	,,	28°	,,	17	15	3
16	,,	6in. B.L.	9lb. 14oz. powder	,,	27° 50′	Loam	12	12	3
17	,,	,,	,,	Direct action	2° 43′	,,	11	10	$3\frac{1}{2}$
18	,,	8in. R.M.L	22lb. 12oz. guncotton	Delay	22°	,,	17	14	2
19	,,	,,	,,	,,	21° 40′	Shingle	16	16	3
20	,,	,,	,,	,,	22° 15′	Loam	18	17	2
21	1887	,,	25lb. 14oz. powder	Directaction	7° 8′	,,	17	17	7
22	,,	,,	,,	,,	7° 10′	,,	16	15	$4\frac{1}{2}$
23	,,	,,	,,	,,	7° 8′	Shingle	16	16	2
24	,,	,,	,,	Delay	24° 45′	Loam	$16\frac{1}{2}$	$16\frac{1}{4}$	$5\frac{1}{4}$
25	,,	,,	,,	,,	22° 55′	Shingle (?)	13	14	3
26	,,	,,	,,	Directaction	8° 26′	Loam	14	$15\frac{1}{4}$	$4\frac{1}{2}$
27	,,	,,	,,	,,	16° 36′	,,	10	8	$8\frac{1}{2}$

To the above results may be added the following, obtained in 1887 with shells buried in slopes of earth or shingle at a depth of three feet.

No.	Shell.	Burster.	Slope.	Crater.		
				Ft.	Ft.	Ft.
28	8-in. R.M.L.	Guncotton.	1 in 3, earth.	15	13	3½
29	,,	,,	1 ,, 6, ,,	16	16	1½
30	,,	,,	1 ,, 4, shingle.	16½	13½	2
31	,,	,,	,,	14	14	3¼
32	,,	,,	,,	14	15	3

Assuming the measurements to have been correctly recorded, the results above collated appear at first sight to be hopelessly bewildering. The best result (13) falls to an 8-inch powder shell, fired at an elevation of only 6°. The 7-inch shell (15), with 15lb. 13oz. of powder, beats the 8-inch shell (18), with 22lb. 12oz., in shingle. Again, delay fuzes—so-called—do not appear to influence the results as much as would naturally be expected. The largest crater is due to a direct action fuze (13); while rounds (16) and (17), which serve for comparison of fuzes, differ but slightly in results. The 10-inch shell, with 44lb. of powder (1), is scarcely superior in effect under similar conditions to the 8-inch, with 25lb. 14oz. (24). The 8-inch Lyddite shell (6) is very decidedly less effective than the powder shell (4), notwithstanding that it has the advantage of a larger angle of descent.

These many anomalies admit of partial explanation. The delay fuzes in 1889 failed altogether (see p. 101). The rounds fired at low elevations (12, 13, 21, 22, 23, 26) should, perhaps, be rejected in estimating results. Three rounds were fired in the systematic breaching of parapets, and the shell, therefore, in some instances fell on the steep sides of previous craters, thereby securing more favourable conditions, while measurements upon a target already much deformed cannot be altogether trusted.

Excluding these rounds, the following points appear worth noticing:—

1. The greatest recorded depth of crater was eight feet six

inches, obtained by an 8-inch shell fired at 16° 36′. The next best result was given by a similar shell fired at 24° 45′, also into loam. Both shells were fired in 1887 with delay fuzes, which acted.

2. The average depth of crater obtained by eight rounds of 8-inch shells, at angles of 21° 40′ to 28°, was only three feet. At a similar elevation, a 7-inch shell (15) gave an equal result. No high-angle fire was attempted till 1889, and, probably, on account of the absolute failure of the delay fuzes, no better results were obtained from its employment.

3. High explosives give no better crater results than powder. This might have been expected.*

4. The average depth of crater given by the buried shells was less than the depth at which they were placed, owing to the falling back of the earth or shingle.

5. The effect of the 10-inch shell, (1) and (2), was not so much superior to that of the 8-inch, (3) and (4), as the considerable increase of bursting charge would seem calculated to produce.

The above deductions are neither sufficiently definite nor satisfactory. Until a delay fuze has been obtained, which is reliable alike with powder and high explosives, nothing can be laid down with certainty. It is highly doubtful whether Foreign Powers at present possess such a fuze.

On one point at least it is desirable that we should be able to make up our minds. In order to cut a trench through a parapet, howitzer fire at low angles of elevation appears to be the most effective *modus operandi.*† To search out the interior of works, and attempt to open up casemates, the high-angle fire of mortars is obviously essential; while a high heavy shell, dropped at a large angle of descent into the emplacement of a permanently worked gun, would probably disable it. Which is the best general policy? On the answer to this question the proper composition of a siege train evidently depends; but until we are in possession of efficient rifled mortars—such as all great Powers have adopted—and have learned how to use them, a definite decision must apparently be postponed.

* Colonel Bucknill, in a recent letter to the *R.E. Journal*, clearly shows why no other result was to be anticipated, and the agreement—in this case—of theory and practice is highly satisfactory.

† See *R.E. Occasional Papers*. Vol. XIV., 1888. Paper VI.

(c). PRACTICE INTENDED TO TEST THE "ACCURACY TO BE OBTAINED WITH HIGH-ANGLE FIRE AT LONG RANGES, UNDER SERVICE CONDITIONS AS REGARDS OBSERVATION."

Ordnance.—7-inch and 8-inch B.L. howitzers.

Projectile.—Cast steel common shell, plugged.

Target.—Wooden screen behind a covering mass (see *Plate* II., *Figs.* 2 and 3).

Range.—3,500 yards.

As it was naturally impossible to observe the fall of plugged shell, "service conditions" were abandoned, and the result of each round was telephoned to the battery, as in 1888. The target was arranged as in *Fig.* 2 for the 7-inch howitzer, and as in *Fig.* 3 for the 8-inch, the horizontal distance between the crest of the covering mass and the target being thus reduced from 43 feet to 23 feet.

The results are summarized in the table given below, and those of previous experiments are added for purposes of comparison.

Year.	Howitzer.	Range, Yards.	Angle of Descent.	Height of Accessible Target.*	Rounds Fired.	Total Hits.	Percentage of Hits.
1889	7-in. B.L.	3,500	11° 40′	5′ 6″	30	7	$23\dot{3}$
,,	8-in. B.L.	,,	10° 26′	3′ 6″	30	4†	$13\dot{3}$
1888	,,	2,400	20° 5′	5′ 0″	20	2	10
,,	,,	1,200	(?)	5′ 0″	20	3	15
1880	8-in. R.M.L.	2,500	12° 12′	9′ 0″	139	46	33
,,	,,	1,600	14° 18′	9′ 0″	112	39	35

These results appear eminently unsatisfactory. The conditions, at least as far as the 7-inch howitzer was concerned (*Fig.* 2), were not extraordinarily difficult. Better results could probably have been obtained using larger angles of descent, by which the height of accessible target would have been increased; but, on the other hand, a heavy correction must be applied for the absence of service conditions. It is clear that revetment walls cannot be effectively

* The "accessible target" means the portion which could be hit with the given angles of descent without grazing the crest.

† Includes two rounds which struck the crest first.

breached according to the methods of 1888 and 1889 without an expenditure of ammunition which would be absolutely prohibitive.

(*d*). Comparative Trials of Ripple Form of Parapet with Siege Battery of Ordinary Type.

Ordnance.—7-inch B.L. howitzer.

Projectile.—Case steel common shell. Direct action. Mark III. fuze.

Targets.—See sections (*Plate* III., *Figs.* 1 and 2).

Range.—3,000 yards.

Twenty rounds were fired at each target. The interior crest of the typical battery received one hit exactly in line, and the dummy gun was recorded as disabled. The ripple parapet received two crest hits, but, respectively, 10 feet and 22 feet to left of line. The parapet of the typical battery received altogether eight hits; the interior ripple three. The grouping in the former case was superior.

For any real purposes of comparison the trial failed entirely, since no attempt was made to screen the typical battery in any way, and the craters in the parapets were "clearly visible." As compared with a properly screened battery, the ripple form would not offer any advantage, or impede the observation of fire to any material extent. As against guns directed by observers who are not constrained to be in, or nearly in, the plane of site of the ripples, the labour of throwing them up would be obviously wasted. The ripple form has, in fact, no *a priori* claim to consideration except under exceptional conditions.

(*e*). Practice to Test the Vulnerability of Fortress Guns on "Blocked-up" Carriages to the Fire of Field Guns.

Ordnance.—12-pounder B.L. guns.

Projectiles.—Forged steel common shell; percussion fuze. Forged steel shrapnel; time and percussion fuze.

Target.—24-pounder S.B. gun, mounted on a blocked-up carriage, firing over a 6-foot parapet. Detachment represented by dummies.

Range.—2,950 yards.

In 14 rounds of common shell, no results of any kind were obtained; but 26 rounds of shrapnel gave the following:—

Bullet hits on dummies...	... 4 (Nos. 1, 4, and 6).
" " gun ...	... 21.
" " mounting	... 17.

The effect upon gun and mounting was *nil*.

A trial of this kind can afford no really useful information. In 26 rounds fired, at deliberate target practice, three numbers of the detachment, covered by a 6-foot parapet, but occupying fixed positions, may be regarded as killed. The numbers were naturally those standing farthest from the parapet, No. 1 being about 23 feet, and Nos. 4 and 6, 15 feet, from the covering mass. These numbers were, therefore, little protected. A fair hit by common shell would probably have dismounted the gun; but, as the experimental officer points out, the probable rectangle at 3,000 yards only allows three per cent. of hits on a target of these dimensions. Under service conditions, therefore, such a hit could only be obtained by the merest chance.

Three or four field guns, steadily firing shrapnel at a fortress gun thus mounted, might possibly be able to keep down its fire; but the gun itself would run little risk, while men sheltering close to the parapet would be safe and able to re-open fire as soon as a lull occurred. The above remarks apply equally to a fortress gun or a siege gun on a high carriage, and have no special reference to the "blocked-up" form of mounting.

Miscellaneous.

One or two other matters call for brief notice. The projectiles of the B.L. howitzers were generally steady when fired with full charges; but some of the 7-inch shells, fired with reduced charges at 60° elevation, were "noisy and unsteady at the end of the flight." Fired at 60°, the projectiles fell point first, except in the case of the 10-inch common shell filled with salt, which appear to have been very unstable.

The tendency of the shell to ricochet when fired at angles below 30° was very marked, as shown below:—

Shell.	Elevation.	Rounds Fired.	Ricochets.
10-inch B.L. ...	28° 25′ and under.	20	13
8-inch B.L. ...	28° 20′ and under.	6	4
8-inch B.L. ...	29° 0′ and under.	4	1

As pointed out by the experimental officer, ricochetting appears to occur when the side of the head strikes the ground previous to the point. With the 7-inch shell, a tangent to the surface of the head drawn through the point makes about 30° with the axis. At this angle of descent, corresponding to about 29° of elevation, the shells should, therefore, be held, and experience seems to show that this is approximately the critical angle.

To overcome the tendency to ricochet, which had been so pronounced in previous years, 7-inch shells, with flat heads and spiral projections, intended to bite the ground, were tried. Ten rounds were tried at elevations from 28° to 36° 20′, which all fell upon shingle, giving only one ricochet. As every round but one was fired at 30° elevation or over, and as at such elevations the tendency to ricochet has been found to diminish rapidly, this experiment was worthless. As might have been expected, the shooting was bad. The fantastic motion of screwing the shell into the earth may well be abandoned, and the proper remedy sought in well balanced projectiles, such as Foreign Powers appear to possess. It is fire at angles above 30° which is likely to produce the best results, when we have learnt how to use it; so that ricochetting, except with high velocity ordnance, will not give rise to much loss of effect.

Major Bogle's system of theodolite observation was tried, and "gave very promising results." Cross-bearings, taken from the ends of a base on to the smoke of an enemy's gun, enable its bearings to be plotted. The angular distance of the burst of shell, to the right or left of the lines of bearing thus laid down, is then observed by means of vertical lines in the field of the theodolites, and the fall of the shell can then be plotted. There seems to be no difficulty whatever in working this system under the conditions of Lydd target practice. As to whether it could be practically applied under siege conditions, where a large number of guns would be in simultaneous action, we know nothing. The value of fire carefully regulated and checked by observation is so great, and indiscriminate bombardment is so hopelessly ineffective and wasteful, that Major Bogle's system well deserves to be carefully tried as a service method. Until we are permitted to carry out siege manœuvres, however, it is impossible to gauge its possibilities with any accuracy.

The balloon equipment arrived too late, and, on account of unfavourable weather, no satisfactory results were obtained.

Willesden canvas was tried as a protection against blast, and—naturally—failed altogether.

General Remarks.

In 1853, it would probably have been thought ridiculous to suggest that a great siege might have to be shortly undertaken. Great Britain had been at peace for nearly 40 years. She might, perhaps, have to fight again—although the then state of her army organization would justify a belief that even this contingency was not contemplated—but a siege would have seemed an idle dream. A similar delusion possibly prevails to-day. No other explanation of our extreme apathy in regard to siege operations can be suggested. If, however, Great Britain is engaged in a European war, the one certainty appears to be that operations of the nature of a siege must be undertaken sooner or later, unless we are to rest content with supplying a small contingent to Germany, and limit our army to a twentieth share in a European campaign. Even this miserable *rôle* might not be open to us, for we might have to fight alone. In such a case, by no means improbable, there is only one course to follow. Utilizing to the full our naval supremacy and unrivalled powers of sea transport, we must strike out hard. It is our sole chance of really injuring most of our possible enemies, and the navy alone would be powerless in the sense referred to.

In the face of such contingencies, the present state of our siege *matériel* is deplorable. While we are limited to a few weeks of annual practice at Lydd, no real progress is possible. A siege school is essential, not merely to enable continuous experiments to be carried on without the enormous delays which now occur, but to fashion some sort of concensus of opinion as to what the requirement of a modern siege involve, and as to how siege operations are to be conducted. From want of any matured scientific opinion, the recent developments of siege ordnance—such as they are—have been in the wrong direction. As has been pointed out in previous years, high-angle fire has been practically neglected altogether. The new B.L. howitzers, with their relatively high velocities, have involved cumbrous mountings and great difficulties as to hold-fasts. It is accurate fire at really high angles with low velocities that we need.

Next year we shall probably be able to experiment with one or two mortars, and a beginning will then be made six or seven years after most of the great Powers have arrived at decisions. What is now most urgently needed is that clear ideas should be reached as to what modern sieges—more especially such sieges as we might be called upon to undertake—really involve. This is the only basis on which a siege train can rest, and the mere change to breech-loading, which was indicated in 1888, coupled with a straining after high velocities, only because field artillery had followed these lines, does not indicate progress.

Even if it could be granted that the existing howitzers were in other respects suitable, their shooting appears to compare unfavourably with that of the ordnance of other Powers. The accuracy of the 8-inch R.M.L. howitzer, formerly good within its limits, appears to have been grievously impaired by the introduction of the central-pivot platform. The experimental B.L. howitzers have by no means attained the accuracy which might be expected of them, in spite of heavy carriages, large charges, and high velocities. Assuming, for example, that the diagrams published by the Grüson firm are correct, a comparison between the shooting of the 15-cm. Q.F. howitzer* with that at present obtained from our B.L. howitzers appears to tell heavily against the latter.

Very much remains to be done before our siege *matériel* can be regarded as in the least satisfactory. Much serious discussion and careful thought are needed before we shall be in a position to undertake effective siege operations. It is only by arousing interest in the subject, and securing the co-operation of many minds, that the necessary task can be accomplished.

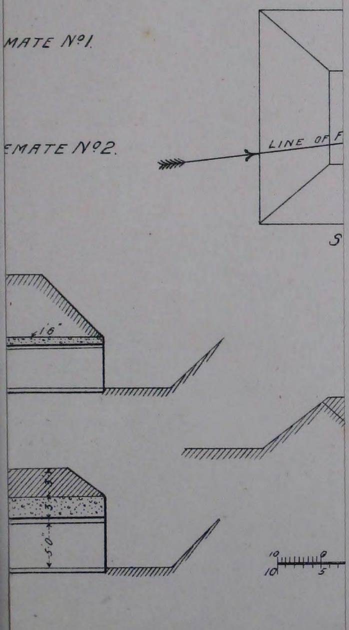
G. S. C.

London, July, 1890.

* Firing 10 rounds in 50 seconds.

)D EXPERIMENTS OF 18

TARCET CASEMATES.



PAPER IV.

ON THE METHOD EMPLOYED IN KEEPING THE NUDDEA RIVERS OPEN TO NAVIGATION DURING THE SEASON OF LOW WATER.

By Major R. H. Brown, R.E.

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1. *Short Description of the Nuddea Rivers.*—The rivers, known in the Irrigation Branch of the Public Works Department in Bengal as the "Nuddea Rivers," are the Rivers Bhagirathi, Bhyrub-Jellinghee, and Matabhanga. They form, as it were, cross roads from the Ganges, at the upper end of the Gangetic delta, to the River Hooghly, and thereby afford short cuts to Calcutta for boats coming down the Ganges from up-country.

The Bhagirathi takes off from the Ganges at the apex of the delta (of which it forms the western side); the Bhyrub-Jellinghee takes off about 45 miles below the Bhagirathi; and the Matabhanga about 40 miles below the Bhyrub-Jellinghee; all three rivers uniting lower down to form the River Hooghly.

The distances from the Ganges to Calcutta by the different rivers are as follow:—

By the Bhagirathi River	246 miles.
,, Bhyrub-Jellinghee River	230 ,,
,, Matabhanga River	191 ,,

The beds of these rivers are composed, as a rule, of loose sand, though in places firm sand, and in others soft or hard clay are met with, and where met with (in the absence of any dredger) give trouble.

2. *History of the Rivers.*—The earliest record of the working of any one of these rivers is given in a report by Mr. Wickes, and is to the effect that the Bhagirathi was dry at its entrance, at Sooty, in January, 1666, Sherwill being his authority.

From a report, dated July 14, 1848, by Captain John Lang, 36th Regiment, Bengal Native Infantry, the following information, as regards the early working of these rivers, is gathered.

In 1781 Major Rennel remarks of these rivers that they were usually unnavigable during the dry season.

Other and later records show that sometimes one river and sometimes another continued open during the dry season.

The Matabhanga is said to have been open every year from 1809 to 1818, and in 1813 ineffectual measures for improving its channel were carried out under the collector of Nuddea, and a toll established.

In consequence of a petition made by the merchants of Calcutta in 1818, Government appointed a superintendent and collector of the Matabhanga, who commenced his duties in February, 1820. In this year was commenced the system now carried on, which consisted in removing from the bed of the channel obstructions caused by sunken boats, timber, and wood-rafts; in constructing "bandels" (hereafter described) to narrow, and thereby deepen, the channel; and also in preventing, by their timely removal, trees and buildings from falling into the river.

Work on these rivers was suspended by Government in 1835, but resumed in 1837, and has ever since been continued.

The history of the rivers shows that their present general condition is much the same as it was 100 years ago; the entrances have constantly shifted, and are still liable to shift; the course of certain portions of the rivers have changed, but, generally speaking, to a small extent only, the change being either an enlargement of formerly existing bends, or, in a few cases, short cuts formed across the chord of a bend, when continued erosion had brought the upper and lower ends of the loop close to one another, a high flood then clearing out a new cross-channel by the shortest route.

The traffic on these rivers (with the exception, during the flood season, of a few steamers and flats) consists almost entirely of boats of native build, carrying loads varying from 3,000 to a few maunds.

3. *Flood Season.*—The rivers begin to rise about the middle of June; attain their maximum towards the end of July or beginning of August; remain high to the end of September; and fall steadily from the beginning of October.

In ordinary years the total rise is 24 to 25 feet; in high flood years 29 to 30 feet.

4. *Work during and before Floods.*—During the floods the rivers require but little attention beyond taking the precaution of prevent-

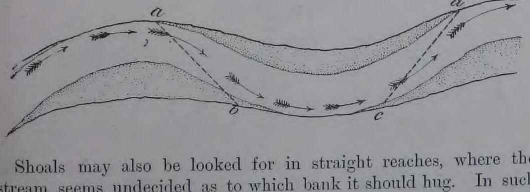
ing trees, by timely removal, from falling into the river in consequence of the banks eroding. But when the rivers are at their lowest, before the floods commence, all wrecks, snags, and other obstructions must be removed from the river beds, or so levelled off, by explosions of dynamite or otherwise, that they shall not remain as obstructions, on which boats may get wrecked, when the following floods are subsiding.

5. *Work on subsidence of Floods.*—Before or after the middle of October (according as the flood subsides early or late) soundings should be taken throughout the rivers, more particularly at the points where shoals may be expected, in order that the formation of loop-channels may be detected early and be closed in good time to obtain the full effect which should result from confining the discharge to one channel.

These soundings will, as a rule, enable the channel which is the best one to adopt to be selected, although it often happens that the channel first selected has to be abandoned for another, which latter, in consequence of changes that take place as the floods subside still further, subsequently proves to be the more favourable channel.

As soon as possible then, after it has become clear which channel should be adopted, the loop-channels should be closed, or made to close themselves, by means of spur-work and "bandel"-work, described further on. There are seldom more than two loops of any consequence to be dealt with, and more generally there is only one, the river dividing itself into two channels, one under either bank, with an island of sand, which appears as the floods subside, separating them.

6. *Shoals.*—Shoals will probably be found wherever the current crosses from one bank to the other (as at *a b* and *c d*), a probability well known to all who are accustomed to crossing rivers on foot. This is the most frequent kind of shoal.

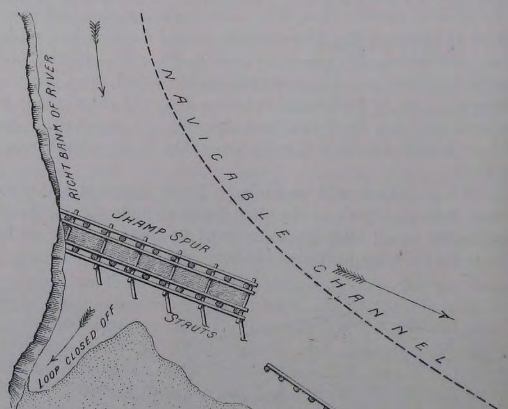


Shoals may also be looked for in straight reaches, where the stream seems undecided as to which bank it should hug. In such cases the river may spread itself out into a broad, shallow channel, or break up into two or more channels. In the latter case one channel must be selected, and the others shut off; in the former the channel must be contracted by "bandel"-work to produce an increased velocity and consequent scouring of the bed.

Whether at a point where the current crosses from one bank to the other, or in a straight reach, where the water either spreads itself out into a wide, shallow stream, or divides itself into two or more distinct channels, the mode of treatment is that, in the one case, all channels but the most favourable are shut off, and the whole discharge confined to one channel; and in the other the wide channel is contracted.

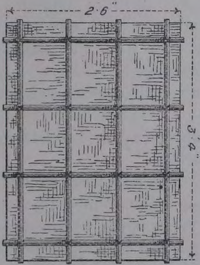
7. *Description of the different kinds of Works.*—There are three different descriptions of work employed in preserving a deep channel, viz., jungle spurs, jhamp spurs, and bandels.

"Jungle spurs" consist of a double row of stout bamboos, 10 to 20 feet deep, and from one to two feet apart, according to the depth of the water, fixed upright in the bed of the river and kept in place



by bamboos lashed to them horizontally, and by cross-pieces from one row to the other. Between the rows of upright bamboos bundles of long thatching grass ("jungle") are packed and trodden down to form an almost solid wall. Struts are added in rear about four feet apart. The spurs are inclined, generally, at an angle of about 45° to the direction of the current, but this angle will vary much to meet the different conditions of force of current, depth of water, directions of channels up-stream and down-stream of spur, etc., in each case.

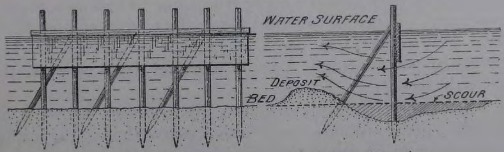
A "jhamp" is a mat, three feet four inches by two feet six inches, made of flat reeds or bamboo slices, and strengthened by thin bamboo strips on both sides of the mat, tied together so as to clasp the mat and give it strength by the provision of an outside skeleton.



A "jhamp spur" is formed of a row of upright bamboos, 10 to 20 feet long and about two feet apart, with struts four feet apart, and horizontal ties (also of bamboos).

To this framework "jhamps" are fastened by their upper edges, which are fixed at the level of the water surface and lowered from time to time, as the water falls.

JHAMP SPUR.



Front Elevation. *Side Elevation.*

The upright bamboos are fixed in the bed by "jumping" them up and down, and moving them backwards and forwards, whereby they work their way down into the sand. They are then driven further in by mallets, sometimes worked from a platform raised on a native boat, but more usually from the ordinary deck of the boat itself.

A "bandel" is the same as a "jhamp spur," except that it is generally of shorter length, and placed at a smaller angle to the current.

These three kinds of work, viz., "jungle spurs," "jhamp spurs," and "bandels," are, for purposes of accounts and reports, further classified as follows :—

(*a*). First class jungle spurs: those constructed entirely of new materials.

(*b*). Second class jungle spurs: those constructed of old bamboos (collected and kept in stock from the previous year's operations), and of new jungle and string.

(*c*). First class jhamp spurs, or bandels, made entirely of new materials.

(*d*). Second class jhamp spurs, or bandels, made of old bamboos, and new jhamps and string.

(*e*). Third class jhamp spurs, or bandels, which are merely first or second class jhamp spurs shifted into a new position during the season's operations, as, for example, when existing bandels are moved inwards to further narrow the channel already formed by them.

(*f*). Sometimes a separate head in the accounts is made for "entrance spurs and bandels," where, in consequence of the depth of water and exposure to waves, the construction and maintenance of them is unusually costly.

A "jungle spur" is used where it is required to *force* the water to take a new direction, or where the current is too sluggish for a jhamp spur to act, and it is desired to collect the water quickly.

It is no good attempting to set up a jungle spur in water of too great a depth. It is found that the grass cannot be forced down between the rows of bamboos below a depth of 10 feet on account of its buoyancy. Hence, as the sand along the foot of a spur will be scoured out to an extra depth of perhaps two feet, it is seldom advisable to put up jungle spurs in a greater depth of water than about eight feet.

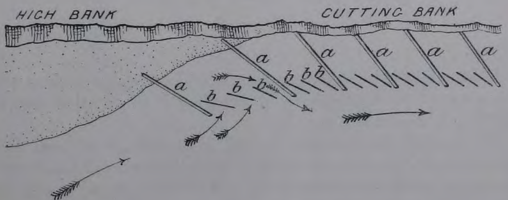
A "jhamp spur" is used to induce silt to collect behind it, and either close the mouth of a loop, cause a contraction of the working channel, or protect a sandbank behind it from cutting.

The objections to "jungle spurs" are that they are expensive to construct, and, since they get buried in sand, will in a succeeding season give trouble, should they be found lying across the navigable channel selected for that season; and this is only too likely to happen, for the grass, when buried in sand, is prevented from decaying, and will remain for years; and, further, the channel of one year rarely coincides with that of the previous year. The grass bundles in such cases resist the scouring action of the current, and are difficult to extract from the bed; it is, in such case, found necessary to abandon the channel and form another clear of the buried jungle spur.

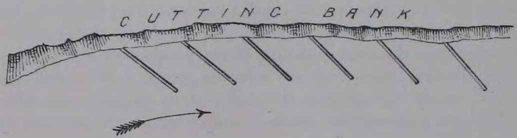
"Jhamp spurs," on the other hand, are cheap, and as soon as they have caused a bank of sand to deposit behind them, which the falling water leaves dry, they can in many cases be removed, and the material made use of again.

8. *Principles for guidance in Laying Out the Work.*—Having now described the different kinds of work made use of to maintain a navigable channel, the following remarks on the general principles on which the works should be laid out may be useful to anyone new to the work.

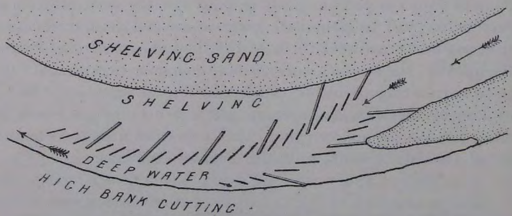
Erosion of Banks: How Prevented.—It is of great importance to stop all cutting of banks as early as possible, otherwise the material from the eroded banks will be deposited lower down and form fresh shoals, and necessitate more work to move the deposit out of the channel. Consequently, the season's work usually commences with putting a stop to any cutting of banks which may be taking place. This is best done by throwing out a jhamp spur above the point where the cutting commences, and carrying bandels down at a short distance in front of the cutting bank, as in the diagram below:—



This is a more effective method than attempting, as is often done, to stop the cutting by short lengths of bandels set up immediately under the cutting bank, as below :—



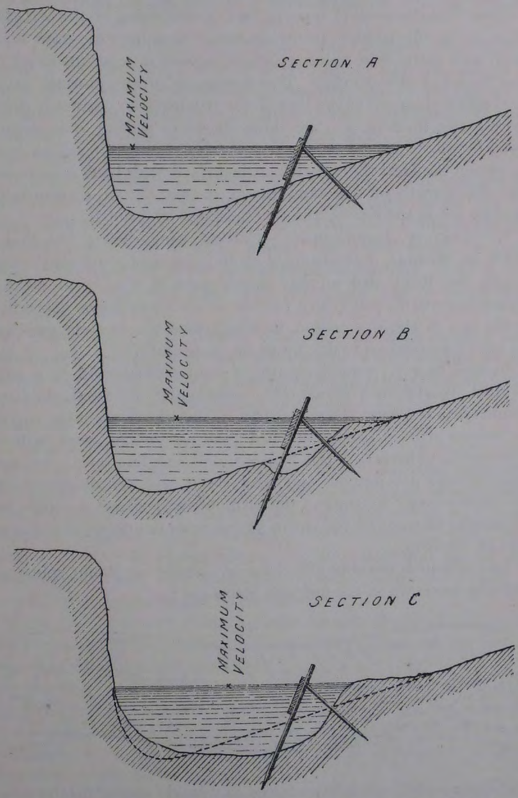
This latter method should never be adopted. When, in consequence of deep water immediately under the bank, the former method is not feasible, it is generally possible, by throwing out a spur at some distance higher up, to divert the set of the current from the face of the cutting bank; but should this last method be either not possible or ineffective, the *opposite* side of the channel should be lined by bandels, as in the sketch accompanying :—



At first sight it is difficult to understand how such a method acts ; but from actual observation and sounding it is surmised that the following is the explanation.

The cause of the high bank cutting is the deposit of sand which takes place on the slack side of the channel, causing the sand island opposite to grow, and so force the water before it on to the high bank. If this deposit can be stopped, so also will be the cutting of the bank opposite.

The cross sections A, B, and C, through a bandel, show the different shapes the channel takes.



Section A shows the channel where the bandels are first set up along the edge of the island or the shallow water facing the cutting bank, before any resulting action has taken place ; section B shows the channel after the bandels have been up five or six days ; and section C when the bandels have completed their work.

From these sections it appears that a deepening of the bed takes place under the bandels from the water escaping side-ways under them with increase of velocity, which it does in consequence of the contraction of the channel. This deepening of the channel having thus taken place along the line of the bandels, the current is drawn more along their faces ; the ridge shown in section B is scoured away by the continued action, and the bed brought level, as shown in section C. Thus the velocity against the cutting bank is decreased, and the growth of the sand island stopped by a corresponding increase along the side of the channel lined by bandels.

9. *Closing of Loop-Channels.*—Cutting banks being protected as much as possible, loop-channels should be made to close, except where the main channel has depth enough already to make it unnecessary to deepen it any further to secure sufficient depth in it at the end of the dry season, in which case the loop-channels may be left to themselves to dry up as the water falls.

In most cases a prompt closure of loop-channels will save much channel bandel-work afterwards, because the increased discharge thrown into the main channel (early in the season when the current is strong) will so deepen its bed that no further work will be necessary ; whereas, if the loop-channels are left open, the main channel will not deepen, and later on it will, in all probability, become necessary to contract the channel by, perhaps, a double row of bandels throughout the entire length from the upper to the lower end of the loop.

Loop-channels are shut off either by jungle or jhamp spurs, and bandels, as shown in the diagram below :—

"Jhamp spurs" are to be preferred to "jungle spurs," for the reason stated before, wherever the object desired can be obtained by their use. "Jungle" spurs are, however, often necessary, in such cases, where it is important to collect and force the water at once into the selected channel ; or where, on account of the great width of the river above the spur, the current is too sluggish for "jhamp" spurs to work.

10. *Importance of Early Attention to Cutting Banks.*—The importance of at once putting a stop to all cutting of banks as soon as a sign of it appears, and the advantage to be derived from the early closing of all loop-channels, is hardly ever fully appreciated by new hands, and sometimes not even by those of some years' experience in this kind of river working.

Detection of Cutting of Banks and Loop-Channels.—The commencement of the cutting of a bank requires no experienced eye to detect, and, if soundings are properly taken, loop-channels should be traced before the dividing islands rise above water, or even betray their existence by the difference in appearance between the surface of the shallower water over them, and that of the deeper channels on either side.

11. *Contraction of Wide Shallow Channels.*—The bank cuttings and loop-channels having been first attended to, wide channels which have an insufficient depth of water must be made to scour out their beds by contracting the channel, by means of a row of bandels on one or both sides, as the nature of the case may require.

A certain amount of judgment is required in order to know when it is necessary to narrow the channel. Much depends upon the velocity, nature of the bed, and the cross section of the channel. If the bed is hard sand or soft clay (hard clay will not scour) a high velocity is required, and a contraction of the channel, where the depth is short, will almost always be necessary, and should be effected when there is a plentiful discharge in the river and a powerful scouring action can be produced.

If the bed is of soft sand, the cross section of the channel will determine whether the current will sufficiently deepen its bed as the river falls, without assistance or not.

In the diagrams herewith, three cross sections of different descriptions are given. Channels whose cross sections take the form of *Figs.* 1 and 2 will probably deepen themselves, while those whose cross section is represented by *Fig.* 3 are not at all likely to deepen themselves to any useful extent.

The reason of this is sufficiently obvious, for a fall in level will decrease the cross section of the water in channels of cross sections (*Figs.* 1 and 2) in a greater ratio to the volume discharged than would be the case in channels of cross section (*Fig.* 3). Consequently, in the former case the velocity would be much increased, and a scour of the bed induced, while in the latter the velocity would not be so affected, and a scour would be wanting.

Fig. 1.

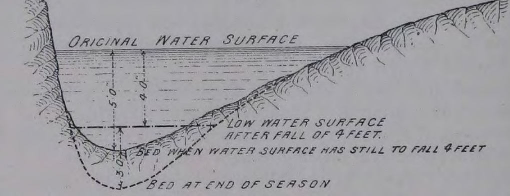


Fig. 2.

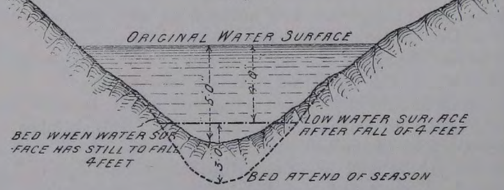
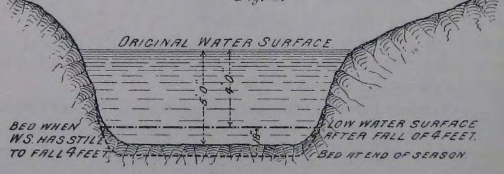


Fig. 3.



The diagrams are drawn to represent the state of the river where it is five feet deep and when it has four feet more to fall to reach its lowest level, the dotted lines representing the form of the channel after the lowest level has been reached, showing, in *Figs.* 1 and 2, that in spite of a fall of four feet a 3-foot depth is still maintained, whereas, in *Fig.* 3, a depth of one foot six inches only is found at the end of the dry season.

The mistake too often made in narrowing a channel (where necessary to do so) is to commence at the upper end of the shallow too low down the river, and, again, to stop the bandels too high up at the lower end of the shallow. The narrowed channel should commence and end in deep water.

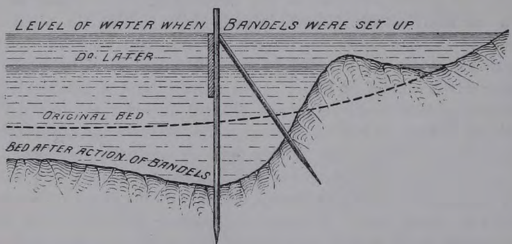
Three feet is the minimum, below which the depth in any shoal should not be allowed to fall, even at the end of the dry season, though it seldom happens that after December a less depth than three feet cannot be found in one or more shoals, and later in the year at many shoals. Hence, taking three feet as the minimum depth to be allowed, the number of feet that the river has to fall to reach low water level, added to three feet, will give the depth of water which should be found at the narrow head of the bandelled channel, and the lower end of this channel should reach to water of a depth rather greater, as in consequence of the scour sand will be carried along between the bandels, and a considerable proportion of it get deposited over the river bed just beyond the termination of the bandels. If the work is stopped short of deep water, the sand, which is being moved forward, is deposited in a curved bar just beyond the bandels, in consequence of the water spreading itself out sideways and losing some of its velocity.

If the bandels reach deep water, the same deposit takes place, but it does not make itself obtrusive.

Again, if the upper end of the bandel-work is commenced too low down, so that the water at this upper end becomes shallow as the river falls from want of scour, in consequence of the high part of the bed being across the wide part of the funnel-shaped mouth of the channel, spurs and bandels will then have to be made *above* the work first set up, and the sand of this shallow portion will have to be passed along the whole length of the bandelled channel below it, since by this time the sand will not be able to escape sideways under the bandels first made, as the space behind them will have already been silted up.

12. *Description of the Action of the different kinds of work.*—To make the foregoing more intelligible, it is necessary to describe the action which is caused by jhamp spurs, bandels, and jungle spurs respectively.

Jhamp spurs and bandels only *check* the flow of water, but do not stop it, and they are placed at such angles as to guide an increased quantity of water into the desired channel, and to increase the volume and velocity in it. This causes the sand to be raised and carried by the water either forward along the channel, or outwards under the jhamps of the bandels. That which is carried outwards gets deposited in ridges parallel to the bandels, in consequence of the water thus escaping losing its velocity as soon at it leaves the contracted channel. These ridges form in lines more or less distant from the bandels, according as the current is more or less rapid. The diagram shows a section through the jhamp bandel to illustrate this action.



Thus a channel, confined between bandels, is formed with sand-banks on each side of it, between which the whole discharge is collected.

So in the case of closing the head of a loop by jhamp spurs and bandels, the set and strength of the current is directed into the selected channel, and some of the water carrying sand, scoured from the bed above or from the foot of the spurs and bandels, escapes under the jhamps into the loop-channel, and spreading itself out, loses its velocity and deposits its sand, thereby causing ridges of sand to be formed, which eventually close the upper mouth of the loop, and so send the whole discharge into the channel to be improved and maintained for traffic.

13. *Selection of Line for Navigation.*—As regards the line to adopt for the channel, it may be laid down, as a rule, that the best line is the line of shortest distance from deep water to deep water, excepting only in such cases in which the shortest line would cross a bed

of clay or hard soil, which could be avoided by adopting another line of greater length.

14. *Further Reduction of Channel.*—Having then stopped all cuttings of banks, closed loop-channels, and narrowed broad, shallow ones, should the depth of water again become too little in consequence of the lessened discharge due to the fall of the river, the channel must be still further reduced in width by moving forward the lines of bandels on each or either side of the channels, as may be found advisable; or when there is only one line of bandels, by bringing this line forward towards the bank which forms the other side, until a sufficient velocity is obtained to scour out the bed to the required depth.

The width of channel formed at the beginning of the season is generally about 100 feet, being reduced at the end of the season sometimes to as little as 40 feet, and, for short distances only, to 30 feet, as two boats cannot pass each other in a channel of less width than 35 to 40 feet; but the width depends altogether on the discharge passing down the river, and its velocity.

At the commencement of the working season, when the discharge and velocity are great, the channel should not be contracted to too great a degree, or else, instead of one channel being formed between the bandels only, others may be found behind either row of bandels, which would defeat the object of the bandels.

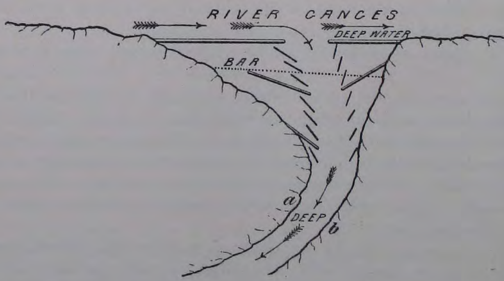
The width of the channel between the bandels should be of the same width from the head to the tail, and not tapering to the tail, as many seem to think is correct.

15. *Alignment of Channel.*—Where a good current exists, or if the shoal is a short one, a straighter channel is best. But if the shoal is a long one, and the current slack, a change of direction in the channel may be useful, when it is found that coarse sand, which will not lift, covers the bed of the channel. This coarse sand is rolled forwards along the bed, instead of being passed over sideways under the bandels, but when it reaches the bend it continues its motion forward in a straight line, and passing under the bandels in front of its direction is got rid of.

16. *Dredging.*—Should the depth of water in the channel, when reduced to the smallest width admissible, still continue short, and if it is intended to keep the river open to traffic, recourse must be had to dredging, or, in the absence of a dredger, to excavating the bed by hand labour. Coolies will work with kodalies in two feet six inches to three feet of water, but unless the shoal is a short one, this

method of obtaining a greater depth is a very expensive one, and only to be resorted to when the current cannot be made to scour out its own channel. Where a clay bed is met with, or where the bed of the channel is coated with a surface of firm sand, on which the increased velocity caused by the bandel work has no effect, this method of deepening the channel must, in the absence of any dredger, be resorted to. The effect of bandel work upon a hard clay bed is almost *nil*, hence in selecting the channel at the commencement of the season, those with sandy bottoms should always be preferred to those in which clay is likely to be met with, unless the latter have such a depth that no deepening of the bed will be necessary throughout the season. A thorough knowledge of the river worked will enable the officer in charge to avoid channels which are likely to give trouble on this account. Clay bottoms, if they have not a layer of sand over them, are easily detected by means of the sounding bamboo, which being pressed hard against the bed will, if there is clay, bring up small portions of it.

17. *River Mouths.*—The above relates to work on shoals at such a distance from the river mouth that the contraction of the channel through the shoals will not cause any diminution of the volume of water entering the river from the Ganges. The entrance to the river and the shoals next below it, if within a short distance of it, must be treated differently.



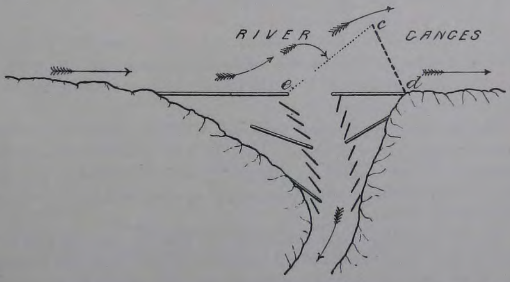
The form and nature of entrances may vary so much that it may be impossible to lay down rules for their treatment, but it should be always borne in mind that, except for some good reason, no work should be carried out which will reduce the discharge entering the river *when the water level is low.*

Where the mouth of the river is funnel-shaped it is well to contract the broad portion, otherwise a shallow bar will be formed across it, which will gradually lessen the discharge entering the river, and interfere with traffic at the latter end of the season.

In the above diagram the method of treating a funnel-shaped entrance is shown. If the bar across the mouth did not exist, the discharge entering the river would still be regulated by the cross section of the river at *a b*, and by the inclination of the bed and width of channel below it. Hence, narrowing the wide mouth up to a certain limit would not decrease the discharge, and would have the effect of preventing any bar being formed.

As, however, a bar, more or less shallow, does exist, as a rule, across the entrance, it is better to narrow it *as early as possible* when an abundant supply is entering the river, and a small diminution of it is not noticeable. In consequence of the diminished volume entering the river, the fall between the Ganges and the river below the entrance is increased, and there is induced a velocity high enough to scour out the bed (if of sand) to such a depth that an adequate supply of water and sufficient depth for the traffic during the dry season is assured.

18. *Bhyrub-Jellinghee Entrance.*—The Bhyrub-Jellinghee entrance, in 1882–83, and 1883–84, was of this nature, and was so treated with



success. In the case of this entrance, it was suggested, in 1882–83, to throw out a spur C D in order to catch the water flowing down the Ganges, and force more into the river.

But this would have been a mistake. The effect of such a spur would have been to have driven the deep channel of the Ganges further away from the mouth of the river, as shown by the thin arrows, and to have created a tendency for a bar to form along the dotted line C E.

19. *Bhagirathi River Entrance.*—The entrance to the Bhagirathi River had, in 1883, a hard clay bank across it, which, as the water fell, appeared above it. Through this bank two cuts were made by hand during two successive dry seasons, which cuts admitted the dry weather supply in 1884. As, however, the cuts were not carried down to any sand stratum below, the floods failed to scour the channels out any deeper, and it became necessary, when the water was low, to put coolies on with kodalies to excavate the clay below water, in order to keep up a discharge into the river, and to obtain sufficient depth for boats drawing three feet.

A dredger would, of course, have got over this difficulty, but there was, in 1884, no suitable dredger available, though the want of one had been so frequently felt. Dredgers of design unsuited to the conditions of working on these rivers had been supplied, but were comparative failures on account of their unfitness for the work.

If possible, it is best to confine the supply entering from the Ganges to one single channel, otherwise both channels remain shallow with their beds high, and hence become liable to close early, as the Ganges falls. Where two entrance channels exist, a bad shoal is generally to be found somewhere near their junction, even if the river does not close early.

20. *Preparation for Rise of Rivers.*—As the rivers rise about the middle of June, all the bandel-work, and as much of the spurs as possible, must be removed from the bed of the rivers during the latter end of May or beginning of June.

The bamboos are the only materials which are fit to use a second season, and as many of these as are in a fit condition for another season's work are stacked at different points along the river banks clear of the floods, and the rest, which are past work, are collected and sold by auction.

By the time the floods commence to rise, the bed of the river should have been cleared of all obstructions, and trees and masonry buildings removed for 50 feet (or more if necessary) from the edge of all cutting banks.

21. *Cost of Work.*—The following is the average cost of the different classes of work described in the foregoing :—

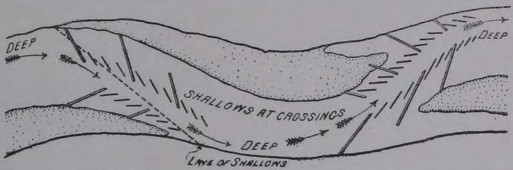
First class spur	Rs.	20	0	0	per	100	running	feet.
Second class spur ...	,,	12	5	0	,,	,,	,,	,,
First class bandels ...	,,	9	6	0	,,	,,	,,	,,
Second class bandels	,,	6	0	0	,,	,,	,,	,,
Third class bandels...	,,	2	0	0	,,	,,	,,	,,

(See para. 7 for description of these different classes of work).

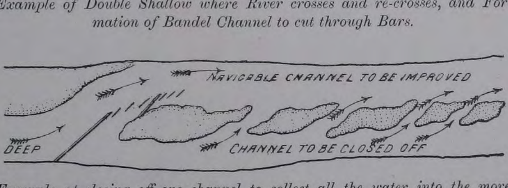
Entrance bandels vary from Rs. 16 5 0 to Rs. 39 0 0 per 100 running feet.

These rates include construction and maintenance for the season.

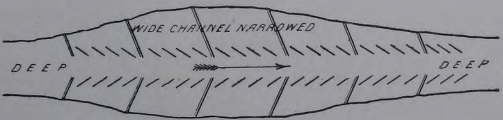
22. *Diagrams of Typical Shoals.*—The diagrams below illustrate the method adopted in dealing with different typical shoals.



Example of Double Shallow where River crosses and re-crosses, and Formation of Bandel Channel to cut through Bars.



Example of closing off one channel to collect all the water into the more favourable one under the left bank.



Example of method of narrowing a broad and shallow length of river.

The photograph of a bandel channel, formed where the River Bhagirathi crosses from the right to left bank at Berhampore, will give an idea of this kind of work (see *Plate*).

PAPER V.

FIELD ARTILLERY.

BY THE LATE MAJOR-GENERAL C. B. BRACKENBURY, R.A.

IN any other country than this, it would be considered absurd to begin a lecture on field artillery by showing that it is an arm of first-class value in war. England was one of the earliest to use artillery in the open field—at the battle of Crecy—but, for reasons which I have neither time nor inclination to give, there is now a large party among us that refuses to accept the conclusions reached by every military power that has lately gained experience in European fighting. Shakspeare says that home-keeping youths have ever homely wits, and if our military wits are only to exercise themselves on what British troops have done of late years against Ashantis in the thick bush; or Zulus, when there was hardly any artillery present; or Arabs, under the same conditions, we might run the risk of having very homely understandings, not to say becoming a trifle thick-headed on this important subject of the use of field artillery. Yet, but for the desire of avoiding anything that might give pain, I could tell you of instances both in the Soudan and Afghanistan—yes, and even in the Zulu War—when the field artillery, which some people think little better than an encumbrance, was the rock upon which shaken infantry rallied, or the active agent in preventing a defeat.

I will, however, presently quote some instances from modern war, to show what field artillery can really do in battle. But first a few words as to experimental firing, which, mind you, always tells against artillery in cases of comparison, because fatigue, rapid movement, and the excitement of combat, have a more detrimental effect on infantry than artillery fire. At short artillery ranges, with care, there is no necessity for very accurate laying, and at long ones the distance of the enemy has a tendency to prevent anything like agitation. The gunner is not always marching and running about like the infantry soldier, and, if he were, his beating heart and panting breath would have no effect on the steadiness of his weapon.

On the other hand, every quickened breath or anxious heart-beat affects prodigiously the aim of the infantry rifle. I, myself, have seen troops, when within a hundred yards of each other, missing almost every shot, simply because, being always on the look-out for a rush, they did not raise their rifles properly to their shoulders, or take aim at all. If two bodies of infantry, in almost any formation, were to shoot at each other at ranges from 600 yards downwards with anything approaching the accuracy of the practice ground, mutual annihilation would result; but we know very well that nothing of that sort ever has occurred in war, and we can guess pretty well that it never will occur.

I suppose that the Engineer officers here present know their Brialmont well, as he is certainly one of the most famous military engineers in Europe. I may, however, remind them of the experiments at Bourges, which he quotes in his *Formations de Combat.* The experiments were as fair as they could be made; whatever slight handicapping occurred was against the guns; infantry and artillery fired at the same or similar targets under the same conditions. The deductions of the Committee were as follows:—

Starting at 800 metres, and up to extreme ranges, the killing effect of artillery is always superior to that of infantry, rising from double at 800 metres to sevenfold at 1,800 metres.

It is most important for artillery to use projectiles giving a large number of pieces.

It is very advantageous on the field of battle for the artillery to communicate to the infantry the ranges which it obtains, if the infantry has to fire at the same object.

Infantry cannot, without great risk, attack artillery in open ground.

Artillery, with its flanks protected and a clear view in front of it, can protect itself against the attacks of infantry advancing from afar.

And now for a very curious deduction.

At 1,000 or 1,200 metres the man-killing effect of the four divisional batteries is about equal to that of the infantry division, whether estimated by the number of rifles which the division can, at a given moment, put in line, or the amount of ammunition carried by the infantry and artillery respectively. Of course, this supposes the infantry to be in a normal formation, not all in one line.

You will say at once that these experiments only show the comparative effect at ranges beginning at 800 metres, and I am quite ready to admit that, on the practice ground, the effect of infantry fire ought to increase more rapidly in its accuracy than that of artillery as the range decreased. But my own observations on various Continental fields of battle make me doubt whether shortening of range increases the accuracy of infantry fire quite so much as some people imagine. Military historians give pictures of battles which are very much unlike anything that I ever saw, and I commend to your attention a little pamphlet written by Captain Norman Bray, in which he has tried to work out what infantry fighting is really like, taking his facts from regimental accounts written after the Franco-German War, not from the admirable but rather courtly pages of the General Staff. I assure you the result of Captain Bray's labours will rather astonish you.

It is also necessary to remember that, even in mere practice, the effect of artillery fire increases marvellously as the range decreases up to the very muzzles of the guns. The only experiment of the kind that I know of grew out of a discussion on this very point, between an engineer and infantry officer on one side, and my unworthy self on the other. They held the thesis that artillery fire was as destructive to life at 1,000 or 1,200 yards as at any lower range. I held the opposite view, and we agreed to get the matter settled at Okehampton, where experiments were then in progress. The infantry officer, who is now a great man in India, went down to Okehampton, by consent of the authorities, and arranged all the details of the experiment, putting his dummies as he thought they would be in attack formation—some of them lying down, others kneeling behind rocks, and so on—spreading them out to a thin line as they came nearer to the guns. Though the battery was supposed to be under cover, men were taken away to represent losses. Three gunners per gun were supposed *hors-de-combat* at 600 yards, two more at 400 yards, and one more—that is six in all per gun—at 200 yards. Some of the killed infantry were brought to life again, or there would have been a sorry spectacle towards the end of the performance. The comparative result was (remember that there were only six guns) :—

At 1,000	yards	one-eighth of the infantry		per minute	were killed.
,, 600	,,	less than one-fourth		,,	,,
,, 400	,,	more than ,,		,,	,,
,, 200	,,	,,	one-half	,,	,,
,, 100	,,	,,	two-thirds	,,	,,

In the first eight minutes, up to and including the 400 yards range, the infantry had presented 400 men and lost 385. At the 200 yards range reinforcements brought up the remaining 15 men to 156; in one minute 81 of them were disabled. Still they stood at 156 for the 100 yards range, and in one minute 113 were disabled. In ten minutes, though never more than from 200 to 300 men in open order were exposed at a time, some of them only partially, and at last only 156, taking every advantage of rocks and hillocks, no less than 579 men were placed *hors-de-combat.*

And now, after looking at the diagrams of the results of experiments with modern shrapnel shell that accompany this paper, let us turn to the more practical question of what field artillery can do and should do on the field of battle. It is very curious how persistently those who disbelieve in it argue on the supposition that they are going to bring horse, foot, and guns against artillery alone. Now pray don't argue yourselves muddle-headed in this fashion. Last year I had made the same remark at Aldershot, yet, in the discussion that followed, one of our best infantry generals, for whose abilities everybody has the highest respect, said :—

"I, for one, if I had a mixed force, should, in the first place, engage my enemy's guns with my guns, which I should consider equal to theirs; I should then break up my infantry, advancing under cover as far as possible."

That is to say, having already an equal artillery, he would win by adding a force of infantry. Well, that would not be very difficult. Then up jumped a staff officer of the Aldershot Division, and he said :—

"I will add that, as an infantry officer and staff officer, I should wait, in an attack on a position, until the time came when our own artillery had made an impression, to let go our infantry, and then trust to the physical training so ably advocated in a late lecture here by Colonel Onslow, and to the leading of the officers I have been accustomed to soldier with, to get quickly over this dangerous zone."

He, you see, would wait till his own artillery had made an impression—that is, established a superiority, and then he would go in with his infantry; only, from what we have said of the Okehampton experiments, he might find the dangerous zone reach a little further than he expected.

And what had the cavalry to say? Well, their chief and spokesman, a distinguished general who has gained laurels in the field made just this pithy speech and no more :—"Nothing will make me believe—at present I am speaking on behalf of my branch of the service—that a brigade or a division cannot make a battery or a brigade of artillery shift its ground. *How* they are to do it is, of course, another matter."

Now, this question of "how they are to do it" runs through the whole argument, including how the artillery can best make use of the powers which must be conceded to it, but conceded only on the condition that it is prepared to make the best use of them, otherwise it will be what the ignorant think it now—more an encumbrance than a benefit.

Look at this table, which was compiled in France.

Losses by different arms in war—

In 1864...	Danes ...	84	per cent. by	musketry fire.
		4	,,	sabre and bayonet.
		10	,,	artillery.
		2	,,	unknown.
In 1866	Austrians ...	90	,,	musketry fire.
		4	,,	sabre and bayonet.
		3	,,	artillery.
		3	,,	unknown.
	Prussians ...	79	,,	musketry fire.
		5	,,	sabre and bayonet.
		16	,,	artillery.
In 1870	French ...	70	,,	musketry fire.
		5	,,	sabre and bayonet.
		25	,,	artillery.
	Prussians ...	88	,,	musketry fire.
		2	,,	rifle and bayonet.
		5	,,	artillery.
		5	,,	mitrailleuse.

On particular occasions, such as the battle of Sedan, about half the French losses were from artillery fire.

At the battle of the Aladja Dagh, in Armenia, more than half the Turkish losses are ascribed by all witnesses to the admirably served and directed shrapnel fire of the Russians. Yet, in 1866, the Austrian losses by artillery fire were only 3 per cent. of their total losses. How was this? Simply because, in 1866, the Prussian artillery had poor guns badly handled. In 1878 the Russians had just begun to understand how to use field artillery, and had at that time a very good gun.

The best comparison, however, is between the German and French losses by artillery fire in the same war, 1870-71. The Germans, remember, lost 5 per cent., the French 25 per cent., although the latter were generally on the defensive. Why was this, and why did the Germans do so much better with their artillery in 1870 than four years previously? The reasons given by their own writers are:—

In 1866—

1st.—The Prussians were imbued with the idea that artillery was a thing to be taken great care of, and it was, therefore, always behind.

2nd.—From want of practical training, the artillery could not hit well enough when it arrived on the field.

In 1870—

1st.—The field artillery had grown bolder, and was pushed to the front at the earliest possible moment, marching near the front of the columns for this purpose; or even, having been trained to make long and rapid marches, pushing forward from long distances to join in the fight.

2nd.—The training of officers and men in shooting had been unremitting, and directed to teaching them exactly what they would have to do in war.

All through the war of 1866 the faults were the same, and it is hardly worth while to go through the battles one by one. Suffice it to say that the artillery was almost always behind at the critical part of the engagement, and, when it came up, was so unpractised in training for battle, that it did not produce half the effect which it ought to have done. Prince Kraft points out the faults of this previous training, and tells how they were caused.

In explaining the reasons why the field artillery made such indifferent practice on service before the great change took place, he says:—"I have never, up to the time of the introduction of rifled guns, known an inspecting general use the effect produced by the fire of a battery as a standard by which to judge of the excellence of its instruction. This was judged by the correct execution of drill, of marching, of the service of his guns, the turn-out of the men and horses, and the time which the battery took to come into action." There was great indulgence for bad practice, for the guns themselves shot badly. There was a feeling that "the artillery would be a very beautiful arm if it had no guns to drag after it." An officer who cared for shooting once created great indignation among his superiors by saying, at a meeting for discussion, that "it was most objectionable that the senior officers on the practice grounds occupied themselves with the inspection of shoes, bits, and harness, and considered the practice only as an opportunity of getting rid of so much heavy shot and shell."

Ranges were measured, and there was great praise for the gun that fired first. This was the three per cent. training. Now for the twenty-five per cent. training and its effect.

"The targets now represented troops, and were much smaller than formerly. The infantry and the cavalry targets were only fifteen paces wide (the breadth of a section or a sub-division); the artillery target represented guns, horses, and men in action. Skirmisher targets were also used, sometimes standing and sometimes lying down (head targets), after the pattern of the targets used by infantry. The smaller targets took more time, but cost less money. Then funds became available to keep a moving target always in use, and to carry out practice at it. In the brigade which I commanded," says Prince Kraft, "it was even found possible to build a small railway on which the target ran. The course of practice began with an 'Introductory Instructional Practice,' in which three batteries at war strength, commanded by captains who had passed through the School of Gunnery, took up different positions from which they had to fire. All the officers looked on. The principal subject of instruction was practice at a moving target, either advancing directly against the battery, or moving obliquely across its front, or passing from flank to flank. Plenty of ammunition was always provided for this practice. Then followed the 'Elementary Practice' (unless it had already taken place); in this the recruits, after they had learnt to fire blank cartridge, gained some idea of the fire of shotted guns against a target.

"After the officers, as well as the men, had been instructed in the elements of gunnery, the true 'Instructional Practice' followed. This was always practised with shell under service conditions. The targets were removed daily, the ranges were daily varied, and a battery was often stopped during its practice and ordered to fire at another target. Not only did the batteries fire one by one, but the divisions also came into action one by one, so that even the youngest subaltern had plenty of opportunity of showing whether he could judge distance, and whether he could pick up the range correctly. Plenty of ammunition was always supplied. Each battery also fired in 'Practice for Prizes,' and, *in addition, fired* 182 *rounds at the inspection of the Inspector-General.*"

There is a good deal more about the practice, but, perhaps, enough has been said. This being the preparation for the 25 per cent. shooting as contrasted with the 3 per cent., and the practice at moving targets being well taught, we must have one more quotation to show what was the difference in effect. At Königgrätz the officers had felt that they could not stop an infantry advance, and were down-hearted in consequence. Hear the result of the change:—

"I could never have believed that the instruction given in time of peace would have borne such excellent fruit in spite of the excitement of action. How agreeable was my surprise when, standing behind the captain of a battery in action, as troops were advancing to attack him, I heard him quietly give the order 'Against infantry in front, 1,900 paces from the right flank, Ready! Fire one gun!' Then he waited, holding his field-glass to his eye, until the enemy approached the point on which the guns were laid, and gave the order, 'Rapid firing from the right flank!' Then there was a hellish sight, for the advancing enemy disappeared from view in the clouds of smoke which the shells threw up as they burst and tore their way through his ranks. After one or two minutes the attacking enemy came out on our side of the smoke. It had passed the point on which the guns were laid, and in spite of terrible loss, approached with undeniable bravery. Then the captain gave the command, 'Cease firing!' '1,600 paces—one gun!—Cease firing!' And when the enemy drew near to the new point on which the guns were now laid, he cried, 'At 1,600 paces, from the right flank, rapid firing!' The effect was brilliant, horrible, and overwhelming. No attack could have resisted it."

This, then, is 25 per cent. shooting, and, as Prince Kraft tells us afterwards, it is nothing to what will happen in the future, since the introduction into all armies of the shrapnel shell with time fuze; an invention which we should always remember was due to a British artillery officer, General Shrapnel.

Other reforms were carried out. The Inspector-General of Artillery, at his annual inspections, judged of the quality of the troops by two points—the hits made at practice and the quick movement of the guns over long distances. "He considered elegant drill as quite secondary, and entirely forbade all artificial movements." The very principles of the new regulations were different. Among other changes—"Whereas, formerly, marching past and correct drill were considered the highest expression of discipline, these were now entirely neglected wherever they interfered with the careful direction of the guns and the ammunition, and thus prejudiced the effect of fire." Marching long distances at a rapid pace and good "field firing" were, thenceforth, the proofs of efficiency and discipline. I once had the good fortune to be present at an inspection of the Artillery of the Guard, at Berlin, by Prince Kraft himself. We started from the city about daylight, trotted most of the way out, when the batteries were placed in a thick wood near the practice ground. They were ordered out, a brigade at a time, and came up at a trot to the spot intended, led by a staff officer. Each battery had a different target to fire at. One target was in a wood, hardly visible, another just showed over the top of a parapet, a third travelled diagonally across the range; in all cases the distances were unknown. The trial shots were taken cautiously, there was perfect order, and no fuss. When sufficient firing had taken place, Prince Kraft and his staff rode up and inspected the targets, the batteries retired at a trot to be succeeded, though at a different place, by another brigade of three batteries.

In thinking of the effect of Prussian artillery fire in 1870, it is necessary to bear in mind certain facts before we can fairly estimate what the power of field artillery in the open really is. We called that shooting of the battery against moving infantry, quoted above, 25 per cent. shooting. It was actually 100 per cent. shooting, for its work was done without aid, and against troops in the open. In the majority of cases artillery is called upon to act against troops under cover, where, for that reason, and on account of the long range, infantry could do nothing, and artillery can do comparatively little actual killing, no matter how well trained. What it can do, and no other arm can do under such conditions, is to produce a moral effect. What is a moral effect? It is simply the end for which all killing and wounding is but one of the different means! There is not a single great general who has ever expressed any other view on the subject but that which may be summed up thus:—*It is not the number of the enemy killed and wounded which ensures victory, but the moral effect pro-*

duced on the remainder. Compare the Egyptian force with which the gallant Valentine Baker endeavoured to relieve Tokar with that little column of British soldiers, hardly stronger than a battalion on war footing, which the equally gallant Herbert Stewart led across the desert to attempt the relief of Gordon. In the former case the mere sight of the Arabs rushing fiercely forward demoralized the Egyptians, who threw down their arms and were slaughtered, flying. In the latter case the British preserved their moral force even when the corner of the square was broken by actual contact, and the Arabs never attacked again with the same courage. The difference was purely moral.

A very excellent officer and writer, the Baron von der Goltz, says, on this point, after remarking how terrible is the task for infantry when attacking a position :—"The best infantry in the world may be paralysed under such circumstances. The braver it is, the more will its bravery enhance its own destruction. In order to avoid this, the artillery must support it. Even though the shell and shrapnel of the latter produce no material losses, they yet bring it about that the defenders hide themselves behind their cover, and pour forth their fire blindly, without seeing whither it is directed. He who has ever in real war learned to know the difference between an attack on infantry not played upon by artillery, and upon infantry which has, for a long time, been exposed to the effect of artillery fire, will never forget it. The explosion of the first shell in the lines of the defenders, who have a sheltered position, produces an almost immediate effect." Now, if upon this the gunner starts up and claims to have produced a decisive effect, he is as wrong as the infantry who would dispense with his assistance. The decisive effect is only produced by the infantry, who must finally advance, turn the enemy out, and occupy the ground in dispute. It is a noble duty, by far the most important of all; and if we gunners find it necessary to speak boldly and firmly concerning the qualities of our arm, it is not that we undervalue the splendid duties and powers of our infantry comrades, but only from an absolute conviction, based on common sense and experience, that when troops of fairly equal quality are contending for the mastery, it devolves on the artillery so to dominate the spirit of the enemy as to achieve that moral superiority which will render the task of the infantry possible.

We have now to see what is the physical effect of field artillery, properly trained and handled, when it has the opportunity of firing at troops which do not render themselves safe by cowering behind earthworks, or burying themselves in bombproofs. We shall see that its power in killing and wounding is immense, and its moral effect irresistible.

Here is an episode both interesting and instructive, the action of Prince Kraft's artillery during the successful attack on St. Privat (Battle of Gravelotte). As everybody knows, the first attack was not properly prepared by artillery, and failed. It was the one instance in war in which long range infantry fire produced a serious effect, decisive for the time. A more decisive effect would have been produced by reserving the French fire; but the Prussian guards were checked, and for some hours an artillery bombardment continued. Then the guards began another attack, the artillery being ordered to support it. Now for Prince Kraft's experiences, which are in strange contrast with the conduct of the field artillery in 1866. "Our infantry, rushing boldly to the attack, very soon masked our batteries, which had again opened a violent fire on the enemy, who were now visible, and I ordered the corps artillery (under Scherbening) and that of the 1st division (under Rychelberg) to accompany the infantry. The right wing of this line of artillery (four batteries of the 1st division, and two batteries of the corps artillery of the guard) galloped straight forward and reached at the same time as the skirmishers the nearest edge of the heights between St. Privat and Amanvillers at the very moment when the enemy's skirmishers were giving way before our own."

Prince Kraft himself accompanied the 2nd heavy battery, commanded by Prittwitz. "The battery galloped up the slope of the hill and joined the skirmishers as they moved to the assault; only three guns at first reached the top, the three others having lost horses as they advanced. At the spot where the battery came up, the crest of the hill is so wide that it almost amounts to a plateau. The enemy's skirmishers were flying before ours. But at a distance of from 300 to 500 paces in front of us masses of the enemy, in quarter column, were advancing to dispute the crest of the height with our skirmishers. You can scarcely imagine the effect which the first shot of Prittwitz's produced on these masses. In an instant they became motionless, as if they had received a violent electric shock. But when shell after shell began to burst in the midst of them, when our line of artillery was reinforced by my other batteries as they arrived in turn at a gallop, and by the three guns of the first battery which succeeded in rejoining us, the columns at once took to flight. Then my 30 guns set to work to find the range by firing trial shots at different points, while on the left the fight was raging around St. Privat." . . . "We had not long to wait for the first movement which the enemy's infantry was to make in our direction. It advanced in quarter column from Amanvillers, and attacked us energetically. When the head of the column became visible over the hill, our trial shots reached it at a range of 1,900 paces, and my 30 guns opened a rapid fire. The enemy's infantry was enveloped in the thick smoke which the shells made as they burst. But after a very short time we saw the red trousers of the masses which were approaching us appear through the cloud. I stopped the fire. A trial shot was fired at 1,700 paces range; this was to show us the point up to which we should let them advance before re-opening the rapid fire; we did the same for the ranges of 1,500, 1,300, 1,100, and 900 paces. In spite of the horrible devastation which the shells caused in their ranks, these brave troops continued to advance. But at 900 paces the effect of our fire was too deadly for them, they turned short round and fled; we hurled shells after them as long as we could see them. Here was an infantry attack which was repulsed purely and simply by the fire of artillery. A few years later I had the opportunity of talking with an aide-de-camp of General de Ladmirault, the very man who had carried the order to make this counter-attack, and who had been present during its execution. Two regiments of infantry had been despatched on this duty. The French officer said to me: 'It was impossible to succeed. You have no idea what it is to have to advance under the fire of your artillery.'

"These infantry attacks were repeated. They continued to come from the same direction. Altogether three were made, but the two last were not carried out with the same energy as the first. They were stopped at about 1,500 paces in front of our line. A mass of cavalry also appeared before the infantry attacked, with the object of trying to disengage the defenders of St. Privat from their position. The head of the mass showed itself near the farm of Marengo, on the high road from Metz to St. Privat; it halted while the column deployed. As soon as we had found the range, with the help of a few trial shots, we opened a rapid fire, and our shells, falling among the crowded ranks of the cavalry, broke up the mass, and it disappeared in the same direction from which it had come. At length our infantry made their way into St. Privat, and the remainder of the batteries of the artillery of the guard hastened up also, and posted themselves on the height to the right of the village."

Let us now take two or three incidents from Prince Kraft's experiences during the battle of Sedan, and remember that these are related by a principal actor in the terrible drama, a man of high rank and unimpeachable integrity and veracity.

"A French battery, horsed entirely with greys, trotted up from the Fond de Givonne to Givonne itself, and tried to take up its position between that village and the Bois de la Garenne. As soon as it appeared on the hill the three batteries mentioned above opened fire on it. It fell to pieces, as it were, and its ruins remained where they fell. It did not fire a single shot. A second and a third battery met with the same fate."

In a French pamphlet which appeared shortly after the war, I read the following:—"The Emperor himself tried to post three batteries at the exit from the low ground of the Givonne. They were demolished without having fired a shot."

Now for a small episode which shows the capacity at long range of those Prussian guns which were much weaker than are any of the present day. They had no shrapnel.

"At one moment something was seen moving to the right in the forest of the Ardennes. By the help of field-glasses this was made out to be some cavalry marching in two ranks towards the north, and passing through a clearing in the forest on the hill. The batteries endeavoured to find the range. With elevation for a little more than 4,000 paces we appeared to hit. I considered that the range was too great for the fire to have any effect, and I was about to order it to cease, when an evident disturbance in the ranks of the enemy proved that our projectiles had reached him. We continued then to fire slowly at this moving target so long as it remained visible . . .

"On the following day Lieutenant von Kass, while doing duty as aide-de-camp, passed by this point, and found on a narrow crest, which ran between very steep ravines, an entire French battery, which had been abandoned there. The team of the leading gun had been blown to pieces by our shells, and the other guns could not pass it; thus the whole battery fell into our hands, a trophy of the accuracy of our fire."

The success of the shooting increased the confidence of the men. Every word of command was obeyed with strict punctilio, and every detail of laying the gun and preparing the fuzes was attended to with the greatest accuracy. They had obtained complete command over the French artillery, and began at all ranges to crush the attempts of the French troops to break out. Please mark especially what complete artillery success brings with it :—"The batteries fired as if at practice. We had spectators, as we have on the practice ranges. Ours were officers of the troops which were held in reserve, military surgeons, and even a chaplain.

"All at once a line of Prussian cavalry, coming from the direction of Illy, approached the northern point of the wood at the spot where the calvary stands. A thick mass of infantry with red trousers rushed out of the forest against them, and fired at them from the quarry by the calvary. It was an exciting moment; will our guns, which are laid exactly on this spot, be able to throw back the enemy's infantry, and prevent it from destroying our cavalry, upon which they have opened fire? This was the question which interested each of us. The chaplain himself said, very justly, to a gunner who was by his side near one of the limbers :—'Now you ought to make plenty of Prussian shells burst in the middle of that French infantry.' 'Make your mind easy, sir,' replied the gunner, who had heard the order given to lay the guns on the enemy's infantry, 'we will look after that; you have only got to watch.' At the same instant the greater part of the guns opened their rapid fire; a cloud of shells, which burst as they touched the ground, enveloped the enemy in a thick smoke, and he very soon fell back into the forest. The chaplain shouted with delight, which made us all laugh. I will not tell you what he said, but if you desire the evidence of one of the Lord's anointed to assure you of the efficacy of our fire, I will give you his name, and you can ask him for information.

"The batteries were once more pointed at the forest, and continued to bombard it. At length the moment to attack was come; orders had been given that a salvo fired by all our guns should serve as the signal to carry it out. We fired the salvo at 2.30 p.m. precisely, as had been arranged, and our infantry, starting from Givonne, began to climb the hill. We were in a state of feverish expectation; every eye was fixed on the forest. We asked ourselves if the capture of the edge of the wood would cost as many lives as had that of St. Privat. But this time the resistance met with was almost *nil*. At most points the French, utterly discouraged, advanced to meet our troops crying, 'Mercy! Mercy! We can do nothing; we are crushed by the fire of your artillery.' Only in the interior of the forest did they try to fight at certain points, and even there the resistance was not stubborn. Unless I am mistaken, the Guard Corps at this place captured from 11,000 to 14,000 unwounded prisoners. The whole of the infantry of the corps lost, in this battle, only 120 officers and 320 men killed or wounded."

Perhaps you may think that this is the imaginative account of an enthusiastic artilleryman. Listen, then, to the cold and measured statement of the official history, produced by the general staff, which says of this episode :—

"So annihilating was the fire of the artillery, that the French were scarcely capable of any organized resistance when the German infantry, towards 3 p.m., moved forward from all sides against the wood."

And in the general retrospect of the battle, the official account speaks thus of the work done by the artillery :—

"The German artillery, in the battle of Sedan, produces an especially grand and decisive effect. Only the surprise, undertaken during the morning mist towards Bazeilles, as demanded by this sort of attack, is made by the infantry alone; but at all parts of the extensive battle-field the whole strength of the batteries was from the first brought into play. Inserting themselves in the columns of route in a position favourable to early deployment, they hastened forward to the battle-field *with the advanced parties of the infantry.* The batteries of the 11th and 5th Army Corps, which have to traverse the difficult road defile at the Bois de la Falizette, deploy, trusting mainly to their own strength, in one long line, though opposed to the hostile masses of horse threatening them, and with their backs to the Belgian frontier. As a general rule, the attack of the infantry is deferred until the artillery has produced its full effect. From the Calvaire d'Illy, the enemy is almost exclusively driven off by the fire of the guns, whereupon a few companies take possession of this important height without a struggle. The shells bursting thickly in the Bois de la Garenne prepare the attack of the battalions of the Guard, and spare the tremendous losses with which previous victories had been purchased."

On the other side, I could quote, from my own experience, many cases of the poor effect of the French artillery fire, of which the Germans, very naturally, say little. The French, you know, had only 5 per cent. guns and 5 per cent. training. Once, at the commencement of the three days' battle of Le Mans, I was with the head of a column moving on a road to attack the village of Changé. Some French guns in position, as volunteer guns might be for the defence of London, began to fire shrapnel at the column. Now shrapnel is the deadliest by far of all artillery projectiles if the ammunition is good and the gunners skilful. We ought to have been destroyed by that fire, but the French fuzes were ridiculous things that could only burst the shells at intervals of some 300 or 400 yards—I forget the exact intervals—and the gunners were far from having that training, the effect of which we have seen on the other side. So these potentially dangerous projectiles shrieked over our heads or burst apparently among the snow clouds. Only a few stray bullets reached us, with little velocity left in them. The moral effect was *against* the French. The men of the 3rd Corps, with which I was, mocked at the shells, and burst into one of their grand *Soldaten Lieder* choruses—Der gute Kamerad—which begins, in their patois:—

Ich hatt' einen Kameraden,
Einen bessern find'st du nit.

A bright flash seemed to come into the men's eyes—the light of battle. Their tramp on the ice-bound road grew firmer and more resonant; and as one of them with whom I had been talking moved off into the fields with his company, he said, in a tone of contempt: "The French artillery can't hit." The roar of many throats in that battle music, the tramp of the men in time to it, and the impotent crashing of the shells far above, combined to rouse the nerves and set the blood afire. It was all as inspiriting as a cavalry charge.

Compare this little episode with that piteous French cry: "Mercy! Mercy! We can do nothing, we are crushed by the fire of your artillery," and we shall get some idea of the difference between the 5 per cent. and the 25 per cent. shooting. It was not a difference in the men, for there exists no nation more gallant than the French. It was simply a question of the right and wrong use of artillery.

We have now to turn the page again, but it is backwards, so far as the use of field artillery is concerned, though the progress of time marks some seven years in advance. On the whole, the field artillery in the Russo-Turkish War was not well used, though I myself saw several cases of its useful employment on a small scale. For instance, I had the great advantage of seeing both the crossing of the Danube, in which the field artillery was a considerable protection to the troops on the other side after daylight, and the first passage of the Balkans by General Gourko's column of some 12,000 men and 32 pieces, 18 of which were field, and 14 mountain, guns. The route was a mere blind trail, which the Turks never thought of defending. Two squadrons of Cossack pioneers went, two days in advance, into the mountains, and made the path fairly practicable, though two guns did fall over precipices, and one was hung up on a tree, the gun and carriage dangling on one side, the team on the other. It may show what guns can do under difficulties if I mention that we marched eighteen miles the first day up-hill, twenty-six miles the second, including the toil up a height of 1,900 feet in eight miles, and a steep descent in the night. On the third morning, by ten o'clock a.m., we had marched nine miles, and were driving away the Turkish detachment which watched the mouth of this dangerous and difficult pass, the mountain guns being at the very head of the column. Two days afterwards, as we moved to turn the Shipka Pass, there was a smart little affair with about 3,000 Turks, who had made shelter trenches, etc., in front of the village of Uflani. The Russian infantry were checked before a defended rose garden (we had left troops behind to guard the pass, and a large part of the force was cavalry), and were suffering considerable losses, when a battery of horse artillery, which had been sent round to the left flank, opened fire with shrapnel. The effect was instantaneous. I saw the Turkish defenders disappear as if by magic, and, riding into the rose garden shortly afterwards, found it strewn with dead bodies, bearing undeniable marks of having suffered from shell fire.

On the whole, the artillery on neither side distinguished itself very much, considering what it might have done. The exceptions were Skobeleff's actions, portions of which I described here last spring. Some of you may remember the affair of Lovtcha, where he so carefully prepared epaulments for guns the night before they were expected to arrive. Then, in the morning, he devoted eight hours to bombardment before he attacked and carried the first position; then rested his infantry while he bombarded again for two hours before his second advance and capture of the final position.

I also mentioned what will, however, bear repetition as an example of how not to do things, the extraordinary orders for the preliminary bombardment at the third attack on Plevna, September 11, 1877. Listen to those orders. They were: general cannonade from daybreak till 8 a.m., the Turks lying of course snugly in their field casemates; then a pause till 11 a.m.; then cannonade till 1 p.m.; another pause till 2.30 p.m., then half-an-hour's cannonade and a general assault at 3 p.m. These elaborate dispositions were all spoilt by a fog. When there was one success in the capture of the

Grivitza redoubt by Russians and Roumanians together, no use was made of it to push artillery forward. Skobeleff alone worked both his infantry and guns well, and went deep into the Turkish defences on the Lovtcha road close up to the town of Plevna, where he held his ground that night and part of the next day. Now, after all this blundering of the Russians in the use of artillery, and after Skobeleff's success in carrying the Turkish lines below the Shipka Pass without bombardment when he could not get his guns through the snow drifts of the Balkans in time, what was that brilliant General's feeling with regard to field artillery? Let it be judged by the fact that when he was sent to Central Asia to take Geok-Tepé, where others had failed, the one point on which he insisted was that he should have plenty of field artillery. His force for that brilliant, if somewhat cruel campaign, consisted of 7,000 men and over 60 guns—about 9 per 1,000—though he had a desert to march over, and the railway had not then been made.

We must not, however, suppose that the Russian artillery was always unsuccessful in that war. We have seen the great use of it at Lovtcha. The defences of Telisch capitulated on October 28th, after bombardment by 66 guns of new pattern for three hours without any infantry attack. Ardahan fell almost entirely before the effect of artillery fire, and Lieutenant Greene, the historian of the war, an officer who was deeply impressed by the poor work done by the guns against Plevna, admits that of the 4,000 to 5,000 Turks killed and wounded at the battle of the Aladja Dagh: "The greater part of the Turkish losses was caused by the admirable employment of the Russian artillery with shrapnel." By that time the Russians were beginning to use their newer equipment, and what with that improvement—for their old guns were very weak—and the experience of war, it must be admitted that in this, their last battle, they had arrived at a more than a 50 per cent. effect. The general result upon the military mind of Europe has been that since the Russo-Turkish War every Continental army has largely increased its field artillery, and the German Government are now asking from the Reichstag for a sum of about three millions sterling to increase and improve the field artillery.

There is one improvement which is manifestly made necessary by the improved fire of infantry. Field artillery should carry portable shields, probably of steel. They must be carried separately from the gun carriages, both because they would otherwise increase the weight behind the horses, and because there may be some occasions when the shields had better not be used. By far the greatest proportion of losses are caused to artillery by shrapnel bullets and infantry fire. Against both of these, and against machine guns, light steel shields would be a perfect protection. If in the open, and attacked by common shell fire, the shields could be thrown down in an instant, but if well placed under cover, or if attacked by infantry, the shields would be invaluable. Skirmishers would, of course, be perfectly innocuous to guns so provided, and every infantry attack would be beaten off with ease. As I have been a constant advocate of their use ever since 1870, I see, with chagrin, that the Germans are likely to be before us in adopting something of the kind. They have already used quick-firing guns at their manœuvres this year, taking with them what they call cupolas; too unwieldy I think for their purpose, but still a beginning. Sir Charles Warren, when going to Bechuanaland, demanded shields for his guns, and some of you will live to see their universal use, if I do not. There will then no longer be a question of the power of artillery to beat off infantry.

The extended use of field guns in all the phases of a battle must cause a great expenditure of ammunition, and the supply of this important part of artillery, both from the limbers and wagons of a battery to its guns, and from the ammunition columns to the batteries, becomes a serious question, which is answered differently in different countries.

In our army, besides ammunition columns for infantry and cavalry divisions, which also carry artillery ammunition, there is an army corps reserve ammunition column, divided into four sections :—

The 1st section is only for corps artillery, taking for it the place of the divisional ammunition columns.

The 2nd, 3rd, and 4th sections are second reserve for the whole of the troops.

Taking the 12-pounder as the gun with which the 1st army corps is armed, it carries :—

	Rounds.
Present with each gun in the field ...	108
In divisional, or 1st section army corps column	74 (78 for A.C.)
2nd, 3rd, and 4th sections	72
Total	254 rounds per gun.

But you see that considerably less than half—only 108 rounds out of 254—are actually with the guns, and when you come to think of what an army corps on the march is like, you will see that the bulk of the ammunition must, indeed, be far from the fighting front. The only way to have ammunition enough is for the batteries to be generous in supplying each other on the day of the battle, and for the ammunition columns to make the best of their way to the front, always on a known road, so as to be ready to fill up the batteries during or after the fight.

During the action the supply of ammunition for the guns needs a good deal of judgment. Each country has its own rules. In our Service the first line of wagons consists of four ammunition wagons, under the captain of the battery; the second line of the remaining wagons, ammunition and otherwise.

If only one battery is in action, the first line of wagons will be 100 yards, or thereabouts, in rear of the least exposed flank. If several batteries are together, the first line must do the best it can, and the second line of all the batteries will be placed in charge of one officer.

The universal rule is to keep the gun limbers full as long as possible, any rounds taken out of them being immediately replaced. Next to these the limbers of the wagons should be kept full.

All this requires a great deal of skill and attention, and very few officers have any notion of the difficulty. For instance, imagine yourself in charge of an ammunition column, perhaps a day's march from the front, and that there is reason to expect an engagement. It is your duty to push forward, but you will find the roads encumbered with troops and carriages; besides, how are you to know where the guns you are to supply are to be found? This is one of those duties which require cool and experienced heads, and which would seem to me impossible to volunteers, for instance, no matter how good.

As for the kind of gun to be used, it would be an advantage, from the point of view of simplicity, if we could manage with only one nature of gun. At present, the 12-pounder B.L. is universal for the first army corps, but its shell has not power enough to cut down the various defensive works which engage so much of the attention of engineers; and, besides, as every other great Power has a more powerful weapon, we might find ourselves at a disadvantage. The whole system—gun, carriage, and ammunition—of a 20-pounder B.L. has accordingly been worked out, and there is nothing to prevent its introduction except the cost which would be involved.

A howitzer of 4·25-inch calibre has also been tried, and is rather more effective against earthworks, but not nearly so powerful against troops. Even against earth the 20-pounder is by no means weak. In the summer of 1889, at Okehampton, a hasty field redoubt was thrown up. The parapet was 10 feet thick, with 5 feet 6 inches command. Thirty rounds of common shell and 30 shrapnel were fired at it from the 20-pounder, and the same from the howitzer. The range was 1,644 yards.

With the 20-pounder, 19 out of the 30 common shells struck the parapet, and made a breach 15 feet wide by 3 feet 6 inches deep, also breaching two traverses. The 30 shrapnel disabled 16 out of 31 dummies with 31 hits.

The howitzer made a more complete breach, but only damaged 7 dummies with its shrapnel.

That one instance will give you as good a standard of comparison as a hundred would do, and as the use against troops would be much more frequent than against works, you will see that, on the whole, the 20-pounder has the best of it.

Its equipment is lighter than the 16-pounder M.L. gun, and lighter than the German 18-pounder. It is a more powerful gun in every way than the heavy field gun of any other nation except Russia, and the Russian equipment is 5 cwt. heavier, namely, 50 cwt. against 45 cwt. for the 20-pounder. The velocity of the 20-pounder is greater at all ranges than that of any Continental field gun, and the shell heavier than all except the Russian. On the whole, it may be considered the best heavy field gun in Europe; while it is kept within the limits of a fair weight for marching. The old 9-pounder smooth-bore, with which my battery of horse artillery was armed in the Crimean War, had about the same weight behind the horses.

And now, having given you some account of what field artillery has done in late wars, and said what our guns are, and how they will be supplied with ammunition, we may conclude with a few words on how artillery should be used in action.

Do not be alarmed; I am not going to say anything about zones. I have seen a few fields of battle, and upon them, hills, and woods, and villages, positions made for artillery, and others where guns would be at a disadvantage; but I never yet saw a *zone*, and do not, therefore, trouble my head much about such things.

It is generally acknowledged that all regular battles will begin with a struggle between the artillery on either side, and that the infantry attack should not be launched till the opposing artillery has been wholly or partially silenced; otherwise it would be very hard on the infantry. Prince Kraft goes so far as to express the opinion that battles may even be decided by the artillery duel, but he does not seem to me to take into account the probability that one side, finding itself over-matched, may withdraw the guns out of fire, only to bring them forward again when the enemy's infantry approaches.

Major-General Hoffbauer, after discussing the question, "In a decisive battle has the attack any chance of success if the defender's artillery is victorious?" says:—"Imagine the defender's artillery in full activity directing its devastating common shell and shrapnel fire, at distances all known and tried, against the broad and deep masses of the decisive infantry attack," the defending infantry being, of course, in the highest spirits, and sure to shoot well. He winds up by hoping that the excellent German infantry will be spared so hard a trial by the success of its artillery; and we may all devoutly hope the same for our own infantry.

Again, after the artillery of the defence has been driven away, must that of the attack proceed to a systematic bombardment of the point to be assaulted before the infantry are launched? Most certainly it must, unless it wishes the infantry to sustain at least frightful slaughter and, probably, repulse.

Should an artillery weaker than its adversary decline the combat from the first? Not unless battle is to be declined altogether. It must try by the excellence of its positions and its practice, by its bringing up every possible piece, and by clever manœuvres to compensate for inferiority in numbers. When it takes up its position it should not only take up ranges, but fire some shots to make sure that the firing will correspond with the ranges which have been found.

When the columns of attack begin their advance, is it wise to leave all the artillery behind, even if the conditions are favourable for shooting over the heads of the infantry? By no means. A portion of the artillery must go forward with the infantry, for if it does not, no guns will be able to make their way to the front in time to perform that most necessary act, the occupation by artillery of an abandoned position; to hold it while the infantry are re-forming their disordered ranks, as well as to repulse counter-attacks and pursue the defeated enemy with fire. Besides, the moral effect of the guns pushing forward is tremendous on both sides.

If the artillery of the defence cannot hold its own, and has to give way, either at first or later, what then?

In such a case the weaker artillery must rely upon manœuvre, rather than on the occupation of any fixed position. Among other things, manœuvre means the unexpected appearance of artillery at points not foreseen by the attack ; fire from positions on the extreme flanks against the flanks of the assault ; cross-fire against the enemy as he enters the position, delivered from retired and suddenly unmasked flank and frontal position within the general positions. All this should go hand in hand with the offensive employment of the other arms.

Now, gentlemen, if you think for a moment, you will see how impossible it is that all this can be arranged except by the general in chief command ; and how important it is, therefore, that generals should fully understand what field artillery really can and ought to do. Those of you who are worth your salt look forward to a time when you may be generals in the field ; but no sudden illumination of mind takes place when the sash is first assumed, nor does any tongue of fire descend to sit on a general's plume. You must get into the right way of thinking and acting when you are young, or, believe me, you will for ever remain stuck fast in the rut of ignorance and incapacity.

And now, what does all our talk come to ? And what is there left to carry away in your minds ?

First.—That the power of artillery has increased enormously of late years, and is still increasing, but only on condition that it can march and manœuvre well, and shoot well. Except as a sign of good discipline, it does not matter a straw whether artillery *looks* well. Those German batteries, in 1870, looked very rough indeed.

Second.—While it is evidently useful to artillery to have protection of earthworks or otherwise at a given moment, it is much more important, on the whole, to make full use of its power of mobility whenever there is an opportunity of snatching a chance of superiority over the enemy ; and this applies quite as much to the defence as to the attack. When artillery carries its own defence against shrapnel and rifle bullets, its gain will be enormous.

Third.—As all regular actions will, as a rule, begin with an artillery duel, it is extremely important that all the guns should, on the march, be well to the front, and that, so far as possible, every piece should come into action at nearly the same time. No reserve of guns is wanted. The whole army is reserve enough. Infantry columns should give way to artillery hurrying to the front. It is going to prepare the way for them.

Fourth.—As for distances, zones, and so forth, the best rule for the attack is to get as near the position of the enemy as that enemy will allow, and consistently with the power of having all the guns in a decent position. When the defender begins to yield, if the ground is favourable, push guns closer. It is wonderful what a moral effect advance produces. Finally, when the infantry advances, send a strong force of guns with them at almost any risk.

The defence should protect its guns, no doubt, by epaulments and so on, but not trust to such protection, but rather to good shooting and wise manœuvres, well thought out beforehand, and clearly commanded from headquarters.

Fifth.—Unless directed to retire by superior authority, a line of guns should simply hold its own against all attacks from the front, remembering what I have shown you of the astonishing increase in the power of fire, as the range diminishes, right up to the muzzle.

Sixth.—Remember, also, that the fire of a single battery gives not the slightest notion of the power of a strong line with fifty or a hundred guns in it. Such a line, if thoroughly well trained and commanded, should be able to concentrate all its fire on one spot, and do in one second what a battery on the practice ground would take many minutes to perform. Excellent as was the work done by the German artillery, in 1870, it was nothing to what may be done hereafter by a proper organization and co-ordination of artillery fire.

Seventh.—About escorts for artillery. Undoubtedly, artillery should not, as a rule, be left to act alone, and above all to march alone. But, unless it is detached from the other arms, it requires no special escort, and especially none of infantry, which greatly embarrasses artillery.

Eighth.—As to ranges. I will not use my own words, but those of Prince Kraft, who ought to know if anybody does. He says: "The effect of artillery fire is already noticeable at 5,500 yards. The effect of sharpnel begins at about 3,800 yards, and at 2,000 to 1,500 is decisive, while at 1,100 to 1,000 yards, and under, the effects of artillery is absolutely annihilating." After seeing those diagrams, and hearing what has been said of the German artillery in 1870, when it had only common shell, you will not think his words exaggerated. It may be that in a battle the artillery may, from conditions of ground, have to commence at even so long a range as 5,000 yards, but it should, if possible, begin closer than that.

To guard against the enemy's sharpshooters it is well to push forward sharpshooters of one's own, some 500 yards or so in front of the artillery position. This is how infantry can assist artillery far better than escorting it.

Ninth.—Smokeless powders have lately been introduced both in France and Germany, and the Ordnance Committee are now experimenting with several kinds. Their decision is likely to come pretty soon, and we shall then, no doubt, have such powders also. I have heard so many times in my life that war was going to be revolutionized that I am sceptical on that head. At first sight it would seem that extreme caution would be necessary, but then we have to remember that the enemy would be extremely cautious too, and we do not find that "extreme caution" is often a winning horse. Of course, there will be all the more need for obtaining information, a splendid chance for the cavalry, but, on the whole, perhaps we may say that skill, combined with daring, will always triumph over this new risk, for that it is a new risk cannot be doubted.

I have been trying to lead you to appreciate the advantage of daring, activity, and skill, in the use of field artillery, and I should like to conclude with this observation. In all your work as engineers, bear in mind the immense moral superiority of the attack. Do not shut up troops more than you can help. Be always planning how you can best favour the counter-attack; and, whether you are preparing ground for infantry or artillery, consider it the greatest triumph of your works that the troops they were intended to cover were soon able to leave them and assume the offensive.

PAPER VI.

MATHEMATICAL AND SURVEYING INSTRUMENTS.

BY ARTHUR T. WALMISLEY, M. INST. C.E.
(*Engineer to the Dover Harbour Board*).

BY invitation received from the Commandant, S.M.E., I am requested to address you upon certain special mathematical and surveying instruments, in which considerable improvements have, during recent years, been effected, but the advantages of which are not so generally understood as they deserve to be. Numerous new text-books are constantly being presented to the profession; but these, so far as the study of land and marine surveying is concerned, appear to be in a great measure compiled from previous treatises on mensuration, combined with extracts from manufacturers' catalogues.

It is not my intention, this evening, to occupy your time with a description of many instruments with which you are perfectly familiar, such as the theodolite, dumpy level, prismatic compass, or the cross staff. For a description of these and other well-known instruments, allow me to refer you to Heather & Walmisley's small book on *Mathematical Instruments* (14th edition), published by Messrs. Crosby, Lockwood & Son. But I hope to be able, in the brief space of time allotted to me, to interest you in the construction and use of such instruments as are illustrated by the plates accompanying this paper, and of which specimens are exhibited upon the table for your inspection.

It is often stated, outside military circles, that military surveying is very roughly done; but this is a great fallacy. When we bear in mind that military sketching is usually executed in a minimum space of time, and often without the advantage of subsequent correction in the field, I have no hesitation in stating that the results compare most favourably with sketching done by civilians in the same space of time, which aim only at approximate accuracy. For works of construction, the civil engineer needs plans of the most accurate description, but over their preparation much time is bestowed.

A surveyor has to select one or two kinds of chain and tape which are commonly employed in the measurement of land, each divided into 100 links (see *Plate* II., *Fig.* 1). The total length of the short chain and tape are each 66 feet, and of the long chain and tape 100 feet. The former is called Gunter's chain, from its inventor, the Rev. Edmund Gunter (1620 A.D.), and its use seems to be quite peculiar to this country. Its length is four poles, or 22 yards, decimally divided into links, each link, being one-hundredth part of 66 feet, will be equal in length to 7·92 inches; but this fact is more interesting than useful, as any portion of a chain is invariably expressed in links. The decamètre chain consists also of 100 links, each of which measures one decimètre. The length of a mètre being 3·28 feet, or 39·37 inches, each link is only 3·93 inches long, or about half the length of one of Gunter's links, and the total length of the chain is only 32·8 feet. Its short length is an argument against its use, to overcome which a chain of this description is often made two decamètres in length, and each link 0·656 feet from centre to centre of the connecting ring. In the reign of Edward I., the statute acre was fixed at 160 square poles or perches. With the use of Gunter's chain, ten square chains equal one acre. At every tenth link from each end of a chain a piece of brass, with notches or points, is fixed to denote the number of the tens. Some chains have, also, a small brass ring midway between each tenth index, to show the fifth link, and thus to facilitate the reading of the unit measurements. Part of the first link at each end is made into a large ring or handle for holding the chain in the hand. This is shown in detail in *Fig.* 1 in the text. The best chains have swivel handle rings, and the links connected by three elliptical rings, by which means the chain is rendered very flexible, and the links are not so liable to twist or coil when the chain is folded up. Every chain is accompanied by ten arrows. A long chain possesses a great advantage over a short one, if it is carefully stepped over hilly ground; and upon level ground the work proceeds quicker with it, as the more often the whole length of a chain has to be shifted in measuring a base line

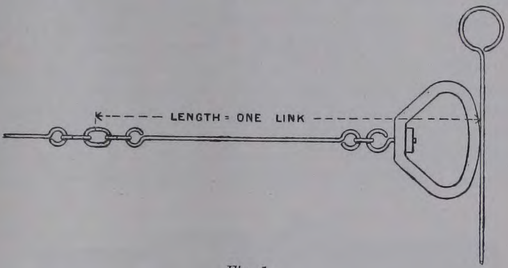


Fig. 1.

the more time is occupied, and the greater are the chances of error in recording the total measurement. A chain 100 feet long is the maximum length that can be recommended, because a longer one would be found very inconvenient to drag, especially in wet weather. Chains, when new, ought always to be examined to see if they are of correct length. They also stretch with frequent use, and need to be occasionally tested afterwards. Special standards, for the use of surveyors in London, have been fixed by the Government upon the north side of Trafalgar Square, and also in the Guildhall, London. Their lengths are derived from the British standard yard, which is the distance at the temperature of 62° Fahrenheit between two marks upon a certain bar, preserved in the Office of Her Majesty's Exchequer, official copies being kept at the Royal Mint, the Royal Observatory at Greenwich, and in the rooms of the Royal Society. The length of the standard yard was finally fixed and legalised by the 5th Geo. IV., c. 74 (1824). Also 41 and 42, Vict., c. 49 (1879), entitled an Act to consolidate the Law relating to Weights and Measures, 1878. These Acts provide that the Imperial standard yard shall be the only unit or standard measure of extension from which all other measures of extension, whether linear, superficial, or solid, shall be ascertained, and also declare that "the pendulum vibrating seconds of mean time in the latitude of London in a vacuum at the level of the sea is 39·1393 inches of the standard, and that the yard shall be in the proportion of 36 to 39·1393 inches." The standards above alluded to for testing chain measurements in London are marked upon pieces of brass let in flush with the masonry into which they are fixed. Permanent standards have likewise been fixed by various municipal authorities in prominent positions over different parts of the country. Your instructor in surveying (S.M.E., Chatham), informs me he uses a "wooden standard yard," as well as fixed marks 66 feet apart, whose corrections have been carefully ascertained from the standard yard. Also a standard steel chain of 100 links, which he does not consider reliable, as the tension and temperature at which it was tested is not recorded. Through the courtesy of Messrs. Elliott Brothers I am enabled to exhibit this evening a 3-foot metal standard

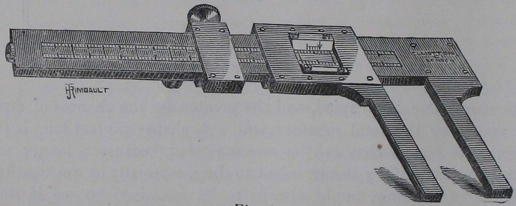


Fig. 2.

rule and a 7-inch standard calliper gauge (see *Fig.* 2 in the text). For the purpose of testing the chain employed in an extensive survey during the process of any work, it is well to fix two pegs upon a level piece of ground near a fence, and at a distance apart just sufficient to enable the outside of the handles of a correct chain, when drawn tightly, to touch the inner sides of the pegs. This arrangement is better than making the chain's length measure from centre to centre of the pegs. The test distance may be set out very accurately with a level staff, or better still with two levels taves placed end to end in measuring the line, provided each level staff has previously been tested upon the Government standards. It is useful to keep a properly tested spare chain in reserve, to be used only for purposes of testing, when a level staff is not near to hand.

Chesterman's metallic tapes, sold in substantial leather cases, are made of linen thread, having fine brass wire interwoven so as to obviate stretching, and resist the effects of moisture better than the usual linen tape, but the wire causes the surface of the tape to wear more rapidly than when no wire is inserted.

As the chain used in the field contains 100 links, plotting and offset scales are decimally divided. The subdivisions upon the edge of each scale read simply a certain number to the inch, as marked upon the scale. Thus, in the scales shown in *Plate* II., *Fig.* 2, the mark 10 simply means that there are ten equal subdivisions to the inch. If, therefore, the scale to which the plan is to be plotted be a scale of one chain to the inch, each subdivision upon the scale would represent ten links, and the unit lengths would have to be estimated by the eye. In some scales, divisions marked "feet" are shown upon one edge, which is intended to give the equivalent in foot links corresponding with the scale of Gunter's links marked upon the opposite edge. Upon reference to *Figs.* 3 and 4 it will be seen that a length of three Gunter's chains, or 198 feet (3×66 feet), would be nearly the same length upon the scale as two chains (200 feet), upon the edge marked "feet." If the chain used in the field be the 100-foot, or any foot-divided chain, and the plan be plotted to a scale of feet, with the use of the scale of decimal equivalents to an inch, the divisions marked feet upon the opposite edge of the scale mean nothing; but if the chain used in the field be a chain of Gunter's links, and the plan be plotted to a scale of one chain to an inch, with the use of a scale containing ten or more divisions to the inch, then measurements scaled with the edge of the scale indicating feet will give the equivalent length in foot links. *Plate* II., *Fig.* 3, shows the method of graphically converting a given scale of feet to a required scale of Gunter's links, and *Plate* II., *Fig.* 4, a given scale of Gunter's links to the required scale of feet. Two straight lines, C A and C B, intersecting at C, are drawn at any angle apart. About 30° is a favourable angle to fix upon. The scale of Gunter's links is applied to the line C A, and its subdivisions are pointed off upon this line. From C as centre, with C A as radius, the distance C A is transferred to B. A line is then drawn from 66 divisions upon the scale of Gunter's links to the point B, and the line C B, representing the length of one hundred Gunter's links, is then subdivided into 66 equal parts, representing 66 feet, by drawing lines parallel to E B from the subdivisions upon the line C A to meet the line C B. Thus a series of similar triangles is formed, and a scale of feet equivalent to the given scale of Gunter's links is arrived at. Conversely, to draw a scale of Gunter's links equivalent to a scale of foot links, as shown in *Fig.* 3, 66 divisions upon the line L F are transferred to the line L G, which is then subdivided into 100 parts by drawing lines parallel to a line G K, joining the point G with the length of 100 divisions from D, measured in the continuation of the line D F. This point is found to be at K, at 30 divisions from M, which scales 70 divisions from L, so that L K measures the required 100 divisions.

Plotting scales are made flat upon the under side, the bevelled edges of their upper side being marked in the direction of their length. Scales of an oval section, as used for the detail drawings of a building, possess the merit of being easily lifted off the paper by tipping either edge with the finger, but the flat section enables a plotting scale to lie steadily on the drawing, and with a feather edge upon each upper side of the scale, the extremities of the sloping strokes indicating the subdivisions lie close to the paper upon which the plan is being plotted, enabling the distances to be easily marked off the thin edge with a needle-pointer. The old-fashioned triangular scales cannot be recommended for use by either engineers or architects. The offset scale is usually two inches in length, and has its adjacent edges accurately at right angles to one another, so that when moved along the edge of the plotting scale it acts as a set square (*Plate* II., *Fig.* 2). Plotting scales of a greater length than 12 or 18 inches, when made of wood or of ivory, should not be generally employed, as their length alters with variations of temperature. Longer scales are sometimes used upon drawings describing works of construction, but then the chief dimensions are generally figured upon the plan. The use of a scale with only the divisions marked upon it which correspond to the scale of the plan to be plotted is strongly advised, and it is well to have these divisions reading from right to left, as well as left to right, upon both edges. When the mind is occupied with the details to be plotted, and their accurate representation, it ought not to be distracted by perpetually thinking if the right edge of the scale is being employed, as would be the case when more than one set of divisions is indicated upon the same scale. This figure shows three kinds of plotting scales. The first represents a plotting scale supposed to be one foot in length, divided into ten divisions to one inch upon both edges, with an offset scale similarly divided, having the zero point in the centre. In practice, with the use of a split offset, the zero point upon the long scale is placed opposite the zero point upon the base line and the plotting scale is set parallel to the base line, so that the zero point marked on the offset scale shall accurately slide along the line.

The plotting scale is placed upon either side of a base line as may be found most convenient, and is maintained in position at an exact distance from the base line equal to half the length of its offset scale by flat weights, as shown, to secure it from movement by the pressure of the offset scale against its edge, thus leaving both hands free for moving the sliding scale upon its edge when plotting the offsets. When a length of ten chains is plotted (the scale of the plan being here supposed to be one chain to an inch) the plotting scale is moved forward and re-set. The centre plotting scale is shown similarly divided to that upon its left-hand side, but here the offset scale is marked to read from the edge which slides along the feather edge of the plotting scale. Hence in this case the plotting scale must be always placed upon the opposite side of the base line to the position of a line representing a boundary or fence which has to be plotted, the edge being maintained by weights upon the base line as shown. It will be observed that should the offsets taken from the chain line cross the base line, the plotting scale would have to be placed first on one side of the line and then upon the other with the use of an ordinary offset, whereas with the use of a split offset scale and offsets limited to the length of an inch upon paper (equal to 100 links in the present case), the offsets could be plotted for a distance of ten chains, or even twelve chains, the length of the scale, with the plotting scale set in one position. In re-setting the plotting scale for continuing the measurement of a base line, lengths of ten chains are measured at a time, corresponding to a length recorded by the use of ten arrows in the field. In the diagram the third ten chains distance is shown plotted with a scale containing a series of divisions marked as "feet" upon one edge, and great care must be exercised by the draughtsman not to apply the wrong side of either the plotting or of the offset scale in pricking off the required distances. A pencil point, however sharp, is not sufficiently accurate. The best needle-point holders are those in which a small bolt is passed through the side of the holder, the bolt having a hole drilled in its head to receive the needle and secure it firm against the holder by turning a mill-headed nut upon the other side of the instrument. The needle can be easily replaced when broken, and is less liable to slip when this method is adopted than when it is held between the two sides of a tapering split tube over which a slide ring is pressed.

Fig. 5, *Plate* II., illustrates the mathematical principle upon which vernier scales are constructed. *Figs.* 6, 7 and 8 show the application of this principle to a box sextant, theodolite, and circular protractor respectively. These figures illustrate the most general subdivisions of a degree that are employed in practice, and a study of their construction by the surveyor will enable any other vernier to be readily understood. The eye can more easily detect the continuity or the want of continuity in a line than it can distinguish the number of lines, or any particular line among a number that are drawn so close together as scarcely to leave daylight between them.

Drawing instruments should be free from all irregular motion in the joints when opened or closed. All compasses should be furnished with double joints, except dividers, because dividers should never be opened in use to any obtuse angle. Long lengths should ither be transferred by scale or by the use of beam compass dividers.

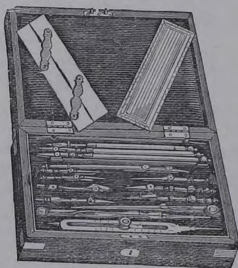


Fig. 3.

Pen and pencil spring-bows also have no double joint. The smallest and the largest set of spring-bow pen, pencil, and dividers are the most useful. The object of the double joint is to enable both the compass legs to be set at right angles to the surface of the drawing paper. All compasses should have needle points, but not the dividers, as they are not pressed into the paper in the same way as the leg of a pair of compasses. When needle points form the extremities of a pair of dividers, the needles cannot be held sufficiently rigid to secure accurate measurement. Fineness of movement, for adjusting the points of a pair of dividers to any required distance apart in dividing up a line, may be assisted by having one of the legs made with a spring action, so as to be capable of alteration for a minimum amount by a screw adjustment acting on the spring. In some instruments, the screw is worked by a milled head attached to the outside of the leg, but it is preferable when worked by a nut sunk into a mortise in the leg. To ascertain if the joint between the legs of a pair of compasses or dividers is satisfactory, open the legs till they are nearly in line, and while slowly closing them, notice if the hand pressure required to bring the points together remains uniform. Any tendency to jerk gives evidence either that the centering is imperfect or the joint uneven.

Proportional compasses consist of two flat pieces of metal arranged side by side, and each fitted with a sliding piece, which travels in a dovetail groove up the centre of each piece. The sides are united by a pin, which forms the axis of the instrument. They can be fixed by means of a mill-headed screw, which clamps the sliding pieces in any position, and thus the instrument can be set to any of the proportions marked upon its sides. These engraved marks usually refer to lines, circles, plans and solids. Before setting the slides to any required ratio, the instrument is closed and the extremities brought together. There is a stud upon one of the sides, and a corresponding notch in the other, the fitting of which, one into the other, ensures the points being over one another; but the makers never attempt to set these steel ends to a sharp point like a pair of dividers, because any such setting might alter the exact lengths required for the proportions indicated by the divisions. Rapidity in setting, for any ratio not indicated upon the sides of the instrument, is greatly aided when a rack is inserted working within one of the grooves fitted with a pinion upon the slide, the milled head for working which is attached to the opposite side to that upon which the clamp screw acts. The scale for circles gives the lengths of equal chords up to 20 units between the shorter points for a given radius measured between the long points. The scale for plans gives the linear distance at one end between the points, which would give an area of the required proportion to that given by a linear distance measured between the points at the other end of the instrument, all dimensions over the given area being similarly measured for squares. The same ratio applies with the scale for cubes and solids, and the construction is very ingenious; but the obtuse extremities of the instrument renders it difficult to compare dimensions in this way with sufficient minuteness to ensure accuracy. Universal drawing instruments, whether in the shape of compasses or scales, cannot be recommended.

The best beam compasses are those known as the Swiss pattern, the top side of which has an open head, so that instead of a beam having to pass through the head of the compass it can be attached to the edge of a straight-edge, or preferably to a beam of T section, so as to resist lateral as well as vertical deflection. For striking arcs of circles of about six inches radius and upwards, a short set square forms a most useful beam, its triangular shape giving rigidity to the connecting piece between the compasses. Beam compasses employed in this way are superior to the use of compasses in which a lengthening bar is introduced, and give greater satisfaction than even the improved tubular system. The compass points always stand at right angles to the drawing paper. In inking in straight lines to join the curves, always ink in the curves first, it being easier to join a straight line to a curve than a curve to a straight line. Drawing pens should always be worked at right angles to the drawing paper. They should never be put away in the box with ink between the nibs, but always dried by passing a piece of blotting paper between the nibs, or better still, a piece of new chamois leather, but not an ordinary duster, because, being made of fluffy material, the threads are apt to come out and adhere to the nibs of the pen.

The pentagraph consists of four bars, mounted upon small castors, the bars being usually made of flat brass, and connected by knuckle joints at B, G, F, H, to enable the bars to travel freely over a plane (see *Plate* I.). The inner arms are each about half the length of the outer arms, and are so attached to the outer arms as to form a true parallelogram in all positions of the instrument. The knuckle joint is made by a kind of double pivot, which is fixed vertically to one of the bars, and works in two centres formed in the attachment of the other bar. The divisions for setting the instrument are engraved upon the adjacent long and short bars, marked, respectively, "graduated long arm" and "graduated short arm." At A, or near the extremity of the plain long arm, at double the distance from B of the short arm H E (= B G) is a fixed vertical socket adapted for the attachment of either the pencil point or tracer, or fulcrum pin; while similar, but moveable, attachments are provided upon both the graduated long and short arms by means of sliding boxes, each fitted with a milled-head clamp screw for use in setting the instrument. The fulcrum contains a lead or brass weight, to which is fixed a bright iron or steel pin, over which the whole instrument revolves. This pin fits exactly into one of the vertical sockets, the instrument when in use being nicely balanced by the six ivory castors connected to the swivel bearings, which are placed under and near the joints, and also at the extremities of the long arms. Professor Willis, in 1821, suggested dispensing with the supporting wheels, and thus eliminating the friction they produced upon the surface of the paper.

This he effected in the eidograph (see *Plate* I.), which consists of three stout bars solely supported by a central fixed stand, over which the instrument works. The figure shows the bar A carrying the tracer, and the bar B carrying the pencil-holder.

In the eidograph there is found to be less vibration than with the comparatively thin flat arms of the pentagraph, and the single support in the former instrument enables greater freedom of action to be attained. Exact and simultaneous motion is imparted to the two horizontal wheels of the eidograph by means of a steel band attached to the rim of the pulley wheels, which are turned in a lathe to equal diameters, so that the movement of the steel band round their periphery produces a guiding action equivalent to that due to the parallelogram formed by the arms of a pentagraph. The steel band is in two lengths, having screw connections to adjust the tension, and so to lengthen or shorten it for adjustment upon either side. Thus the arms attached to the wheels can be set to exact parallelism, and they will remain parallel at any angle with the central bar which unites them. The central bar is clamped to the sliding box, which connects it to the fulcrum support.

When employed for reduction, as shown in the figure, the portion of the central bar carrying the bar marked A is heavier than the portion carrying the bar marked B. Hence a balance weight in an eidograph is needed, and placed upon the short end of the central bar to steady the instrument in such a position as to balance it over the fulcrum under C. In both the pentagraph and the eidograph, the pencil-holder, the fulcrum point, and the tracer should, under all circumstances, be in one straight line, when the instrument is set ready for use, so that a fine string stretched from the outside centres (as shown by the dotted lines in the diagrams) should pass over the middle centre, otherwise the instrument is not correctly set.

In the eidograph, this straight line may take up any position round the fulcrum bearing C, whereas in the pentagraph it may radiate round the outside centre A. In the pentagraph, when the fulcrum pin is placed in the socket of the sliding box upon the graduated long arm of the pentagraph, and the pencil-holder in the socket of the graduated short arm, with the tracer at A, the instrument will reduce in any set proportion, and the reduced plan will be drawn erect, that is, with its north point looking the same way as the original drawing; but when the fulcrum pin is placed in the socket upon the graduated short arm, and the pencil-holder in the socket upon the graduated long arm, the reduced copy appears reversed, or upside-down, to the original plan.

A reverse plan is thus drawn when an eidograph is employed, but the adoption of the reverse process permits a wider range in the ratios to which the instrument can be set, as the proportions can be increased up to the same scale as the original, whereas when the fulcrum is placed upon the outside or graduated long arm of a pentagraph, the proportion of reduction cannot exceed half-size. Before commencing a drawing, after setting the instrument, it is expedient to traverse the tracer approximately over the boundary of the plan while watching the movement of the pencil point over the space required, in order to ascertain if the paper and the original plan are placed in the best position with reference to the fulcrum weight.

As soon as the most convenient position is ascertained the fulcrum point can be attached to the drawing table by pressing in the needle points, which are generally provided upon its under side, or the fulcrum base can be prevented from shifting over a plan, without marking it, by laying between the paper and the fulcrum weight a large indiarubber ring of sufficient diameter to hold the needle points.

Great care also must be exercised in preparing a cedar-cased lead pencil prior to fixing it in the socket, so that when revolved in the vertical tube it marks a point and not a circle. Faber's patent point cases are excellent in this respect (see *Plate* I.). In both the pentagraph and the eidograph the pencil-holder is constructed so as to be loaded with one or more weights at the top, thus enabling the pencil lines to be marked with more or less distinctness as required. Provision is also made for lifting the pencil-holder off the paper by means of a silk cord attached to it, which, after passing along the bars and over guiding pulley wheels round the angles of the instrument, is twisted tightly round the tracer-holder, so that, by depressing the cord near the tracer-holder, the pencil point is easily lifted off the drawing paper, and thus prevented from making misleading lines or marks.

It is important that the drawing paper should lie perfectly flat upon a level table, otherwise the castors upon which a pentagraph is mounted will sustain frequent jerks. Irregularities in the surface of a drawing table also lead to inaccuracies of draughtsmanship, especially when an eidograph is employed. With many large plans the instrument will not embrace the whole sheet, and the plan has to be divided into sections. Under such circumstances junction lines must be ruled, and a portion of each section upon both sides of the junction line should be repeated upon each reduced piece of plan, to ensure sufficient overlap for joining the reduced portions accurately together when making a complete copy.

To produce an enlarged copy, the proportions in which the arms of both instruments are set remain the same, but the pencil-holder and tracer exchange sockets.

The enlargement of plans by these mechanical contrivances can, however, never be trusted if great accuracy of measurement is important. Where possible, the best way is to re-plot the entire survey from the field-book to the enlarged scale required.

The mathematical principle of the pentagraph may be thus explained.

Since H F (see *Plate* I.) is always parallel to B A, and the angle F H E, by construction, is equal to the angle A B E, the triangles F H E and A B E are similar. Hence H F : B A : : E F : E A.

If, therefore, the fulcrum be placed at E, the pencil point at F, and the tracer at A, a plan can be reduced to one-half the scale, because H to F, measured from centre to centre of joints, is one-half the length of B to E, measured from the centre of the joint at B to the vertical axis of the fulcrum at E; and, therefore, $E F = \frac{1}{2} E A$. So also A B C and K H C being similar triangles, H K : B A : : C K : C A. Again, A B D and H L D being similar triangles, H L : B A : : D L : D A.

In the diagram, the point F bisects the line E A, and it is clear, if E be regarded as a fixed point, and A be moved to N, that F will move to O, and E O will equal $\frac{1}{2}$ E N, so that the new position of F will continue to bisect the distance between E and the new position of A. Again, if A travel to M in a direction at right angles to E A, then F would travel half this amount, and at the same angle, so as to remain in the centre of the straight line joining the point E and the new position of A. Hence the triangles remain equiangular in all positions of the moveable points; and, therefore, every movement of A gives proportional movement to F, which, in this case, is seen to be one-half.

In the eidograph, the sliding arms and central beam are marked with 100 graduations upon each side of the centre, each division being, by the aid of a vernier, read to one-tenth of its length. To set this instrument to reduce or enlarge to any required proportion, take the sum and difference of the fractional terms. Then, as the sum is to the difference, so is 100 to the number required, and to this number the arms and centre bar are to be set. For example, let it be required to reduce one-third; then, $3+1=4$, and $3-1=2$. Then, as $4:2::100:x$, and $x=50$. The arm carrying the tracer is to be lengthened to division 50. The centre bar is to be set to division 50 on the pencil side of zero, and the arm carrying the pencil is to be shortened to division 50. The instrument, thus set, will give a tracing with the pencil one-third of the size of that traced by the tracer.

The only adjustment which may be put out is the parallelism of the bars passing under the wheels. This is to be corrected as follows:—Place all the verniers to zero, and, with the arms at right angles to the centre bar, make a mark with the tracer and pencil points, then wheel the instrument half round, and placing the tracer into the mark made by the pencil, the pencil should fall into that made by the tracer; if it does not, half the error is to be corrected by letting out and taking up the spring passing under the wheels by means of the screws in the middle of the wires.

To reduce a plan drawn to a scale of five feet to one mile, to a plan drawn to a scale of one chain to the inch:—

Five feet to one mile = 88 feet to the inch.

One chain to the inch = 66 feet to the inch.

$$88-66=22. \qquad 88+66=154.$$

$$\frac{22\times 100}{154} = 14{\cdot}28.$$

If, therefore, the index points on the slides be set by the aid of the verniers to 14·28, the reductions of the plan can be effected.

The circumferentor (*Plate* III.) consists of a circular box containing a very sensitive magnetic needle, mounted upon a stand with folding sight vanes, which can be raised for use perpendicular to the compass box. In each vane there are slots and holes provided one over the other, a fine line of silk, horse-hair, or wire being strained down the centre of each slot, and the circular holes are each crossed by lines at right angles to one another, the intersection of which is used in ranging the opposite sight vane in line with a distant station. These sight vanes are alternate, the aperture serving as an eye-piece in the one being exactly opposite the aperture by which the centre of an object is ranged in the other.

With this instrument the relative direction of roads or streams may be roughly determined by a comparison of each with the magnetic meridian indicated by the needle when at rest. The needle revolves upon its bearing in the centre of the dial, and the divisions are marked upon the compass box, as shown in *Fig.* 2, which represents a plan of the instrument with the sight vanes raised as in *Fig.* 1. When carried from station to station, the instrument is closed, with a cover over the compass box to protect it from accident, the sight vanes being folded down for convenience of packing. The needle in *Fig.* 2 is released to play freely by pulling out the stop-piece marked M (*Fig.* 3), which represents a plan of the underneath portion of the instrument, and also shows the position of this stop-piece, with reference to the set screw H, which clamps the instrument to its stand. The fixed divisions upon the dial in the compass box are, in the best instruments, marked upon a raised circular rim, which forms the outer edge of the silvered plate marked A, in the centre of which the needle is carried. These divisions are engraved consecutively to 360° in a contrary direction to the figures upon the face of a watch, and are usually cut upon both the outer and inner edges of the face of this rim, with the figures indicating the degrees placed in order in a circle between them, as shown in *Fig.* 2. Upon the inner portion of this plate the letter N denotes the north, coincident with the line marked 360° upon the graduated rim, and the letter S, immediately opposite, denotes the south point upon the dial coincident with the line marked 180°.

The plate over which the needle travels is further divided within the raised rims by cross lines, at right angles to one another, into four parts, each quadrant being semi-divided, and containing subdivisions reading from zero at the points marked N and S, advancing in tens of degrees to 90° at the points marked E and W. In working with a circumferentor, when the south side of the compass is turned towards the surveyor, he can read the bearing from the north end of the needle with facility. The inner circle of divisions upon the raised rim enables us to read to degrees the angle of intersection at the centre of the compass between the direction of the needle pointing to the magnetic north over the line marked N and S upon the dial and the line ranged by the sight vanes, while the addition of the vernier enables us to record angles within three minutes, or one-twentieth of a degree. The compass box is connected with an exterior gimbal ring, the latter carrying the arms upon the ends of which the sight vanes D D are attached. Some instruments have spirit levels, B and C, fixed at right angles to one another upon these arms. A vernier is fixed to the inner edge of the box which holds the compass, its zero point being placed in the same vertical plane as the centre line of the sight vanes, and in a line at right angles to the axis of the gimbal ring. A circular rack and pinion, worked by the milled screw K, shown in *Fig.* 3, communicates to the vernier plate an absolute horizontal motion round the outer circular rim of the dial plate. By means of this spur and pinion movement great steadiness of action is obtained. The gimbal ring carrying the sight vanes can be fixed rigidly to the compass box by means of the turn-stops L L, as shown in *Figs.* 1 and 3, or inclined, as shown in *Fig.* 4, when required to suit the declivity of a heading or tunnel. In *Fig.* 4, it will be observed that the turn-stops L L are unclamped by reversing. With the use of an arc, marked F, which can be attached by the screw E, or removed at pleasure, a gradient may be measured while the compass box remains level and records the magnetic bearing. Two scales of graduations are engraved upon this arc, one indicating the degrees of a circle between zero and 45°, while the other scale gives the corresponding values of the versines of the angles registered.

The compass box is commonly mounted upon a ball and socket tripod, fitted with a turned and bored ferrule-joint, and differs in this respect from the screwed head shown in the illustration of a ball and socket tripod stand (*Plate* IV., *Fig.* 1).

In order to find the bearing of a line by the circumferentor, place the instrument over the station point, with the gimbal ring clamped to the compass box, as in *Fig.* 1, and guided by the spirit bubbles, set it level by means of the ball and socket joint. The needle should be immediately released on setting the instrument, to give it time to set. If the circumferentor has no spirit levels attached, it may be set up approximately level, by unclamping the needle and noticing when it swings freely. Then turn the instrument round so that the 360°, or point marked N upon the dial, is coincident with the marked or north end of the needle, and carefully make this coincidence, when the needle comes to rest, as accurate as possible by turning the milled screw K, which is situated below the compass box. Having done this, tighten the set screw H. Then, by means of the milled screw K, turn the sight vanes in the direction of the proposed line. Open, if necessary, the turn-stops L L, and so place the sight vanes D D that the centre of the object viewed is bisected by the cross-hairs, the dial plate being, as shown by the plan in *Fig.* 2, open upwards, the divisions can be read entirely round the circle.

It will be observed, upon reference to the dial plate in *Fig.* 2, that in some instruments the right-hand point, when looking towards the north, marked N, from the centre of the plate, is lettered west, and that the opposite point upon the left is lettered east. Thus the relative positions of east and west are reversed. The true position is indicated upon the compass card shown in *Fig.* 5. This is done to enable the surveyor to book the direction of a line with reference to the magnetic meridian in the way in which the line has to be plotted on paper, the reading in the field giving the angle of the magnetic meridian with the given line. Thus we record one relatively to the other. In the same way we speak of the sun rising in the east, and setting in the west, but this appearance is due to the earth turning upon its axis from west to east in 24 hours. It will be found an advantage to maintain a uniformity of method in registering the angles, and always to book the relation that the magnetic north bears to the line of observation as recorded by the figured dial plate when entering the bearing in the field-book.

In Lean's dial, illustrated in *Plate* IV., *Fig.* 2, it will be observed, in the first place, that the gimbal ring action, which was seen to be attached to the compass box in *Figs.* 1 to 4 of the circumferentor, is omitted, and that the two side arms which carry the folding sight vanes are permanently fixed parallel to the compass dial. The sight vanes D can be removed, and the direction ranged by a telescope, which traverses a vertical arc, marked F, above the compass box, by which arrangement all vertical angles are measured. The addition of the telescope enables the surveyor to take longer and more accurate sights than when no telescope accompanies the instrument. The vertical arc consists of a flat metal ring with pieces radial to its centre, marked E, to which is attached a saddle body-piece carrying the telescope. Upon each face of the arc a scale of divisions is engraved. One scale shows vertical angles in degrees from zero to 90°, marked from about the centre outwards, the subdivisions being recorded by a vernier upon which an index arrow registers the angle to be read. The vernier plate is attached to the traversing body-piece of the telescope. By means of an index årrow marked upon a plate fixed at the back of this vernier plate, and which points to a scale upon the other face of the arc, the horizontal equivalent of any measurement taken along an inclined plane can be arrived at, the scale giving the difference between the hypothenuse and the base of a right-angled triangle in terms of the number of links to be deducted from one chain's length of 100 links, when measuring up or down a plane inclined to the vertical at the angle indicated by the scale of degrees, marked upon the face of the arc first described. The arc upon which the scales are marked gives the nominal size of the instrument. If the circle of divisions has a diameter of six inches, this instrument would be called a Leans' 6-inch miners' dial. The sight vanes D are secured as required to the side arms of the compass box by the set screws, marked Q, which are attached at the holes marked W, and the vertical arc F is attached at the holes marked V. The telescope can be clamped to the arc by means of the mill-headed screw marked N, the tangent screw marked J being intended for slow motion in final adjustment when the screw N is tightened. When the index attached to the sliding vernier stands at zero, the line of sight in the telescope (which joins the centre of the diaphragm marked S with the optical centre of the glass T) should be parallel to the dial in the compass box, and when the telescope is so clamped the compass box can be set level by means of the long spirit bubble marked C, which is fixed under the telescope, and the transverse or short bubble marked B upon the projecting arm of the compass box. The needle is set free by withdrawing the lever stop-piece M, and having set the mark N or 360°, marked upon the compass dial, so as to coincide with the north point of the magnetic needle when at rest, the compass box, with the arms carrying the sight vanes, or arc and telescope, may be made to turn round the dial by means of the milled head K of the pinion working the revolving gear.

In the more expensive forms of circumferentors to which a telescope is attached, we find parallel plates with distance screws between them added, as the increased weight of the upper portion requires a wider base than can be obtained with an ordinary ball and socket joint. These plates clamp the body of the instrument, and are screwed on to the head of a tripod stand, the horizontal position of the compass box being determined in setting up by means of one or more spirit levels, so fixed as not to interfere with the action of the needle.

The circumferentor, under these circumstances, resembles a theodolite, which records angles between any two or more given directions independent of the magnetic meridian, the addition of a compass in a theodolite to give the bearing of lines being quite subsidiary to the general purposes of the instrument. Great care must be exercised in taking the bearings with the circumferentor. The ordinary magnetic needle, when mounted so as to be free to move in any direction, would come to rest in a position which would be not only so many degrees to the west or east of the astronomical or true north, but its north end would also dip. The needle in a compass box is, however, so pivotted as to be constrained to move in a horizontal plane only, and by means of a sliding counterpoise, which is attached so as to be adjustable upon the needle itself, the tendency to dip is obviated. The compass box attached to a circumferentor being usually of a large diameter, it is necessary to ascertain that the long needle which it contains is properly balanced to obviate the effects of dip, and the same precaution is also observed in the compass box attached to a theodolite. Imperfections of the needle may be produced either from the loss of magnetic power in the poles of the needle, the blunting of the central pivot over which it turns, or local attraction by masses of iron whose presence may be unsuspected. The needle in a circumferentor should reverse to every graduation of the divided surface. Thus when the compass is turned half round and the sight viewed a second time in the direction first indicated, the needle should cut opposite degrees at each trial. The blunting of the central pivot when the needle is not in use may be prevented by a lifting screw or stop-piece, marked M, which is worked by a concealed spring, and throws the needle bearing off the supporting centre.

The plane-table is an instrument which was extensively employed in surveying before theodolites attained their present perfection of construction. A plane-table was usually made of wood, forming a board about 16 inches square, having its upper edge rabbeted to receive a boxwood frame, within which drawing paper was stretched and retained. One face of the frame was graduated to 360° from a centre in the middle of the board, while the reverse face of the frame was usually divided into equal parts for the purpose of ruling parallel lines. A compass was let into one side of the table, intended principally for use when setting out the instrument at new stations. The index bar had a perpendicular vane at each end made of brass, in which the eye, upon looking through one sight vane, was made to bisect the vertical thread upon the opposite sight vane in setting the index bar upon any required distant object. The direction was then marked off by the edge of the bar upon the board.

A good drawing board is made in sections (see *Plate* IV., *Fig.* 3), to prevent warping, and when used as a plane-table is either set upon a firm tripod, or over a plain ball and socket stand, as shown in *Fig.* 4 of this plate, so as to be adjusted horizontally.

Sometimes a plumbing arm is added, which can be set at any given point on the paper, the plummet hanging from the arm determining the corresponding point on the ground.

Plate IV., *Fig.* 4, shows:—A, an hemispherical concave metal cup, fastened by screws to the wood top of the tripod. B, the upper or convex part fitting accurately into the cup and clamped to it at will by the clamping-piece C and nut D; a strong spiral spring in the hollow cylinder between C and D serves to hold the two spherical surfaces of the socket together and allow of the easy movement of the one within the other. Greater binding power between the moveable portions is thus provided than in the smaller ball and socket stand. The plane of the socket B supports the table, and is connected with its under surface by three segments of brass bars, two of which are shown at E E by capstan-headed screws.

For military purposes in open country, where rapidity is a main object, the plane-table commends itself, as the map is produced at once in the field. The straight edge is called an alidade when a telescope and a vertical arc are attached to it. When a micrometer is applied to the alidade of a plane-table the instrument forms a topographical stadia.

The advantages to be secured in the rapidity of work by the use of this graphic method for surveying are greatly limited by the climate of the country in which this system of mapping is adopted. An excellent description of several improved forms of tripod heads, which have been added to plane-tables in use abroad, and also of the optical advantages secured by the substitution of telescopes for ordinary sight vanes, is to be found in a paper upon "The Economic use of the Plane-Table in Topographical Surveying," read at the Institution of Civil Engineers, by Mr. Josiah Pierce, M.A., in February, 1888 (Vol. XCIII., Part III.).

Colonel W. H. Richards' cavalry sketching case consists of a small drawing board, about six inches square, fitted upon two of its opposite edges with wooden rollers, having clamping screws at one end, and the rollers are made to revolve in sockets upon a head and a foot-piece fixed upon the remaining two opposite edges, which are graduated into divisions of an inch at points exactly opposite to one another. Upon these rollers a continuous strip of drawing paper of any required length, say six inches in width, is wound, and is thus stretched across the board between the two rollers. In the centre of the top or broad head-piece a small magnetic compass is placed, counter-sunk in a collar in which it can be revolved by means of a projecting catch-piece, and upon the glass face of the compass a fine line is engraved to guide the operator in setting the needle to a working meridian. A metal pivot is attached to the centre of the back of the board, by means of which the board can be either fastened round the left wrist or mounted on a tripod stand, and thus made available for service both on horseback and on foot. When not in use, the board is usually carried in a leather case, which is strapped by a horseman to the saddle in a similar manner to a shoe case, or it can be attached to the waist-belt by a pedestrian.

Captain Willoughby Verner, in a very practical treatise upon *Rapid Field Sketching and Reconnaissance*, thus describes the use of the board :—"The working meridian is set in the required position

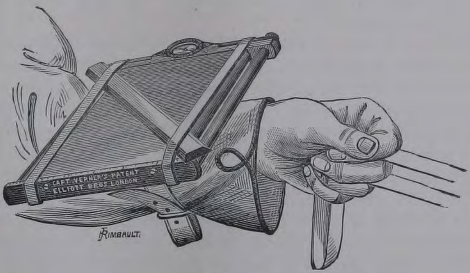


Fig. 4.

by turning the compass box round in its socket, and the relative position of the 'working meridian' to the board itself having been determined so as to get the board in a direction best suited for the route to be surveyed, the board is set for sketching by revolving it on the pivot beneath it until the working meridian coincides with the direction of the magnetic needle when at rest." A simple, straight-edged piece of wood, about 10 inches long by $\frac{3}{4}$-inch wide, is held by a couple of indiarubber bands round the board to serve as a ruler for determining the direction of any distant object, its position being delineated upon the sketch with a line ruled in pencil. Further particulars may be obtained from Messrs. Elliott Brothers, 101, St. Martin's Lane, the makers of this useful instrument.

In Hoffmann's tripod head (see *Plate* V., *Fig.* 1) the plumb-bob is suspended vertically under the actual centre of the head, and the setting up is approximately effected without the use of the levelling screws, their use being reduced to a minimum, and only applied for final adjustment to a perfect level, the operation at the same time clamping both the joint and the centering arrangement. The levelling screws remain at all times perpendicular to the plate to which they are attached, and to the screw cap on which they rest. No extra screws are required to clamp the head, the clamping becoming easily loosened for re-setting by turning two adjacent side screws, and tightened again by working two opposite levelling screws in the usual way, after shifting the head, by moving the sliding plate and working over the centre, which, it will be observed, is common to the two spherical tops, that centre being the point to which the plumb-line is attached.

Figs. 2 to 6, *Plate* V., illustrate Doering's tripod head, made by Messrs. Elliott Brothers, which resembles the system adopted for a ship's compass, with the addition of vertical arcs at right angles to one another respectively, which are clamped to each other by the thumb screw marked L, and by the thumb screw marked P to the frame, which is fastened upon an ordinary tripod stand. Tangent screws for slow motion in adjustment are also provided at H and K.

Figs. 7 to 11, *Plate* V., show Jahn's tripod head, also made by Messrs. Elliott Brothers, in which adjustment is effected by means of the wedge-shaped connection marked B, which is turned horizontally by the milled edge marked A for the position shown in *Fig.* 7, and by means of the vertical screw marked C for the position shown in *Fig.* 8.

Figs. 1 and 2, *Plate* VI., show Pastorelli's tripod head, combining the ball and socket system with the arrangement of outside parallel plate screws for clamping and final adjustment.

Tribrachs.—In these the parallel plates form a tribrach (*Plate* VI., *Figs.* 3 to 6), having three radiating arms or branches, near the outer extremities of which connecting adjustment screws are placed, and the comparatively greater distance from the vertical axis of the instrument at which these screws are worked enables great fineness of adjustment to be attained. With a four-screw arrangement of parallel plates, care must be taken that all four screws bear upon the lower plate, or the instrument cannot be expected to work steadily. If one screw be moved more than the other, one of them is apt to be raised off its bearing plate, and the upper portion carrying the limb and stage will then rest upon the three remaining screws and be liable to rock, but with a three-screw arrangement of parallel plates the disposition to rock is obviated, as the instrument requires at least three points to rest upon, and the elevating screws form the only attachment when locked between the tripod head and the instrument. In order to avoid bending the central connecting portion of a four-screw arrangement, when adjusting the parallel plates by means of their elevating screws, a slot, shown in *Plate* VI., *Figs.* 9 and 10, has sometimes been introduced into the upper plate. The upper plate of a three-screw arrangement is often made $\frac{1}{8}$-inch thick, with a vertical flange carried round its edge, and at the projecting extremities of each arm solid bosses of a suitable depth are cast, which are tapped to receive the threads of the elevating screws. In *Fig.* 3, *Plate* VI., each screw terminates in a semi-circular ball, which rests in a socket upon the lower parallel plate, and is secured by a locking plate, which is clamped by tightening a set screw. Thus a uniform motion is obtained without indenting the lower parallel plates on which the screws rest. In a four-screw arrangement, the screw ends are upon this account often made to bear upon small thin pieces of leather glued to the top of the lower plate. In the arrangement of a three-screw combination of parallel plates (shown in *Fig.* 3) it will be observed that any tendency to vibrate in working the instrument is kept below the locking plate, and that the locking plate (a plan of which is shown in *Fig.* 6) assists to maintain the rigidity of the parallel plate connection. *Fig.* 4 illustrates the detail attachment of one of the vertical screws, and *Fig.* 7 shows the washer plate for securing the locking plate in position by means of the clamp screw. To counteract any wearing away that may occur after some time in the screw portion of the projecting arms to the upper plate, a vertical slit is often made in the end of each arm, and a side capstan-headed screw provided to each for clamping the joint.

Figs. 11 to 16, *Plate* VI., show a framed stand made by Messrs. Troughton and Simms, in which the middle plate has two pivot connections, the centre lines of which meet at right angles to one another at the centre of the plate. To one of these pivot connections the top plate is attached by a screw bolt, which is secured by a capstan-headed nut. To the other pivot connection the lower plate is attached in a similar way. The lower plate is connected to the framed stand as shown in *Figs.* 11 and 12. This arrangement allows of the axis of the instrument being exactly centred over the station mark.

The plumb-bob, which is usually supplied within a theodolite box, is scarcely heavy enough for ordinary field work. One such as those shown in *Figs.* 17 and 18 of *Plate* VI., is more generally adopted. The American form claims to possess merit, because, as shown in the diagram, it contains a concealed reel R, on which the string, or whip-cord, S, is wound by turning the head H on top, and the reel is reversible. The friction upon the reel within holds the plumb-bob at any desired vertical distance from the point of its suspension.

The sextant (*Plate* VII.), and other reflecting instruments, though primarily intended for use at sea, may also often be advantageously employed by the military engineer. The rays from a certain object or station are intercepted by a mirror G (*Fig.* 1), which is revolved upon an axis at right angles to the face of the instrument until the rays are reflected in another glass E, and thus made to appear in contact one over the other through a telescope in line with another given point or station.

A sextant (*Figs.* 1 to 4) is usually made in the form of the sector of a circle of about 60° in angular extent, S S S (*Fig.* 3), but records angles upon the graduated limit (*Fig.* 1) up to 120°, its construction depending upon the principle (as stated by the late Professor Rankine in his work on *Civil Engineering*) "that if there are two plane-mirrors whose reflecting surfaces make a given angle with each other, and a ray of light in a plane perpendicular to the planes of both mirrors is reflected from both successively, its direction after the second reflection makes with its original direction an angle which is double of the angle made by the mirrors with each other." The instrument is so framed as not to be liable to bend. An arm G, carrying an index L, and bearing a vernier scale to the divisions on the arc, is attached to, and works round the centre S; a microscope B is appended for reading the divisions. At the back of the instrument is a clamp screw C for temporarily fixing the index arm in any required position, and outside the arc, at D, is a tangent screw for imparting a slow motion when setting the instrument. A mirror G is fixed upright on its edge, and being attached to the radiating index arm, is called the index glass. The mirror fixed at E, which is half silver and half plain (see *Fig.* 2), is termed the horizon glass. In the latter mirror (E) the unsilvered half is the furthest from the face of the instrument. Both mirrors have their reflecting surfaces accurately at right angles to the face of the instrument. A telescope A (*Fig.* 4), carried by a ring O, is directed towards the horizon glass. The object of the up and down-piece in which it works is to vary the proportions of the light reflected from the silvered glass G, and through the unsilvered part of the horizon glass E, so as to produce an equalization of brightness, which will be found to assist an accurate observation of angles.

The instrument is held by the handle K in the observer's right hand, circle down, and placed with its face as near as possible in the plane passing through the eye and the two objects, between which the angular measurement at the eye is required. For altitudes, therefore, the instrument is held in a vertical plane. For horizontal observations it is held in a horizontal plane, and for oblique angles in an oblique plane. The zero of graduation upon the limit is placed so that the index of the vernier shall indicate zero when the two mirrors should be parallel to each other. To ascertain this, set the zero on the index to zero upon the graduated arc, and direct your observation to the most distant object that can be clearly seen, in order to reduce the deviation from parallelism between the direct and reflected rays to a minimum. If the image reflected from the silvered glass G does not appear to coincide with the direct vision through the unsilvered part of the horizon glass E, the quantity of their deviation constitutes what is called the *index error*. The arm is adjusted until the two images coincide, and the graduated arc sub sequently read. Should the index now point to the left of the zero *i.e.*, on or within the arc, it shows that the angle recorded is too large by the amount between the index and the zero upon the arc, but should the index point to the right of zero, *i.e.*, off or without the arc, the angle read will be too small when the images coincide, for at the point where the index is, when the two images coincide, the graduations ought to commence. The graduated limit of a sextant is usually divided by a vernier to read to 20 seconds in a small instrument, and to 10 seconds in a large size. H and I are sets of coloured glasses, technically called "darkening glasses," for use as shades when it is required to moderate the light from any bright object, such as the sun, which might prove too dazzling to view with the naked eye. When both the reflected and direct images require to be shaded, as would be the case when the sun's diameter is measured, and his altitude is taken with reference to an artificial horizon, the dark glasses near the eye-piece should be used without applying the other dark glasses.

The following figure shows a smaller type of sextant, known as the box sextant, ordnance pattern.

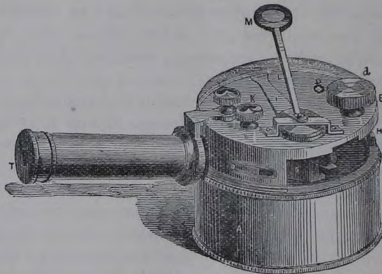


Fig. 5.

The reflecting circle (*Plate* VII., *Figs.* 5 and 6) is an ingenious contrivance to secure accuracy of observation devised by the late Mr. Troughton, senior.

It is similar in principle and use to a large sextant, but has three vernier readings L L L moving round the same centre as the index glass G, which is upon the opposite face of the instrument.

The limit forming a complete circle, the three index arms are made to radiate at angles of 120° from the centre G. The instrument is prepared for observation by screwing the telescope A into its socket O. Then holding the circle by the short handle N, adjusting the drawer to focus exactly the same as with a sextant, direct the telescope to the fainter object and make the contact in the usual way. Now read off the degrees, minutes, and seconds recorded, not only by that branch of the index to which the tangent screw D is attached, but also the minutes and seconds shown by the other two branches. The average result would serve to diminish some of the errors of manufacture, but by measuring the same angle of observation in the other three arcs, and taking the mean of six results obtained with the use of three verniers of the instrument in two positions, the errors become practically eliminated. The additional three observations are obtained by reversing the plane of the instrument and holding it by the opposite handle K, making the contact as before. Thus by observing both forwards and backwards with this instrument, if the true angle is increased by one way of observation, it is diminished the other way by the same amount, and hence not only need the ordinary index error be neglected, but the contribution to error produced by the different glasses is also corrected, and any geometrical error in the setting of the centre of the instrument becomes also obviated by reading the three branches of the index L L L.

The foregoing instructions for taking angles apply equally for taking altitudes by the sea or any artificial horizon, these altitudes being recorded as angles in a vertical plane. Meridian altitudes cannot, however, be taken both backwards and forwards in the same day, because there is not time at noon. All that can, therefore, be done is to observe the altitude one way, but even then you have the advantage of a mean of that altitude by the use of the three combined different verniers. Both at sea and land, when the observer is stationary, the meridian altitude should be observed forwards one day and backwards the next, and so on alternately from day to day, the mean altitudes deduced from such observations giving the true amount.

The station pointer (*Fig.* 7, *Plate* VII.) has a double radial arm and an intermediate fixed arm. Whereas a protractor is used to set out the direction of an angle from any given centre, the station pointer accomplishes the reverse of this, and determines the position of a centre at which a given angle is formed. It is employed for surveying such station points as are inaccessible of chain measurement, and is very useful in coast surveying. The moveable arms being set to the angles subtended by two distant station points with a third distant station point, and clamped, the instrument is placed upon the drawing and carefully moved about until the bevelled edges of the three arms respectively bisect the known positions of the three objects or points observed. The positions of the observed stations being accurately shown on the plan, the position at which the angles have been taken is easily pricked off through the centre of the instrument. *Fig.* 6 in the text illustrates the angles taken at points A B C, which the fixed stations D and F make with the direction of E. These angles can be taken with a sextant, the intersection point at which the angle is observed being determined with a station pointer. In the case of a river section on the line E C, the bearings of the two side stations are taken right and left of a given line of section C E. *Fig.* 7 in the text shows another method with the use of two theodolites upon shore set up at the terminations of a given base line.

Tacheometry (or "rapid measurement"), by means of an optical instrument, was first adopted in Italy. The theory of telescopic measurements is ably explained in a paper upon "Tacheometry, or Rapid Surveying," by Mr. B. H. Brough, Instructor in Mine Surveying at the Royal School of Mines, to be found in the *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. XCI., Part I. Also by M. Henri Bonnami, in a pamphlet entitled *Manuel de l'Operateur au Tachéomètre*, published in Paris in 1883. In mountainous districts, where chaining is laborious and inaccurate, or upon mud lands or places where the nature of the soil over which the chain is pulled makes the links of a chain difficult to read, tacheometry becomes invaluable.

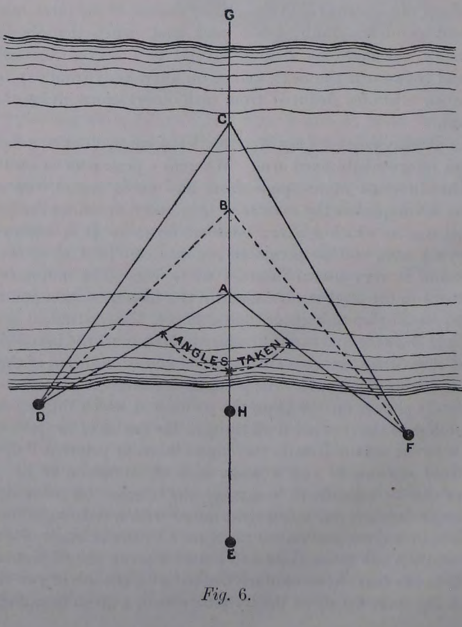


Fig. 6.

The *Station Pointer* is used for plotting the position of any soundings, A B C. The position is fixed by taking simultaneously the bearings of three known objects on shore, D E F. Or, in the case of a river section on the line E C, the bearings of two objects, D and F, right and left of that line.

Section Line, No............ Date..................

	Angle.		Time.	Sounding.		R. S.
Column for any general remarks.	In this column the angles D C F, D B F, D A F, are to be entered.	In this column the description of the points D and F on shore are given.				In this column the reduced soundings are entered, being the heights above the given datum.

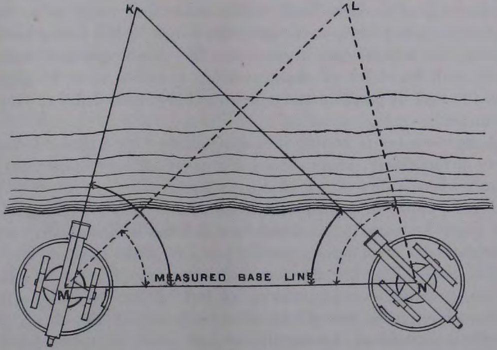


Fig. 7.

The primitive form of instrument employed was invented by Mr. William Green, in 1778, in which a tube containing three parallel wires was employed in conjunction with a stadia or special staff.

The tacheometer (*Figs.* 5 to 13, *Plate* VIII.), and the omnimeter (*Figs.* 1 to 4), enable the surveyor to determine the horizontal distance of any required station from the centre of either instrument by means of a vertical measurement read off a level staff. In the tacheometer two parallel horizontal wires are placed in the diaphragm at a given distance from one another, each being at an equal distance from, and at right angles to, the centre line or longitudinal axis of the eye-piece.

If, as in *Fig.* 10, the distance apart of the two parallel wires from each other be one-hundredth of the focal length of the object glass, every foot which is read upon the level staff will represent 100 feet of horizontal distance when the instrument is properly set up and its telescope adjusted in a level position. In the same manner, two feet read upon the staff would represent 200 feet of distance. Thus the angle formed by the rays of vision being constant, as shown in *Figs.* 11, 12, and 13, the distance varies according to the readings upon the staff. In *Fig.* 8 the cross-hairs are fixed so as to record a horizontal distance of 200 times the height read upon the staff; *Fig.* 9 is set to record 50 times; and *Fig.* 10, 100 times the distance. The eye-piece, as shown in *Fig.* 6, is fitted with a slide and rack, so as to be traversed up and down to the positions shown by the dotted lines by turning the milled-headed screw D. The diaphragm itself remains fixed, and the object of the traversing eye-piece is to be able to read the staff by means of the upper and lower cross-hairs at varying distances.

A tacheometer is almost invariably made with a three elevating-screw arrangement, because they are generally sold upon the Continent, where a three-screw base is preferred.

Fig. 11 shows an ordinary telescope without a stop-piece, in which the angle between the inclined line and the horizontal has not a constant value for different relative positions of the eye-piece and the object glass. The introduction of the stop-piece in *Figs.* 12 and 13 serves to maintain a constant value, but by thus choosing certain rays and rejecting others, the effective power of the object glass becomes diminished, hence the object glass is made large in order to balance this defect by allowing more light to enter the telescope. Special graduated staffs are made, but with an intelligent employment of the instrument an ordinary level staff is quite sufficient.

The third lens B (see *Fig.* 7), introduced into a tacheometer between the eye-piece and the object glass, was suggested by Porro, a

Piedmontese officer, in 1823. The tube, it will be observed (*Fig.* 7), is of smaller diameter between the lens A and the stop-piece at K than between the stop-piece at K and the lenses at C. The object of this arrangement is to admit of the inner tube, which carries the eye-piece, being held in position while it can be moved in and out for focussing distance by the attached mill-headed screw at the side, which revolves a pinion wheel travelling on a rack fixed inside this inner tube, and so drives it backwards and forwards as required. The stop-piece K is generally at or about the centre of the outside tube, though it need not, of necessity, be placed in the centre. The diameter of its opening is carefully calculated to suit the cone of rays transmitted through the object glass C to the inner lens B. The distance between the plano-convex lens fixed at B to the inner end of the tacheometer tube and the stop-piece at K is a fixed distance in each individual instrument, and the tacheometer tube which contains them is fixed by a maker's screw, marked H, to the outside tube containing the object glass C. The distance between the inner lens B and the object glass C also remains constant. The object glass is formed of two lenses, as shown in section, the outer being of crown glass and the inner of flint. The focus of the inner lens B coincides with that of the object glass, consequently the rays travel to the eye-piece in the instrument in a parallel direction to one another (see *Figs.* 12 and 13). In an ordinary telescope the angle of the cone of rays transmitted through the object glass has not a constant value, but when an ordinary telescope is converted into a measuring telescope, a constant value to this angle must be arranged for, and this the construction of the tacheometer provides.

The omnimeter, the invention of Eckhold, a German engineer, (*Figs.* 1, 2, and 3), has a powerful microscope Q R permanently fixed at right angles to the telescope C D.

Both the microscope and the telescope move upon the same axis, at right angles to one another, in every position. Thus a line through the centre of C D is always perpendicular to the line through the centre of Q R. Hence, in *Fig.* 4, if M A represent the central portion of a level staff, the distance O A may be calculated from the readings given by the scale (*Fig.* 2), coupled with the difference of the divisions read upon the staff (*Fig.* 4), thus algebraically expressed we have—

$$\text{Horizontal distance} = \text{O A} = \frac{\text{M N} \times \text{O A}'}{\text{M}'\text{N}'}.$$

This is a most useful application of the instrument, but when it is desired to find any vertical height, then

$$A\,N = \frac{M\,N \times A'\,N'}{M'\,N'} = \frac{A'\,N' \times O\,A}{O\,A'}.$$

The height from the centre point of the axis of rotation to the face of the divided scale, measured at right angles to it, is termed the base line or constant, and is determined relatively, thus—

$$O\,A' = \frac{M'\,N' \times O\,A}{M\,N}.$$

This is usually determined by the maker by taking O A about 100 feet and placing a 10-foot staff M N vertically in this position.

The scale (*Fig.* 2) is usually four inches in length, divided into 100 equal parts, the principal divisions being pointed out by numerals engraved over or near them so as to be readily read by the aid of the microscope Q R, and each of these 100 parts is halved by an unnumbered line so that the whole scale is divided into 200 equal parts. By the addition of a micrometer screw E F the scale can be moved backwards and forwards exactly one of these 200 subdivisions. The circle E F of the micrometer screw is further divided into 100 equal parts by lines properly marked and numbered. Each of these 100 parts is divided into five equal parts by means of an attached vernier. Hence, the 4-inch scale S T is accurately and visibly divided into 100,000 equal parts. Having set up the instrument at one end of a given line in the field, the staff is held by the assistant at the other end of the line to be measured, and the micrometer of the instrument carefully adjusted to zero. Point the telescope to an upper reading of the staff, clamp the telescope in this position, and read the scale. Should an exact division not fall between the two pairs of the microscope, the scale must be pressed forward by turning the micrometer circle to the right until this is effected, and both the micrometer circle and the scale are then read. A numbered division, such as 67 on the scale, indicates 67,000 out of 100,000 parts as above described; an intermediate unnumbered division indicates 500, so that if the hair-lines which designate the centre of the microscope fall between a numbered and unnumbered line and the micrometer circle reads 235, the total is either 67,235 or 67,735, according to the position of the unnumbered line with reference to the hairs of the microscope. It is to be observed that the readings on the micrometer circle are plus for apparent rising gradients of sight, and minus for downward gradients of sight, and that after any reading is recorded the micrometer circle should be re-set to zero. The telescope and microscope being unclamped, a similar operation is performed with respect to the lower reading of the staff, held in exactly the same vertical position as when the first reading was taken, care being taken that the assistant has in no way shifted the staff, and supposing the scale should now read altogether 66,015, we have—

1st reading (say)	67,735
2nd reading	66,015
Difference	=1,720

Now, if $O A_1$ = six inches by construction, and the scale, four inches in length, contains (as stated above) 100,000 parts, it is clear that $O A_1$ would measure 150,000 such parts. Hence, the difference of the staff readings in feet (M N) × 150,000 and divided by 1,720 will give the horizontal distance required from O to A. In the centre of the divisions upon the scale (see *Fig.* 2) a departure point is marked, corresponding to the position of A_1 in *Fig.* 4, to indicate the position of the line of sight when the longitudinal axis or line of collimation in the telescope is parallel to the face of the scale, and the surveyor is assisted in levelling the telescope in this position by means of the bubble tube attached to the telescope. Any error in this departure point may be ascertained, the micrometer circle being constructed to be turned beyond 500 or a half division on the primary scale, and the operator may correct, after first carefully levelling the instrument, by holding the milled head tightly between the thumb and finger, and turning the micrometer screw E F to the right or left the quantity required. If too tight to move, loosen the screw in the milled head a little, taking care to tighten it again when the error is removed. Sometimes heights are distinguished as being positive or negative according as the readings upon the graduated scale of divisions are greater or less than the readings which designate the departure point on the scale. To military engineers, for ascertaining the height of a hill or the depth of a valley, the omnimeter is likely to prove a most useful instrument. The height of the transverse axis of the telescope from the ground can be arrived at by measuring the distance of the upper face of the scale E F to the ground with a steel tape and adding on the known constant distance $O A_1$ (*Fig.* 4).

The planimeter is an instrument by which the area enclosed within any very irregularly curved boundary may be most accurately estimated, and the same mechanical contrivance may be also advantageously employed when the area forms a combination of more than two or three geometrical figures, but in the case of a single triangle or circle, the area can be arrived at quicker by the application of the ordinary rules of mensuration.

The simplest and most elegant form of planimeter is that of Professor Amsler, of Schaffhausen. As shown in *Plate* IX., it consists of two arms, A E and B D, so jointed together by means of vertical pivots as to be able to move with perfect freedom in a horizontal plane. In a fixed scale instrument (*Fig.* 4), the pivots are fixed to the arm carrying the needle point, but in a proportional scale instrument (*Fig.* 3), the pivots are fixed to a sliding box, which is clamped to the bar carrying the tracer.

In both instruments the measuring apparatus is connected to the arm carrying the tracer.

The needle point attachment is fixed at the extremity of one arm B D, and the instrument when in use revolves round this point. The instrument being thus constructed, it is necessary to provide a perfectly level table or drawing board for the planimeter to work upon, and in order that the tracing point and roller as well as the needle point may at all times touch the surface of the paper, and travel over it without jerking, it is important that the paper should lie perfectly flat upon the board upon which it is laid. The roller being very accurately fixed with its axis parallel to the arm A E, is completely under the guidance of this arm, the arm being moved by means of the knob E fixed over the tracer S attached to the other end of the arm.

Professor Williamson, of Trinity College, Dublin, in his elementary treatise on *The Integral Calculus*, has proved, in traversing round the boundary of any given area, that when the tracer S has returned to the starting point, after moving round the entire outline of the required area, the length registered by the wheel K in a complete revolution (the arms A E and B D returning to their original position), is independent of the position of the wheel upon the moving arm A E, and that, therefore, the whole length registered by the revolving wheel at K is the same as if it were placed at the intersection of the centre lines of the two bars B D and A E. A small weight is supplied, which is placed over the needle point to prevent it shifting from its assigned position after the needle point has been gently pressed into the paper over which the instrument is to be worked. The roller L has movements as exhibited in the plate: (1), sliding without rolling along a line in the direction of the length of the arm A E; (2), rolling without sliding along a line at right angles to the direction of the length of the arm A E; (3), a compound motion, partly rolling and partly sliding, when caused to travel at any inclination otherwise than a right angle with the direction of the length of the arm A E.

The final position of the last case may be found for purposes of proof when studying the instrument by the application of the principle of the parallelogram velocities. The roller carries a drum L divided into 10 equal parts, and again spaced out into 10 subdivisions of each part. A vernier (*Fig.* 2) also is attached, enabling hundredths, or a tenth of an unit part of the circumference of the drum, to be easily read. The axis of the roller is lengthened to carry an endless screw cut upon it, which works into a horizontal worm wheel of ten teeth, so as to record revolutions of the roller. In a proportional scale instrument the rolling portion of the apparatus is contained within the sliding box (see *Fig.* 3), while in a fixed scale instrument the end of the bar carrying the needle is cranked (*Fig.* 4), so as to clear the rolling portion attached to the bar carrying the tracer.

Sir Frederick Bramwell, in a communication to the British Association, in 1872, shows in a very practical way that the proportional scales of a planimeter are derived from the areas found when the adopted length of the bar, A E, is multiplied by the entire distance travelled by the revolving wheel K. By changing the radius of this arm the units of superficial measurement are altered. Hence, when the index is set to one square decamètre the arm is 167·5 m.m. long (from centre of pivot connexion to centre of tracer), the roller is 59·6904 m.m. in circumference, therefore $167{\cdot}5 \times 59{\cdot}6904 = 10{,}000$ square m.m. = one square decamètre, and when the index is set to 10 square inches – diameter of roller = $\frac{3}{4}$-inch, circumference = 2·35 inches, and length of arm from centre of pivot to centre of tracer = $4\frac{1}{4}$ inches; so that $2{\cdot}35 \times 4{\cdot}25 = 10$ square inches. In the proportional planimeter, made by Messrs. Elliott Bros., the bar carrying the tracer is marked: (*a*), 1 □ dem.; (*b*), 0·1 □ f.; (*c*), 2,000 □ M 1:500; (*d*), 10 □ in.; (*e*), 0·5 □ dem.; indicating respectively: (*a*), one square decamètre; (*b*), one-tenth of a square foot; (*c*), 2,000 square mètres on a scale of 1:500; (*d*), ten square inches; and (*e*), one-half a square decamètre. The constant numbers engraved on the top bar: (*a*), 20,834; (*b*), 20,830; (*c*), 21,105; (*d*), 22,174, are units of complete circumscribed areas when the needle point is fixed *within* the figure to be measured. In the fixed planimeter the only number given is 16,434 upon the weight which is placed over the needle point. When required to be so employed, the proportional planimeter will be found to balance better, as the fixed instrument in some positions is apt to turn over.

Figs. 6 and 7, *Plate* IX., exhibit an example which shows the plan of a proposed reservoir, giving contours at five feet apart, this being the vertical interval between the levels taken. The square inches of area upon paper found with the use of a planimeter, multiplied by the scale of the drawing, gives the area in square feet of each horizontal section, the boundary of which is indicated by the dotted lines on the plan. In the table the mean areas multiplied by the depth gives cubic feet, which, multiplied by $6\frac{1}{4}$, gives capacity in gallons.

The contour calculations are given for altitudes of 50·00 to 100·00.

No. 1 top bank contour is thus calculated :—The area is divided into a triangle and two outside enclosures, the latter being calculated by a planimeter—

$$\begin{array}{r} 41{\cdot}00 \\ 23{\cdot}98 \\ \hline 64{\cdot}98 \\ 50{\cdot}90 \\ \hline 115{\cdot}88 \\ 60 \\ \hline 6{,}952{\cdot}8 \\ 60 \\ \hline 9)417{,}168{\cdot}\text{—} \\ \hline 4{,}840)\ 46{,}352 \\ \hline \end{array}$$

9·58 acres = area of top bank level.

No. 2 level, 80·00, two planimeter calculations—

$$\begin{array}{r} 29{\cdot}52 \\ 32{\cdot}00 \\ \hline 61{\cdot}52 \end{array}$$

No. 3 level at 65· = 21·24, one planimeter calculation.

A separate tracing is made of each contour for purposes of calculation, not only so as to preserve a record of each planimeter reading, but to prevent the confusion that may arise in traversing one contour line near another, and also to avoid the inaccuracy which the jerking produced by the tracer passing over the holes in the original drawing left by the needle in plotting would cause.

PLATE I.

GRAPH.

TA FIXED FOR REDUCING ONE HALF.

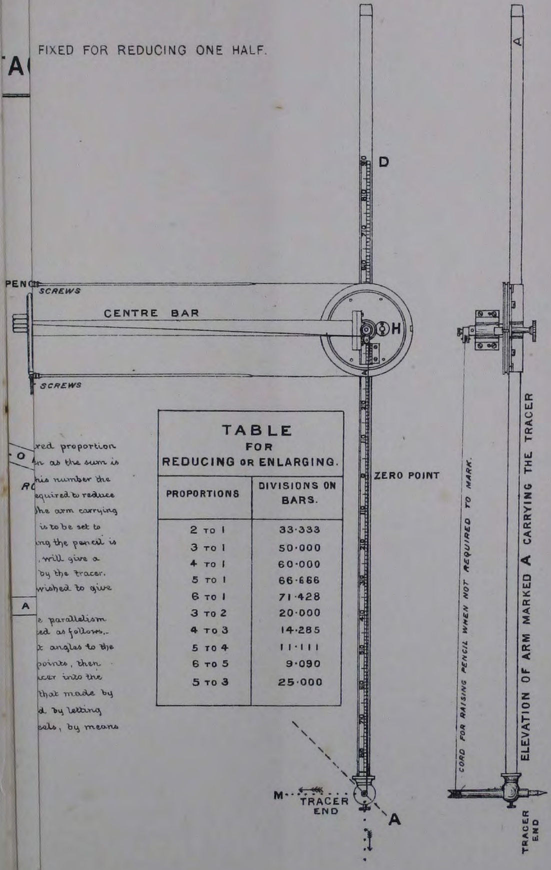


TABLE FOR REDUCING OR ENLARGING.	
PROPORTIONS	DIVISIONS ON BARS.
2 TO 1	33·333
3 TO 1	50·000
4 TO 1	60·000
5 TO 1	66·666
6 TO 1	71·428
3 TO 2	20·000
4 TO 3	14·285
5 TO 4	11·111
6 TO 5	9·090
5 TO 3	25·000

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PAPER VII.

SHIPS *VERSUS* FORTS.

By Captain T. S. Jackson, R.N.

Purely naval attacks on fortresses have been few in number, and have only been successful when the ships possessed a decided superiority over the batteries, or at places where the garrisons were decidedly inferior in skill and courage to the attacking crews. Ordinary sea-going ships-of-war are not, and never have been, intended by their designers to engage forts. They are built to fight other ships. This important fact, usually forgotten, goes far to account for the difficulties under which ships labour in an engagement with coast defences.

The old wooden line-of-battle ships were no match for the fortresses of their day, and there is no reason to suppose that modern ships-of-war, protected in a great measure as they are against projectiles, are more fitted than their predecessors for an attack on batteries on shore. No doubt ships have been successful against forts. In many cases the rapid and concentrated fire of a squadron directed against a number of crowded and ill-protected guns on shore has silenced all opposition for a time. Where a military force has been at hand, or when a sufficient landing-party has been available from the squadron, this temporary success has sometimes been rendered complete. Occasionally, the object of the attack, such as the enforcement of demands made on a semi-civilized Power, has been attained by the mere fact of temporarily silencing the defences. But, as a rule, attacks on shore batteries by sea-going ships not specially equipped for the purpose, have not been attended with success calculated to encourage naval commanders to engage in such operations. The risk of serious damage to, or loss of, ships, and the certainty of heavy loss to the crews, are, of course, merely conditions which are common to all forms of naval warfare, and are not peculiar to attacks on fortresses. But the enormous expenditure of ammunition necessary to produce any considerable effect on well-designed shore defences, and the possible difficulty of replenishing the ships' magazines after an engagement, are factors which must be taken into account. The vicinity of a hostile squadron, and the probability of having to fight a naval action before the damages incurred in an action against coast defences have been repaired, and before ammunition has been completed, will generally suffice to prevent an attack.

Every modern improvement in guns and their ammunition tends to increase the superiority of shore defences over ships. The increased accuracy of fire of modern guns can be taken advantage of, to its full extent, only when the guns are mounted on shore. The inaccuracy of fire from ships is due to the unsteadiness of the platform, not to faults of the weapon or want of skill in its use. This cause of error is a constant factor, and is not affected by improvements in the guns. The shore gun has only to be pointed correctly. The gun afloat must not only be correctly laid, but must be fired at the instant the sights are brought on by the motion. Modern mountings have greatly improved naval shooting, but cannot compensate for the inherent defect of a floating platform. No satisfactory means of range-finding exists afloat; while on shore the position of a ship is determined by looking at her through a telescope. Although better arrangements for range-finding may hereafter be made on board ships, it is improbable that they will ever equal those used on shore.

There are fortresses, and fortresses. Given 50 years ago, prior to the introduction of shell-fire from guns, a masonry battery such as Southsea Castle, or an earthwork on a low site crowded with guns and insufficiently traversed, place alongside it a number of wooden ships of the old type, mounting at least 10 times the number of guns in the work, a naval success was then possible, or even probable. The introduction of direct shell-fire greatly enhanced the risk incurred by wooden ships in attacking batteries without proportionately increasing their powers of offence.

At the present time, a squadron of ironclad ships anchored within close range of a fort of the type of Picklecombe, or Garrison Point, might possibly destroy it. But at what cost? The attack would have destroyed an obsolete work at the expense of damage to valuable ships. In these cases the defences have been purposely supposed to be of a character which distinctly invites naval attack, by offering the ships an artillery duel on not unequal terms. In order to estimate the chances of success of a naval attack on modern works of fortification, it is necessary to look at the case from another point of view. Instead of an iron-plated fort, barely calculated to keep out the projectiles in use 20 years ago, suppose that the defence consists of heavy guns, dispersed in earthworks, placed on high sites wherever possible without receding too far from the limit of navigable water, and nearly invisible from the sea. Now the ships have no defined object to aim at. Instead of every shot telling on iron shield or masonry, no shot counts as a hit which does not strike a gun or its mounting. Every projectile which strikes the parapet is, practically, thrown away. The target offered to an enemy by the largest gun is extremely small. The diameter of the breech of the 16·25-inch B.L. gun is 66 inches. Making a liberal allowance for the exposed portions of the mounting, the area of the target does not exceed 35 square feet when the gun is end on. If the guns are *en barbette*, and on a low site, they may possibly be silenced for a time, but the instant the fire of the attack slackens the fire of the defence will re-open; while against disappearing guns the ships are absolutely powerless.

Direct fire alone is, however, not the only resource of the defence. High-angle fire, which may now be said to be in its infancy, and which will be greatly developed in the near future, should alone be sufficient to keep ships from anchoring; and without anchoring, experience has shown that the greater part of their fire is thrown away. Submarine mines, the moral effect of which cannot be entirely disregarded if their efficiency is denied, will add to the difficulties of the attack.

Although naval attack on a fortress, carried out by means of ships constructed for fighting other ships, is likely to result in the discomfiture of the attacking force, vessels may be constructed much better fitted than ordinary battle-ships for a fight against forts. At present no such vessels are afloat. It is highly improbable that they will be constructed, except by a nation whose power at sea is uncontested. Further consideration of possibilities in this direction may, therefore, be disregarded as far as the defence of the British

Empire is concerned. We may build such ships ourselves, but no other nation is likely to do so.

Mortar boats were built in large numbers during the war with Russia, and the same class of vessel was afterwards used with good effect in the operations on the Mississippi. Specially designed floating batteries took part in the attack on Kinburn. The first monitor was built to fight the *Merrimac*, but the seven vessels of the same type which succeeded her were intended to operate against the defences of Charleston. Defensively, they were well fitted to engage batteries.

On the whole it may be said that at the present day a purely naval attack on a properly designed fortress, garrisoned by the troops of a civilized Power, might be *magnifique*, but under no conceivable circumstances could it be termed *la guerre*. Instances of naval success may be quoted in opposition to this view, but, as a rule, they occurred prior to the days of direct shell-fire and accurate shooting. Lord Clarendon said of Blake*:—"He was the first man who brought ships to contemn castles on shore, which had been thought ever very formidable, and were discovered by him to make a noise only; and, though he hath been very well imitated and followed, he was the first that gave the example of that kind of naval courage and bold, resolute achievement."

In combined naval and military operations against fortresses, the co-operation of a fleet has often proved most valuable to the attack. The results of a temporary success in action are in this case secured. The ships are risked for a definite purpose, and if they are lost it is in an operation of practical warfare, not from a quixotic desire to show that the navy can do something, a sentiment which has caused more than one useless action between ships and forts.

Another legitimate use of ships is to force a passage defended by batteries. Where the squadron has consisted entirely of ships-of-war, this operation has been invariably successful. Some ships have been damaged, and have failed to get past, but the bulk have succeeded. Where the squadron has consisted partly of transports the loss has been greater; but even in this case the passage has been forced. I know of no instance of ships having been prevented from passing batteries by artillery fire alone, unaided by natural or artificial obstructions.

Attacks by ships on partially defended harbours, such as our

* Yonge's *Naval History*.

coaling stations abroad, have frequently been successful. The garrisons of such places are generally small, and the landing-party of a squadron has some chance of gaining at least temporary possession of a work after its guns have been silenced. Very few minutes suffice to disable guns if the necessary guncotton charges are ready; and in the old days spiking was even more quickly performed. Many of the most successful of these attacks have been surprises. Small Colonial garrisons are likely to slacken in vigilance during a long war. Months of waiting for an enemy who never appears, and is hardly ever heard of, renders it difficult to keep up the requisite belief in his proximity. In our wars with France and Holland surprises were common, and it seems not improbable that, under similar circumstances, our minor coaling stations might be liable to be caught napping. Telegraphic communication would probably be cut, and the visit of mail steamers uncertain. The garrisons would be dependent for news of the outer world on the colliers, and on our own cruisers who might occasionally arrive, coal, and be off again.

A sort of confession of faith on the subject of ships *versus* forts having now been made, the next step is to call evidence in support of the views advanced.

During the eighteenth century there were many naval attacks on fortified harbours, but it is difficult to obtain any detailed account of the operations. In 1739, Vernon took Porto Bello, and was beaten off by Cartagena. In 1743, Commodore Knowles was unable to make any impression on either La Guayra or Puerto Cabello, though the latter place would seem to have been an ideal object of attack in the days of close-alongside tactics, and in 1797 its fortifications were unable to protect the *Hermione* from the cutting-out expedition sent to recover her.

Very few instances of naval attack on forts occurred during our long war with France and Spain. Engagements with batteries were generally incidental to other operations, such as cutting-out expeditions, and were not begun by the ships with the primary object of destroying the works.

The battle of Algiers affords an excellent example of the manner in which a naval attack should be conducted against an enemy inferior in skill and discipline. Lord Exmouth's force consisted of two three-deckers, three 74's, one 50-gun ship, four frigates, five sloops and brigs, and four mortar vessels. A Dutch squadron of five frigates and a corvette joined the expedition at Gibraltar. The broadside force of the combined squadron, omitting small craft, amounted to 410 guns. A good plan of the bay had been previously obtained, and the position each ship was to occupy had been determined by the Commander-in-Chief. The squadron was permitted to stand in towards the mole, and the flag-ship and the *Leander* were secured in their positions before the enemy opened fire. This was clearly a blunder on the part of the Algerines. The batteries should have fired directly the leading ship came within range. As shields with ports too small for the guns were not then in use, there was no excuse for waiting. The ships must have suffered severely while shortening sail and anchoring under fire. There is no good reason for withholding the fire of shore guns after a ship is within range. As it was, the fire of the two vessels in position when the action began covered, in great measure, the advance of the rest of the squadron. Naval gunnery was not scientifically taught in those days, but Lord Exmouth had regularly exercised his men at target practice on the passage from England. He had, evidently, a very clear idea as to the capabilities of his guns and the skill of the men who worked them. The *Queen Charlotte*, at Algiers, was placed 100 yards from the mole head. At this range her first broadside had a terrific effect. The other ships anchored in equally effective positions as they came up. The boats of the ships were provided with carcasses, with which they succeeded in setting fire to the Algerine ships inside the mole. The action lasted from 3 to 11 p.m., when the combined squadron hauled off. Lord Exmouth's biographer states that the "sea defences of Algiers, with great part of the town itself, were shattered and crumbled into ruins." This would appear, however, to refer only to the town and mole batteries, for he afterwards remarks:—"Warps were run out to gain an offing, but many of them were cut by shot from the batteries southward of the town, which had been very partially engaged, and *also from forts on the hills out of reach of the ships' guns.* Here we have the old story, which cannot too often be repeated:—Closely packed guns on low sites silenced by the fire of ships; dispersed guns on high sites holding out.

A light land-breeze favoured the withdrawal of the squadron. Next day the Dey acceded to all demands, and the affair was, therefore, a complete success. Our loss was heavy, 141 killed and 742 wounded. The expenditure of ammunition was, as usual in such cases, enormous. It was, perhaps, fortunate that the submission of the Algerine Government obviated the necessity for a renewal of the action.

During the operations against Mehemet Ali's force in Syria, our ships were frequently engaged with coast defences. The most important of these affairs was the capture of Acre. The fortifications of Acre were of the ancient masonry type, and the garrison most indifferent gunners. The explosion of a magazine, which did great damage, seems to have been most effective in disheartening the Egyptian troops, who evacuated the place on the day after the attack. The allied squadron, under Stopford, which was engaged on this occasion consisted of eight two-deckers, besides frigates, corvettes, and steamers; yet, according to Yonge, "the walls were so solid that our cannonade, heavy as it had been, had failed to breach them in any part; and so high that the attempt to scale them would have been full of difficulty." The killed and wounded in the squadron amounted to 60.

In 1845, there was some sharp fighting on the Paranâ. Four batteries had been constructed on the right bank of the river, at Obligado, mounting 22 guns. The river was obstructed by vessels chained together and moored across the stream. The batteries were attacked by a combined French and English squadron of three paddle steamers and eight sailing ships. All were small craft, the depth of water allowing only vessels of light draught to come so far up the river. The sailing ships began the attack, and suffered considerably while taking up their positions. The chains securing the vessels forming the barrier were cut, and the steamers advanced through the gap. The batteries were then silenced, and a landing-party completed the work.

Later on, the squadron conveyed a number of merchant ships past another fortified position on the same river. At San Lorenzo, the enemy's guns were mounted on cliffs 70 feet high; they were, therefore, more or less out of the reach both of our projectiles and our landing-parties. The shore opposite the batteries was low, but afforded some cover. A rocket battery was established here during the night, unknown to the enemy. When our steamers advanced the rockets opened fire, and—by their moral effect it is supposed—assisted greatly in keeping down the fire of the batteries. The convoy passed in safety, with the exception of four vessels, which ran on shore and were burnt to prevent them from falling into the hands of the enemy. The late Admiral Sir Cooper Key commanded a small vessel during these operations. His experience of the batteries on the banks of the Paranâ made him an advocate of high sites and dispersed guns, and he endeavoured to secure the adoption of his views in the defence of Plymouth. Unfortunately, iron structures were preferred.

The attack on the sea forts of Sebastopol, by the allied squadrons, on October 17, 1854 (see *Plate* I.), was unsuccessful, and in no way tended to advance the siege. The ships did not begin the action until hours after the French siege batteries had ceased firing. The range at which all but the English in-shore squadron engaged was far too great for the guns of the period. Whether Kinglake is correct in ascribing all the blunders committed that day to the French alliance may be doubted, but divided counsels prevailed, and plans were altered up to the last moment. The fire of the ships produced no considerable effect on the sea defences of the place, and the naval attack does not appear in any way to have assisted the land operations.

The proceedings of the French and Turkish, and of the main body of the English ships, are of little interest. They engaged a number of masonry forts at ranges varying from 1,600 to 3,000 yards. Forts Alexander and Constantine were casemated works, with an upper barbette battery. The Quarantine Fort mounted 58 guns, *en barbette*, but had no casemates. The fire of the French and Turkish ships was principally directed on this last work. The depth of water was sufficient to allow ships to anchor within 500 yards. A barbette battery on a low site, with deep water close alongside, would appear to offer ideal conditions for naval attack, but long bowls were preferred to close action.

Three guns dismounted and 35 casualties among the garrison was all the effect produced on the fort by some hours' bombardment at long range.

The British in-shore squadron originally consisted of the *Agamemnon* and *Sans-Pareil*, screw two-deckers; the *Albion* and *London*, sailing two-deckers; and the *Arethusa*, sailing frigate; these three last being towed by steamers lashed alongside. The *Agamemnon* took up a position 800 yards from Fort Constantine. The *Sans-Pareil* anchored close astern of her, about 900 yards from the fort. The *London* anchored astern of the *Sans-Pareil*, 1,500 yards from Constantine, but only 700 yards from the Telegraph battery. The *Arethusa* and *Albion* prolonged the line. The upper battery of Fort Constantine was speedily silenced, the gunners were driven from the guns and took refuge in the casemates. The fire from the lower tier of the guns continued, but slackly. At a later period of the engagement the *Rodney*, towed in to support the *Agamemnon*, tailed on shore under the fort, which she engaged for two hours. She hauled off after dark without serious loss.

So far then the ships of the in-shore squadron had done very well. But the effect produced by their fire on Fort Constantine was soon counter-balanced by the damage done by the Wasp and Telegraph Batteries to the vessels under their guns. These two little works on the cliff drove ship after ship out of action, and sustained little or no injury from the heavy fire to which they were exposed. The Wasp was a square tower, 27 feet high, 50 feet side, on a cliff 130 feet above the sea level, mounting eight guns, one in each corner and one in each face; five guns bore on the ships. The Telegraph Battery was an earthwork on the same cliff, 100 feet above the sea level, mounting five guns, all pointing seaward. The *Albion*, *Arethusa*, *London*, and *Sans-Pareil* were successively obliged to retire. The *Bellerophon* and *Queen*, coming in to support, were both set on fire and driven off. The Telegraph Battery seems to have done the greater part of the damage, and sustained absolutely no loss either in men or material.

Todleben remarks—"La cause principale du tir si efficace de ces batteries était sans contredit leur position élevée. Ajoutons que par leurs dimensions restreintes elles offraient moins de prise aux coups de l'ennemi."

There are many lessons to be learnt from this action. Among the most important are the following:—

1. One head in command of a force is better than two, and infinitely better than four.

2. Two little open batteries on a high site drove six ships out of action; while an open barbette battery on a low site was silenced, and the fire of a casemated battery much reduced by three ships, assisted by others, at long range.

3. Ships engaging at or about the extreme range of their guns sustain considerable loss without inflicting any serious injury on land defences.

The sunken hulls of the Russian ships formed an effective barrier at the entrance of the harbour, and prevented any attempt on the part of the allies to run past the defences.

Submarine mines were then in their infancy, and, indeed, were hardly admitted to be legitimate children. The value of passive obstructions was, however, well known, and such defences were frequently used.

The attack on Kinburn deserves notice because the assailants were provided with vessels specially constructed to engage forts, and these ships were iron-plated. This then was the first trial of ironclads in action. The principal fort at Kinburn was a casemated work, mounting 70 guns, and was singularly well fitted to serve as a target for a powerful squadron, and especially for the ironclad floating batteries. The fort held out for about two hours. The iron-plated batteries proved a complete success. Their armour, which now-a-days would be pierced by projectiles of comparatively small calibre, was quite proof against the shot from the fort, while the spherical shell broke into fragments on striking. This was the first skirmish of the battle of armour against guns, and it appeared that a type of vessel fit for action against forts had been built. The floating batteries engaged at Kinburn were French, but we soon followed suit in the construction of these ships, and by the time peace was concluded, had several afloat.

The two first naval Powers of Europe were at war with Russia. Their ascendency at sea was complete and unassailable. One squadron of the Russian fleet was blockaded in the Baltic ports, the other was sunk as an obstruction at the entrance of Sebastopol harbour. Wooden ships had failed against the forts of Sebastopol, and in the Baltic had not been risked in attacks on Cronstadt or Sveaborg. The allies could, evidently, afford to indulge in the luxury of special ships for special purposes. Such a policy, however, is clearly only possible to a combatant whose naval supremacy is absolutely unquestioned.

In 1858 a squadron of French and English gunboats attacked the forts at the mouth of the Peiho. The Chinese made no serious attempt to obstruct the passage, merely placing as an obstacle a series of bamboo cables, which snapped across the stem of the leading vessel. While the heavier gun-vessels engaged the batteries, the lighter gun-boats, carrying the landing-parties of the large ships, which were unable to cross the bar, ran past. The men were landed in rear and took possession of the works, which had little or no gorge defence. Our loss was small, and was almost entirely confined to the vessels engaging the batteries at anchor. Next year's affair proved that the Chinese had profited by the lesson taught them on this occasion. They placed piles across the river, and greatly improved their batteries. Our gunboats were detained under the fire of the forts, and suffered very severely, as the range did not admit of much missing, even by Chinese gunners. Two vessels were run on shore to prevent them from sinking. However, after four hours' fighting, the guns of the forts were nearly silenced, and about seven o'clock in the evening a landing was decided on. When these batteries had been captured the year before, our men had been landed on the river bank in rear of the defences, but now the obstructions rendered this course impossible. Below the forts, mud banks extend some distance seaward. On the right bank our men disembarked and struggled to storm the southern batteries. They were met with a heavy musketry fire. Their loss was great, and few reached the edge of the ditches in front of the batteries. The outer ditch was crossed, as the tide had receded and it was nearly dry; but the inner ditch was full, and checked the advance. Nothing further could be done, and the survivors of the storming-party were withdrawn and re-embarked. Our total loss was 80 killed and 350 wounded, more than a third of the number actually engaged. One gun-vessel and two gun-boats were lost. On the whole, this was as hard fighting and as thorough a thrashing as we have had for many years.

During the Civil War the United States navy were engaged in operations of every description against land defences. Purely naval attacks, combined naval and military attacks on fortresses, bombardments, ships forcing a passage through channels defended by batteries, gun-boats acting in support of armies in the field; every variety of operation may be studied in the history of the war.

When the *Monitor* had proved a success, and her improved sisters, carrying heavier guns, had been constructed, an early opportunity was taken of testing the offensive and defensive powers of the new vessels against batteries on shore. For this purpose the *Montauk* was sent to engage Fort McAllister, an earthwork on Genesee Point, in the Ogeechee River, mounting nine guns, the heaviest of which was a 100-pounder rifle. The *Montauk*, supported by three gun-boats, attacked the fort on two occasions. She was struck 13 times during the first, and 46 times during the second action, without sustaining any serious damage. One gun was disabled in the fort, but whether this result was due to direct fire, or a shell from a mortar, is not stated. As only two of the guns in the fort were of a calibre calculated to do the slightest damage to an ironclad, and it is doubtful whether even one of these could penetrate the turret, it is not surprising that the armour of the *Montauk* proved more than a match for the projectiles fired against it. The lesson had yet to be learnt that this class of vessel was offensively unfitted to attack forts. The number of hits scored in these two affairs is most creditable to the Confederate gunners, considering the small target offered by the *Monitor*. "A cheese box on a plank," was the apt description of these vessels given by American seamen. About a month after this affair, three monitors attacked Fort McAllister at a range of 1,200 yards. The action lasted for eight hours, after which the ships drew off, having sustained no injury; while, according to the report of the naval commander, no damage was done to the fort which could not be repaired in a few hours. Admiral Dupont, who commanded the South Atlantic squadron, seems now to have had a clear idea of the value of slow-firing turret ships for use against forts, more especially against earthworks, but the Navy Department at Washington thought differently. As is usual, the views of the gentlemen with their legs under office tables prevailed, and on the 7th April, 1863, the Admiral attacked Fort Sumter, Charleston (see *Plate* II.), with the whole of his ironclad force. The squadron consisted of seven monitors, one broadside ship, the *New Ironsides*, mounting 11-inch S.B. guns, and the *Keokuk*. This last-named craft could only by courtesy be called an ironclad. The maximum thickness of her armour was two inches, with a $\frac{3}{4}$-inch skin. She carried two 11-inch S.B. guns in oval casemates. The armament of the monitors was in most cases one 15-inch S.B., and one 11-inch S.B., but in one or two vessels a 150-pounder rifle gun was substituted for the 11-inch S.B. At noon, the squadron moved up the main ship channel until brought up by the obstructions laid down by the Confederates between Sullivan Island and Fort Sumter, the formidable nature of which seems to have been unknown till they were approached. The attack was made on the flood tide, and the ships were, consequently, obliged to turn. Anchoring does not appear to have been part of the programme, though this manœuvre would apparently have prevented confusion. As it was, the *New Ironsides*, flagship, anchored twice to avoid collision. The *Keokuk*, which was the rear ship of the column, was thus forced into the hottest berth of all, and after half-an-hour's hammering, hauled off in a sinking condition, having been struck by 90 projectiles. The distance at which the ships engaged is differently stated in the Federal and Confederate accounts of the action, but was apparently between 600 and 2,000 yards. Fort Sumter, being a brick and masonry fort, afforded a most satisfactory target to the ships, and was considerably damaged, especially by the 15-inch S.B. shell. One gun was disabled out of 44. Though the heaviest guns in the Confederate batteries at Charleston were 10-inch and 9-inch S.B. and 8-inch rifles, the damage done to the attacking ships was heavy. Four of the monitors had one gun disabled out of two on board; the turret of the *Nahant* was temporarily disabled, and was "not in good order for a month." The *Keokuk*, as above stated, was totally disabled, and sank next day. No turrets were actually penetrated, but flying bolts and nuts made them extremely unpleasant quarters. The action lasted from 3 p.m. until evening, when the ships withdrew by signal.

In this attack the ships had an object to fire at which could be clearly distinguished. Every shot or shell which struck Fort Sumter produced a visible effect, and this is always cheering to seamen gunners. The practice on both sides appears to have been excellent. The result was the complete failure of the attack.

The monitors had proved the invulnerability of their vital parts. They had also shown that the disablement of their armament by the impact of projectiles or by accident to the fittings was merely a question of time. The value of obstructions was again shown. The leading monitor, the *Weehawken*, had been specially fitted with a torpedo raft on her bows, the principal effect of which appears to have been to render her steering wild, and thus to throw out the whole line. One torpedo exploded near her. Her captain reports, concerning the obstructions:—"The appearance was so formidable that, upon deliberate judgment, I thought it right not to entangle the vessel in obstructions which I did not think we could have passed, and in which we should have been caught."

This was not the first occasion on which Charleston had successfully resisted a naval attack. In 1776, a British squadron of two 50-gun ships and four frigates, under Sir Peter Parker, attacked the place. Most of the ships grounded, and one frigate was abandoned and burnt. The rest of the squadron retired, having made no impression on the forts, and having suffered heavy loss.

Purely naval attack on Charleston having failed, combined operations were then commenced by the Federals. General Gillmore established himself on Morris Island, and constructed batteries to attack Fort Wagner. The co-operation of the navy now proved of the greatest value. The ironclad ships engaged Fort Wagner whenever it was necessary to assist in the operations of the army. The ships could always keep down the fire of the fort as long as they were actually firing at it, but never did any permanent injury to the work. Wagner was built entirely of timber and sandbags. Injury to such a work can be repaired without much difficulty when it is situated on a sandy island, and it is not surprising that the fire of the squadron did no considerable damage. But the ships swept the dunes of Morris Island and kept General Gillmore's front clear. Though the Confederates could throw any number of men into Fort Wagner, they never attempted a sortie, and the Federal works were pushed steadily on.

One of the earliest operations of the Civil War was the capture of the forts at Hatteras Inlet by a squadron of wooden vessels, under Commodore Stringham. The gun power of the squadron was enormously superior to that of the forts, which were entirely overmastered, and eventually surrendered, and were taken possession of by the troops which accompanied the expedition. The principal interest attached to this affair is the method of attack. During the first day's bombardment the ships kept under way and followed each other in an elliptical course. On the second day the ships anchored and kept up a steady fire from their heavy pivot guns. Concerning the attack by ships under way, Admiral Porter remarks:—"The plan has the advantage of bothering the enemy's gunners, as the ships are constantly changing their range; but it detracts from the accuracy of the fire on board the vessels, and it tends to lengthen out an engagement. At Hatteras, what should have been finished in six hours took twenty-four to accomplish." In these days, when the shore gunner has efficient range-finders while the sea gunner has none, which is the more likely to be bothered by change of range?

The method of attack by vessels circling in line ahead was pursued by Admiral Dupont against Forts Walker and Beauregard, two earthworks defending the entrance to Port Royal. Fort Walker mounted 23 guns, 15 of which fired to seaward; Fort Beauregard 20 guns, 15 of which fired to seaward. With the exception of one 6-inch in Beauregard, all were smooth-bores, varying in calibre from 32-pounders to 10-inch. Admiral Dupont's squadron consisted of 11 regular men-of-war and six armed merchant vessels, carrying in all 151 guns. Twelve thousand troops accompanied the expedition. Fort Walker, as the stronger work, was the principal object of attack. The fire of the ships was altogether too much for the Confederates, who evacuated Fort Walker, on which Fort Beauregard hauled down its flag.

In these two engagements, at Hatteras Inlet and Port Royal, wooden vessels obtained complete success against earthworks. Believers in the capacity of ships and seamen to perform miracles when called upon, may reasonably quote the victory of the United States navy on these occasions as evidence in favour of at least a portion of their faith. But it must be remembered that in the early part of the Civil War the crews of the ships were vastly superior in discipline and skill to the garrisons of the works they attacked. The navy, fortunately for the Union, with few exceptions, supported the Federal Government; and although the immense increase in the number of vessels in commission necessitated the enlistment of people of all sorts, yet the nuclei of the crews consisted of disciplined and trained man-of-war's men. The earthworks in question were not up to date, and were very insufficiently traversed. "Looking from the direction of the enfilading fire from the north at Fort Walker, the wonder was that the ammunition of the guns had not been exploded, and that many more of the men who served the guns were not killed. It seemed almost a miracle that explosions did not occur in the passage-way from which the powder and shells were supplied."* The Confederate engineers profited by the experience of these defeats. Earthworks were built with heavy traverses and bombproofs, to which the gunners retired when the fire of the ships was too galling, only to return to their guns when there was a lull.

The armament of ordinary men-of-war has always consisted entirely of direct-firing guns. High-angle fire from ships against ships has hitherto been considered useless, and this opinion will probably be adhered to, at all events until a range-finder is invented for use afloat. High-angle fire is, however, of such admitted value against shore defences that in organised naval attacks on forts it has been usual to supplement the regular men-of-war by mortar boats. Mortars were used to a great extent in the bombardment of Sveaborg; and, at the conclusion of peace with Russia, in 1856, this country possessed a very respectable fleet of mortar boats, which would have proved invaluable in case further operations in the Baltic had been required. These vessels require smooth water; but in smooth water their fire has always been effective.

The bombardment of Forts Jackson and St. Phillip is a striking instance of the value of mortar boats as an adjunct to a squadron. These forts were situated at the Plaquemine bend of the Mississippi, 90 miles below New Orleans (see *Plate* III.). The river at this point makes a bend running north-east for a mile and three-quarters, and then resuming a south-east course. Fort St. Phillip, on the left bank of the stream, consisted of a brick and earth structure, with two water

* *Navy in the Civil War.* Vol. II.

batteries on either side, mounting in all 40 smooth-bore guns, 21 of which were 24-pounders, and one 7-inch rifle. Fort Jackson, on the opposite bank, and rather below St. Phillip, was a pentagonal brick casemated work, mounting altogether 62 guns, one of which was a 7-inch rifle, the remainder being smooth-bores. Of these latter 25 were 24-pounders, and 10 were flanking howitzers. The river was blocked a short distance below the forts by hulks chained together, and rafts of logs. A Confederate squadron of armed merchant steamers and tugs was stationed above the obstructions. The Federal squadron consisted of eight corvettes and sloops, and nine gunboats. The mortar flotilla comprised 20 schooners, each carrying a 13-inch mortar, with one gunboat and five other steamers in attendance. The mortar boats were organised in three divisions, two of which were anchored close under the right bank of the river, the leading vessel being 2,850 yards from Fort Jackson and 3,700 yards from St. Phillip. The remaining division was placed close to the left bank, the leading boat being 3,700 yards from Fort Jackson. The hulls of the first two divisions were screened by the trees from Fort Jackson, and, to render their masts indistinguishable, each carried a bunch of brushwood at the masthead. The bombardment of Fort Jackson began on April 18, 1862, each mortar boat firing a shell every 10 minutes. After the first day's firing the second division was moved from its exposed position, and joined the other boats under the shelter of the right bank of the river. All the mortars opened fire again next morning, and continued till noon, after which one division fired while two rested. On this day one mortar boat was sunk by a shot. The bombardment was kept up in this manner until the morning of the 24th April, when the squadron passed the forts. Colonel Higgins, commander of Fort Jackson, ten years afterwards gave a graphic description of the effect of this continuous bombardment.* He states that nearly every shell fired lodged within the works. "On the first night of the attack the citadel and all buildings in rear of the fort were fired by bursting shell, and also the sandbag walls that had been thrown around the magazine doors." The fire could not be subdued, and Fort Jackson was helpless. "I was obliged to confine my men to the casemates, or we should have lost the best part of the garrison." "On the morning of the 24th, when the fleet passed, the terrible precision with which your formidable

* Porter; p. 179.

vessels hailed down their tons of bursting shell upon the devoted fort made it impossible for us to obtain either rapidity or accuracy of fire, and thus rendered the passage comparatively easy."

A passage having been cleared in the line of obstruction, the squadron weighed at 2 a.m. on the 24th, and proceeded up the river in single line ahead. The machinery of the ships was partially protected by means of cables, and the hulls were daubed with river mud to render them, as far as possible, invisible. As each heavy ship opened fire on St. Phillip, the garrison were driven from their guns, only to return to them directly the ship moved on. The leading ships passed the obstructions without accident, but there was some confusion among those in rear, owing to smoke. Above the forts the Confederate flotilla took part in the action. Unfortunately for the defence, their vessels were under two different heads. The ships of the Confederate navy did good work; the river defence craft did nothing. Admiral Farragut lost one corvette, the *Varuna*, rammed by a Confederate steamer. The fire of Fort Jackson was greatly kept under during the passage, not only by the continuous streams of mortar shell to which it was exposed, but also by the flanking fire of the steamers attached to the mortar flotilla, which enfiladed the water batteries. The *Itasca*, *Winona*, *Kennebee*, gunboats, failed to pass the forts. After the passage of the fleet, the bombardment of Fort Jackson was resumed, and on the 29th the forts capitulated.

The reduction of the forts was then entirely due to the vertical fire of the mortar flotilla. There can be little doubt that the corvettes and gunboats would have been able to force a passage without the aid of the mortar boats; but had they done so the Mississippi would not have been open to the sea, and an action must have been fought whenever it was necessary to forward supplies to the ships above the forts. Moreover, the Federal loss in the advance on New Orleans would necessarily have been greatly increased, had not the garrison of Fort Jackson been shaken before the engagement with the ships began. As it was, the difficulties of the Federal squadron arose more from the strength of the current, and the attack of the Confederate steamers, than from the fire of the forts.

That ships-of-war can run past batteries, as long as the channel is unobstructed, and they are not detained under fire, has been proved over and over again, even in the days of sailing ships. During the naval operations on the Mississippi many instances occurred. The batteries at Vicksburg were passed on several occasions, in spite of the difficulties of navigation. If batteries alone could ever stop ships it might be supposed that they could do so at Vicksburg. The Mississippi here doubles in a manner which can be best understood from the plan (see *Plate* IV.). Vessels passing up the river, after running past the town, have to make a sharp turn against the current, which strikes them on the bow, and are thus liable to be raked at a moment when the commanders have quite enough to do to attend to the navigation of their ships. The bluffs at this point are 260 feet high; they continue close to the water till below the town with slightly diminishing height. They then recede from the river, their height gradually diminishing to 150 feet. At the time of Farragut's first attack, one 9-inch and three 8-inch S.B., and one 18-pr. rifle guns were placed at the highest point of the bluffs above the town, where they raked the ships before and after they passed their front. Just above these, two 24-pr. rifle, and two 24-pr. S.B. guns were placed. Half-a-mile below the town was a battery 50 feet above the river, mounting two 32-pr. rifle, and four 42-pr. S.B. guns. Along the crest of the hills, below the town, were placed two 10-inch S.B., one 8-inch S.B., one 42-pr. S.B., and five 32-pr. and two 12-pr. rifle guns. These were scattered over a mile or more, "so that it was hard for ships to make out their exact position. The distance from end to end of the siege (*sic*) batteries was about three miles, and as the current was running at the rate of three knots, while the speed of the fleet was not over eight, three-quarters of an hour at least was needed for each ship to pass by the front of the works. The upper batteries followed them for at least 20 minutes longer. Besides the siege (*sic*) guns, field batteries in the town, and moving from place to place, took part in the action; and a heavy fire was kept up on the vessels from the rifle pits near the turn."* Admiral Farragut's squadron consisted of five screw corvettes and six gunboats, with 16 mortar boats and their attendant steamers. The enemy's position was shelled during the 26th and 27th June, without producing any great result. The mortar boats had not now a closed fort of limited extent to deal with, as at Fort Jackson, but an extended position, the guns of which were mostly well dispersed. According to Admiral Porter, Farragut deemed the mortar flotilla "indispensable to shell out the heights." "But," says Porter, "the soldiers in the hill forts refused to stay shelled out, and when the mortars stopped playing on them they would come back from the fields and again open fire. . . . . There

* *Navy in the Civil War.* Vol. III.

was an area of 28 square miles, within which the Federals might throw all the shot and shell they liked. The Confederates did not mind it much, even when the shot fell in the city."

Farragut ran past Vicksburg early in the morning of the 28th June. His loss was 15 killed and 30 wounded; but eight of the former were scalded to death on board one of the steamers of the mortar flotilla, the boiler of which was pierced by a shot. The total casualties from the enemy's fire on board the ships which ran past were, therefore, only 37. Farragut then reported that the forts had been passed, and could be passed again as often as necessary, but that it would not be easy to do more than silence the batteries for a time. Vicksburg was impregnable by naval attack.

Farragut's squadron re-passed Vicksburg in July. The passage down was effected with trifling loss, though the action was fought in daylight. The fact of the current being with, instead of against, the ships, no doubt had much to do with this.

In March, 1863, Farragut passed the batteries of Port Hudson with his flagship, the *Hartford*, the other vessels of his squadron failing in the attempt to force a passage. The Confederate batteries mounted 11 S.B. guns, varying from 10-inch to 24-prs., and eight rifled guns, from 80 to 50-prs. The bluffs on which they were placed are from 80 to 100 feet high, and line the left bank of the river for a mile and a-half below a sharp bend. The squadron consisted of four corvettes and three gunboats, which on this occasion were lashed on the off quarter of the larger vessels. The ships weighed at 10 p.m., and proceeded up the river. As the deep water was on the starboard hand under the bluffs, the ships passed close under the batteries. Reflecting lamps had been placed, and large fires lit on the shore, to show up the ships to the aim of the gunners. The smoke from these fires and from the guns proved more formidable obstacles than the fire of the enemy. The *Hartford* could, to a certain extent, see where she was going, as she shot ahead of the smoke from her own guns; but the view of the ships astern of her was much impeded. At the bend of the river the *Hartford's* bow was swept round by the current, and she touched the ground. With the assistance of the gunboat, which was lashed on her port side, she got off and rounded the bend. The next ship, the *Richmond*, was struck by a shot, which displaced the weight of a safety valve and allowed the steam to escape to such an extent that she could not stem the current, and was compelled to retire down the river. The *Monongahela* came next; her gunboat, the *Kineo*, was struck by a shot, which jammed the rudder and rendered it useless. The *Monongahela* herself ran on shore on a spit opposite the town, and was got off by the *Kineo*, which then, being unable to steer, drifted down the river. The *Monongahela* went ahead again, but when near the bend her engine broke down from a heated crank pin, and she drifted past the batteries and anchored below. The last ship, the *Mississippi*, a heavy old paddle corvette, also grounded on the spit. She had no gunboat to assist her, and was eventually, after suffering greatly from the fire of the batteries, set on fire and abandoned. Thus but one corvette and one gunboat succeeded in passing the batteries, while the squadron lost a corvette in the attempt. The casualties on board all the ships amounted to 114, including 64 missing from the *Mississippi*, 25 of whom were believed to have been killed.

In February, 1863, the *Queen of the West*, a stern-wheel river steamer, protected by cotton bales, ran past Vicksburg at daylight, and on her passage rammed a Confederate steamer which was made fast to the levee. In so doing the cotton was set on fire by the explosion of a shell. She then steamed down the river, throwing the cotton barricade overboard, and succeeded in escaping. The *Indianola*, an ironclad steamer, was sent down a few nights after the passage of the *Queen of the West*. She passed the batteries without injury.

On the night of April 16, 1863, the squadron of the Upper Mississippi passed the Vicksburg batteries. These vessels were not sea-going men-of-war. They were either river steamers with extemporised defences, or light draught vessels especially built for river service. As coal was scarce below Vicksburg, most of the vessels had a coal barge lashed to their starboard side. When the leading ships came abreast of the batteries the Confederates illuminated the shore with tar barrels, and opened a heavy fire. Every possible means had been taken to protect the vessels. The weak points on the sides were covered with heavy logs. This may, perhaps, account for the low speed maintained, which was little more than the drift of the current. It was certainly insufficient to give steerage way, for some of the vessels were turned completely round by the eddy as they drifted down. One transport, laden with stores, was set on fire and sank, and another had to be towed on shore when out of range to save her from a like fate. The armed vessels suffered very little, and their crews lost only 13 wounded. Six transports ran the gauntlet a few nights afterwards. One sank after getting by, and the others were more or less damaged.

Thus instances occurred over and over again of squadrons and of single ships running past batteries. In no case could guns on shore block the passage. The guns used in these engagements, in spite of the inferiority of the Confederates as to ordnance, were far more capable of doing serious damage to the ships to which they were opposed than are the guns of the present day capable of inflicting vital injury on modern ironclads. Knocking the upper works to pieces and killing or wounding a portion of the crew will not stop a ship. Only three fighting ships, in all the engagements which have been quoted, were prevented by the enemy's fire from passing batteries.

In the advance on New Orleans, the *Varuna* was rammed by an enemy; the *Kennebee* and *Winona* fouled obstructions and were separated from the rest of the squadron. The *Itasca* alone was disabled by the fire of the forts, a shot from which struck her boiler. In Farragut's first run past Vicksburg, the *Brooklyn*, *Kennebee*, and *Katahdin* remained below, owing to misconception concerning the Admiral's intention. As these three vessels were under the fire of the batteries for about double the time during which they would have been exposed had they followed the rest of the squadron, it is reasonable to suppose that they could have passed with the others. No ship on this occasion was disabled by gun fire. Farragut's return run down the river was accomplished without injury to the ships. Porter's squadron passed Vicksburg with the loss of one transport—not a fighting ship. More damage was done by the batteries in the passage of Port Hudson by Farragut than in in any other engagement of this description. The movement succeeded, for its object was gained by the presence of the *Hartford* and *Albatross* at the mouth of the Red River. The *Kineo* and *Richmond* were undoubtedly stopped by gun fire, and the latter carried the *Genesee* out of action with her. The *Monongahela's* failure was due to an accident to her machinery. The *Mississippi* ran on shore. To quote, again, from Captain Mahan's excellent volume:—"It is sufficiently apparent, from the above accounts of the experiences of each vessel, that the failure of the greater part of the fleet to pass was due to other circumstances than the Confederate's fire. The darkness of the night; the stillness of the air, which permitted the smoke to settle undisturbed; the intricacy of the navigation; the rapidity of the current, then running at the rate of five knots; the poor speed of the ships, not over eight knots; were known beforehand, and were greater elements of danger than the simple fire of the enemy."*

* *Navy in the Civil War.* Vol. III.; p. 138.

It will be observed that all these runs past fortified positions were made at night. The *Queen of the West*, indeed, passed Vicksburg after daylight, and actually delayed under the fire of the batteries for the purpose of ramming a Confederate ship. But this daylight run was unintentional. Admirals Farragut and Porter evidently considered that ships had a better chance of slipping past in the dark, and to obtain the immunity from the enemy's fire which obscurity afforded, were ready to encounter the risks to navigation which are unavoidable in a night action. Their operations were carried on in a rapid stream, and in nearly every case the ships had to make a difficult turn while under fire. To criticize the solution of a tactical question, independently arrived at by two eminent seamen, is an unpleasant task. The Admirals had their work before them, and nobly performed their duty. Yet the results of their action show that the passage of a narrow channel in the dark was a mistake.

The case of a broad channel, which presents no difficulties of navigation, is different. At one time there was a project, strongly supported by owners of villas on the shores of the Firth of Clyde, of forming a line of defence between Uilean Point and the Cumbraes. Suppose that line of defence completed, and batteries of heavy guns established on both sides of the channel. Here, if a ship or squadron wished to force a passage, darkness or fog would be chosen. In clear daylight there would be a chance of passing without being hit. In even a moderate mist, still more in darkness, there would be a certainty of passing without injury. There being no danger whatever in the channel, all anxiety as to navigation would be removed from the mind of the Commander.

Now, on the other hand, consider a position like Vicksburg fortified according to modern ideas. Not that the Confederates were behind their age; on the contrary, they were far ahead of it, as may be seen by the dispersion of the guns along the heights. Still, there would be some improvements. No water battery would be found unless it were a dummy erected for the purpose of diverting the fire of the ships from more important objects. Along the shore would be placed numerous electric search-lights, which would brightly illuminate the passing ships, dazzle the eyes of their captains, and at the same time render the guns on the heights above invisible. The search-lights on board the ships would only add to the confusion. Without exaggeration, it is not improbable that the search-lights, judiciously used, might alone prevent the passage of the ships, and that the latter would devote themselves, as a preliminary operation, to extinguishing the lights by machine-gun fire. Under these circumstances, would not an Admiral prefer daylight to darkness? Would it not be better to expose ships to the enemy's fire than to run the risk of grounding under the batteries? Farragut's squadron, in the battle of Mobile Bay, suffered little from the fire of Fort Morgan, though he passed it in daylight. He lost many more men in his action with the *Tennessee* than from the guns of the fort. Here the channel was mined, but that did not stop the ships, though one monitor was destroyed. But mark the effect of obstructions. The *Brooklyn* recoiled from what appeared to her Captain a nest of torpedoes. She was thus exposed to the deliberate fire of Fort Morgan, and suffered accordingly. The flagship pushed on and "passed with no great injury or loss of life." Before forcing a channel the effect of probable obstructions should be taken into consideration. But when the operation has been begun, and the ships are fairly in for it, the proper frame of mind for a commanding officer is, undoubtedly, that indicated by Farragut's "Damn the torpedoes, full speed ahead."

The Mediterranean Squadron, in 1878, passed the forts of the Dardanelles in a snow-storm, which rendered it difficult to see the next ship ahead or astern, and impossible to make out the land. The flagship ran on shore in a position which would have been awkward if the Turkish Commandant had had orders to dispute the passage. In this case the Admiral had no choice as to weather.

However, looking at the matter from the artilleryman's point of view, no general rule can be laid down as to the probable time for an attempt of this nature. The passage of a clear channel, however strongly defended by batteries, may be effected at all times of day and night, and in any sort of weather. Ships can only be stopped by obstructing a channel to such an extent as to delay them under fire.

In all these instances, the immediate object of the attacking squadron was attained when the batteries had been passed. It must be clearly understood that the term forcing the passage of a channel does not mean forcing the entrance of a harbour. This is a very different matter, as ships effecting such a manœuvre are usually under fire after they have entered. The channel must lead somewhere, and there must be tolerably clear water, and an absence of artillery fire after the defences have been passed. There are very few defended channels in this sense in the British Empire. The Holms, Port Philip, and, perhaps, Hong Kong and Halifax, are instances.

The immunity of batteries on high sites from damage by the fire of ships was shown on many occasions during the operations on the Mississippi and its tributaries. Thus Fort Henry, an earthwork on a low point, was taken by four armoured and three wooden gunboats. A force of 10,000 men, under Grant, was present, but was not engaged. A few days afterwards, Fort Donelson, the main battery of which was 100 feet above the river, beat off the same force. The plunging fire of the upper battery was too much for the gunboats, though they appear to have silenced the "water batteries" of the fort. At Arkansas Point, on a low site, the flotilla, assisted by a military force, was successful. At Grand Gulf a combined attack failed, as the gunboats were unable to silence the fire of batteries 75 feet above the stream.

Probably no coast fortification has ever been subjected to such artillery fire as that directed upon Fort Fisher in the two successive bombardments (see *Plate* V.). "Fort Fisher consisted of two lines of works at right angles to each other. The land front ran across the sandy peninsula, which was here about half-a-mile in width, and mounted 17 heavy guns, bearing north, to prevent an attacking force from advancing in that direction." These guns were practically protected from a seaward fire "by heavy bombproof casemates, with capacity for sheltering 4,000 or 5,000 men. The sea front extended from the great battery at the angle of the two faces along a beach to the south-west, a distance of over three-quarters of a mile, and was terminated by a huge erection, 80 feet in height, known as the 'Mound Battery.' . . . . On the sea face of the work were mounted 54 heavy guns, protected by traverses against enfilading fire, and some of these traverses were also bombproof. In the 'Mound Battery' were three or four 150-pr. Brooke rifles, making the total number of guns in this formidable work 75. . . . . One mile westward of the 'Mound Battery,' at the end of Federal Point, was a heavy armed earthwork, mounting six or eight 11-inch Dahlgren guns."*

Admiral Ammen gives the armament as 38 guns, which is more likely to be correct.† Probably Porter includes all the guns captured. The whole of the works were constructed of sandbags.

The attacking squadron consisted of the *New Ironsides* and four monitors (one of which, the *Monadnock*, carried four guns in two turrets), three wooden frigates, and from 30 to 35 other vessels,

* Porter; p. 694.
† *Navy in the Civil War.* Vol. II.; p. 241.

ranging from heavy corvettes to armed merchant steamers. The armament of these vessels amounted in all to nearly 400 guns of all descriptions and calibres. The monitors carried 15-inch smooth-bores, which appear to have been by far the most effective guns used, as several of the heavier Parrott rifles burst during the first attack.

General Butler, who commanded the troops which were to assault Fort Fisher after the bombardment, proposed to operate on the nerves of the enemy before the attack by exploding a powder vessel, placed as near to the fort as the depth of water would permit. The navy had no faith in the efficacy of this mode of attack. The *Louisiana*, a small steamer, was prepared for the purpose, and loaded with 150 tons of powder. The craft was anchored in position by a volunteer crew on the night of the 23rd December, 1864. At 1.30 a.m. she exploded with a shock which was not felt by the attacking squadron, and did not disturb the garrison. The Confederates imagined that a blockade runner, laden with ammunition, had been blown up. The squadron weighed at daylight on the 24th December, and opened fire on the fort at 11.30 a.m. When all the ships had anchored and were engaged, about 250 guns must have been pouring in their shell at the rate of 115 projectiles a minute. After standing this fire for an hour and a quarter the Confederates were driven to their bombproofs, and the fire of the fleet was then moderated. After firing for five hours the ships withdrew. With the exception of some men scalded on board the *Mackinaw*, a boiler of which was struck by a shell, the only casualties on board were the result of the bursting of Parrott guns.

On Christmas morning the transports with troops had all arrived, and it was arranged that the navy should again attack the fort, and that the army should land, and, if possible, assault. At 7 a.m. the fleet weighed, and engaged the fort while the army landed on the beach about five miles to the north, protected by a squadron of gunboats. The second day's bombardment of Fort Fisher was kept up for seven hours, and seems to have been deliberate target practice. The casualties on board were very few. Then began a difference of opinion between the naval and military commanders. Admiral Porter's report says:—"I suppose about 3,000 men had landed when I was notified they were re-embarking. I could see our soldiers reconnoitring and sharpshooting, and was in hopes an assault was deemed practicable. One gallant officer, whose name I do not know, went on the parapet and brought away the rebel flag we had knocked down. A soldier went into the works and led out a horse, killing the orderly who was mounted on him, and taking the despatches from his body." General Butler says, in a letter to the Admiral :—" Upon landing the troops and making a thorough reconnaissance of Fort Fisher, both General Weitzel and myself were fully of opinion that the place could not be carried by assault, as it was left substantially uninjured by the navy fire. We found 17 guns protected by traverses, two only of which were dismounted, bearing up the beach." General Whiting, the Confederate G.O.C. of the district, states that the fleet disabled five guns on the 24th and four on the 25th.* He doubts the success of an assault at that time.

The navy were profoundly disgusted at the refusal of the military commander to assault the place. They argued that if the skirmishing line could advance unmolested to within 50 yards of the work the remainder of the troops could do the same. Admiral Porter wrote some very plain-spoken despatches on the subject, the gist of which was telegraphed by the Secretary of the Navy to General Grant. The result was conveyed to the Admiral in a confidential despatch, dated December 31st, which begins :—

"Sir,—Lieutenant-General Grant will send immediately a competent force, properly commanded, to co-operate in the capture of the defences in Federal Point."

Porter, however, was not content with official despatches. He had written to Grant immediately after Butler's troops had re-embarked, urging him to send "other troops and another General."

General Terry was placed in command of the troops now told off for the attack on Fort Fisher. The fleet of men-of-war and transports left Beaufort on January 12, 1865, and on the 13th, 8,000 men, with their stores and provisions, were landed, the disembarkation being effected in six hours. The presence of the *Brooklyn* and 17 gunboats prevented any resistance being offered to the landing. When the troops were safe on shore the fleet stood in three columns and took up the positions shown on the plan. The bombardment lasted from 4 p.m. till dark, when the wooden vessels were ordered to withdraw, while the ironclads keep up the fire during the night. On the 14th, all the small gunboats carrying 11-inch guns were ordered to take up positions commanding the north-east face of the fort, and to fire slowly and deliberately with the view of dismounting

* *Navy in the Civil War.* Vol. II. ; pp. 224, *et seq.*

the guns opposed to an assault. This was kept up from 1 p.m. till the next morning. At the same time line No. 1 kept up a rapid fire on the same face to keep the enemy from their guns.

On the 15th, the fleet went into action in the morning, and had all reached their stations by 11 a.m. Their fire was kept up rapidly till 3 p.m., when by signal it was diverted to the upper batteries. At the same time 1,600 seamen and marines, who had been landed for the purpose, attempted to reach the sea face of the fort, while the troops assaulted the north-east face. The landing-party from the squadron was repulsed with heavy loss. The troops succeeded in establishing themselves in the work, and after some hours hard fighting from traverse to traverse, in which they were assisted by the fire from the ships, compelled the surviving Confederates to surrender. The loss of the garrison was 700 killed and wounded out of 2,500. The gunboats prevented any reinforcements from reaching the fort.

The preliminary bombardment at the second attack was carried out with the definite purpose of silencing the guns on the north-east face of the work, or Fort Fisher proper. Porter's order was to fire deliberately. "Fire to dismount the guns, and knock away the traverses." "All firing against earthworks, when the shell bursts in the air, is thrown away. The object is to lodge the shell in the parapets and tear away the traverses in which the bombproofs are located. A shell now and then exploding over a gun *en barbette* may have good effect, but there is nothing like lodging the shell before it explodes." *

Forty thousand shell were fired during the bombardment. The supply was unlimited, and the ships had no difficulty in filling up with ammunition after each day's firing. Porter says that all the guns facing the ships "were dismounted or injured so that they could not be used, or the muzzles filled up with sand or dirt, which rendered them useless." Thus it is difficult to distinguish between permanent and temporary injury. As a land force was present, the question was of little interest to the fleet, for the main object was to keep the guns silent during the assault; and in this they were perfectly successful. In discussing the subject of naval attack on coast defences, however, a gun choked with sand can hardly be termed "disabled."

The interest excited by the first encounter between ironclad

* General Order, No.78. Porter; p. 718.

squadrons has caused the attack on the forts of Lissa to be somewhat overlooked. Yet the proceedings of the Italian squadron, previous to its naval action off Lissa, are not without interest. The engagement with the forts greatly affected the result of the subsequent engagement with the Austrian squadron. That result shows clearly that it is the height of rashness for a fleet to engage in operations against coast batteries when within striking distance of an enemy's fleet not greatly inferior in force. There were two fortified bays in the island of Lissa—San Georgio and Comisa. Admiral Persano's plan was as follows:—Rear-Admiral Vacca, with three ironclad ships, to attack the batteries at Comisa, and to prepare for a landing, if it proved impracticable elsewhere. Vice-Admiral Albini, with the wooden frigates, to try to land the troops at Porto Manego, after silencing the battery at San Vito, which defended it. The Commander-in-Chief, with the bulk of the fleet, to attack the batteries of San Georgio. The ships moved into position at dawn on the 18th July. San Georgio was attacked by eight ironclad ships, and according to the official Italian report, at half-past one in the afternoon Fort San Georgio and all the outer fortifications of the port were silenced, with the exceptions of the telegraph tower, the height of which was too great to allow the ships to batter it effectively. This exception is worth noting. The *Formidabile*, *Maria Pia*, and *San Martino* were ordered to enter the port and engage the interior batteries. In the meantime, Admiral Vacca had been obliged, on account of the elevated position of the batteries, to abandon the attack on Porto Comisa and joined Admiral Albini, who, also on account of the high positions of the shore batteries, had not succeeded in his attempt on Porto Manego. Both these squadrons then re-joined the Commander-in-Chief. At 6 p.m. Admiral Vacca's squadron kept up the fire on San Georgio, and the remainder of the squadron formed line. In the meantime, the gunboats had cut the submarine cable between Lissa and the mainland; had destroyed the semaphores; and had intercepted a message from Trieste stating that the Austrian squadron would leave Pola that evening. This intelligence was incorrect. Tegethoff had no intentions of putting to sea until he was convinced that the Italian attack on Lissa was serious.

On the morning of the 19th the ironclads of Admiral Vacca's division, and afterwards the wooden frigates, were ordered to attack the batteries which the enemy had repaired during the night. In the meantime, the *Affondatore*, with two wooden frigates and a corvette, joined, bringing up the number of troops to 2,200.

Persano then decided to land. The unarmoured ships and gunboats were to protect the disembarkation of troops. The *Terribile* and *Varese* were ordered to attack Porto Comisa, in order to occupy the garrison of that place, and to effect a diversion. The other ironclads were directed to attack San Georgio. At three o'clock the attack commenced. The *Formidabile* entered the harbour and engaged the castle battery at a range of 300 mètres, receiving a heavy fire from that work and from another battery on the south side of the entrance. To support this ship Admiral Vacca entered the harbour and silenced the battery which was raking her. His squadron then left the harbour, followed soon after by the *Formidabile*, "covered with glory." In the meantime, the wind had freshened to such an extent as to impede the disembarkation, which had barely been begun. The landing was put off till next morning, when the appearance of the Austrian squadron put a stop to further operations. The *Formidabile* was struck by 90 projectiles. Though none of her plates were perforated, they were indented, and, in some cases, bent. The ship was not in a condition to take part in the naval action, and was leaking when she afterwards arrived at Ancona.

The experience of Lissa is not calculated to encourage any naval commander to engage in an attack on shore defences when he may at any moment be called upon to fight a naval action. When Persano attacked Lissa he knew that Tegethoff was only 150 miles off, say 20 hours. The Italians had 12 ironclad ships against the Austrian seven. Their unarmoured force was about equal to that of the enemy. Taking into consideration the probability of the appearance of the Austrian squadron on the scene, ordinary prudence would appear to point out the necessity of keeping a force equal to that of the enemy ready to act against them. Admiral Persano's force was insufficient to furnish a covering squadron ready to fight the Austrians, and at the same time to carry on operations against Lissa. He was, consequently, forced to begin a naval action with his ships separated, some covering the disembarkation of troops, some actually engaged with batteries.

It has been contended by Admiral Colomb, whose opinion on any point of naval history naturally carries great weight, that Admiral Boüet-Williaumez, in command of a fleet vastly superior to that of his enemy, "yet would not risk the simple bombardment of an ill-defended coast town, Kolberg, because of possible interruption at the hands of the inferior German squadron, which was 700 miles distant."* If the French Admiral considered that by bombarding Kolberg he could induce the German squadron to leave port and fight him at sea, he would have been amply justified in attacking the place. The most probable explanation of Boüet-Williaumez's conduct is that given by Admiral Bourgois, who says that Kolberg was spared, not from apprehension of the arrival of the German squadron, but because of the reprisals which such an operation would inevitably have entailed on the French towns in the possession of the enemy. "Sans utilité pour nos operations dans la Baltique, il eût provoqué de sanglantes représailles sur notre territoire envahi, et infligé au pavillon français une tâche ineffaçable."†

Simple bombardment does not entangle a fleet in any way, or render it less fit for a sea fight unless the expenditure of ammunition is excessive. Ships seriously engaging coast batteries, on the other hand, must sustain some damage, and the crews must be more or less exhausted. A squadron, under these conditions, is not fit for action against an enemy of approximately equal force, whose ships are whole, and whose crews are fresh.

The consensus of naval opinion appears to be that no naval attack on a fortress will be made unless the officer in command of the attacking force is absolutely free from fear of interruption. He may be so strong as to be able to deal with an enemy's squadron as well as with his fortifications. He may be in such a position that serious interruption is impossible. If so, he will be under no apprehension of interference, and may possibly attack. If this principle is accepted, it follows that while any attack on a defended port in the United Kingdom is in the highest degree improbable, an attack on a distant coaling station might possibly be made by an enemy who was prepared to risk his ships to little purpose.

The bombardment of the forts of Alexandria (see *Plate* VI.) gave an excellent opportunity of comparing different methods of manœuvring ships when attacking batteries. The *Invincible* and *Penelope* remained at anchor during the whole engagement; the *Monarch* steamed backwards and forwards in a line parallel to the shore. The *Sultan*, *Alexandra*, and *Superb*, at the beginning of the action, engaged under way, steering an elliptical course past the lighthouse batteries at a distance of about 1,500 yards. After passing the batteries twice in this manner they anchored, shifting their positions as requisite.

* *Journal U.S. Institution.* Vol. XXXIII.; p. 161.
† *Les Torpilleurs.* Vice-Admiral Bourgois.

This plan was also followed by the *Temeraire.* The *Inflexible* dropped a small buoy at a known range, and steamed up to it to deliver her fire.

According to Captain Goodrich, of the U.S. navy, who was an eye-witness of the engagement, the prize for good shooting must be awarded to the *Inflexible* and *Temeraire.* Both of these ships fired at known ranges only, while the captains of the principal guns on board both ships had the advantage of a clear and uninterrupted view. The plan of fighting a ship under way was evidently the worst of the many adopted. Sir W. Hunt-Grubbe, who commanded the off-shore squadron, only tried the elliptical course in line ahead twice. He then anchored his squadron, to get more accurate shooting. The Egyptians did not use the few mortars mounted in their works, and would have produced no effect had they fired them. In the absence of high-angle fire, the ships could anchor with comparative impunity, and the action resolved itself into deliberate shooting at the enemy's guns. The ships engaged belonged to the Mediterranean squadron, and it is, therefore, needless to say were in a high state of efficiency. The gunnery may certainly be taken as above the average. The effect of the fire may fairly be regarded as a standard of what can be done by ships against batteries under exceptionally favourable conditions for the former. The failure of the percussion fuzes, no doubt, greatly diminished the amount of damage done to the works themselves, but, probably, did not greatly affect the damage to guns. The *Inflexible* engaged Oom-el-Kabebe at a range of 3,800 yards. Her practice is described on all hands as admirable. As the fort was only 80 feet above the sea, and was protected by a parapet eight feet high, her shell struck with a descending angle, and had some searching power. As a result, one S.B. gun was disabled, and this gun was not in action, while the damage to the parapet could have been repaired in a very short time. So much for the effect of slow fire from heavy guns at long range.

Mex, which has been described by Major Clarke, R.E., as a "prehistoric work," was attacked at short range by the in-shore squadron, assisted by the *Temeraire* outside the corvette pass. "In view of the tremendous fire to which Fort Mex was subjected, and the comparatively short range at which all the ships, except the *Temeraire,* engaged it, it is almost impossible to believe the fact that not a single gun here was dismounted or disabled during the action proper. . . . The 8-inch gun . . . was bowled over by the *Penelope* long after the fort had ceased firing, and from a distance stated to be about 300 yards." So says Captain Goodrich, in his official report on the action. The men in Mex were, however, driven from their guns, which were then disabled by a landing-party, who destroyed the carriages of two heavy guns by exploding guncotton, and spiked the remainder. This was an excellent piece of work; well conceived, well carried out. But Egyptian troops, or men of a similar stamp, are necessary for the success of such an enterprise. Most men will run away on occasions, but those with some grit in them can be brought up to the scratch again. The scanty protection given to the gunners at Mex gave them ample excuse for leaving their guns, but the landing-party should not have been permitted to effect their purpose without interruption.

On the day following the bombardment the forts were in a position to renew the action, and the ships had expended a large proportion of their common shell. The garrison, however, was demoralized, and, so far as the ships were concerned, the affair was over.

It has been remarked that the fire of ships of the modern type, carrying a small number of heavy guns, is not so effective as that of older vessels, carrying a large number of guns. At Charleston, the Ironsides proved superior, offensively, to the monitors. The *Minotaur*, *Agincourt*, and *Achilles* might, probably, have been more useful vessels than the *Inflexible* for the attack on Alexandria.

The French operations in the river Min show the danger of admitting a large naval force into a fortified port when diplomatic relations are strained. Owing to the presence of their squadron above the defences of Foo-Chow, the French were able to begin their attack by the bombardment of the arsenal, instead of having to fight their way up the river in order to reach it. The Chinese batteries on the banks of the Min were constructed to fire down the river, not to fight an enemy coming from Foo-Chow, and offered little resistance. One ship, however, *La Galissonnière*, arrived in the river, while the rest of the squadron were engaged with the upper forts. She engaged the batteries at Kimpäi Pass. At first the firing was wild; but when the Chinese got the range, a shot from a 21-cm. Krupp gun struck the ship forward on the starboard side, and, says the American report, "would have inflicted very serious injury on the vessel had it been filled with powder instead of charcoal." As it was, *La Galissonnière* had to be repaired at Hong-Kong. The Hotchkiss guns on board the French ships were worked with great effect against the Chinese gunboats at Foo-Chow, and in the later engagements against the troops on the banks of the river. The

Chinese on shore seem to have shown less than their usual amount of fight, owing, doubtless, to their batteries being taken in reverse. The loss of the French, which was inconsiderable, was mainly caused by the fire of troops from behind the crests of the hills. Submarine mines do not appear to have been laid down by the Chinese, though their suspected presence in the Kimpäi Pass caused the French Admiral to spend two days in creeping. The bombardment of the arsenal did not inflict any very serious injury. Only three months afterwards the Chinese were able to launch a vessel which had been "much damaged" by the French fire.

Of the many other engagements between French ships and Chinese batteries little need be said. The batteries were invariably silenced, but permanent success was only attained by the attack when a landing-party could be sent to complete the work.

Raids on minor coast defences were frequent in the days when the effective range of musketry did not exceed 200 yards.

A very successful harrying system of operations was carried on by our frigates and smaller vessels during the great war, especially on the Mediterranean coasts of France and Spain. This kind of work, partaking largely of the nature of a spree, seems to have been very congenial to our seamen. Moreover, it filled their pockets. Insignificant ports were protected by small batteries. Probably no one would have thought it worth while to expend ammunition in attacking these works for their own sake, but the enemy's coasters occasionally took refuge under them when chased by our cruisers. Our craft would then open fire, and would frequently land a force and rush the battery, as the quickest and most effective method of silencing it. The garrisons of these minor coast works were composed to a great extent of invalids and pensioners, and our landing-parties were frequently successful. Sometimes regular troops were at hand in sufficient number to beat off our men, but even then the loss was seldom heavy, as the fire from the ship covered the re-embarkation of the men. These constant worrying operations had a distinct military value. Telegraphs and signal stations were destroyed; supplies sent by sea were cut off. A whole district might be kept on the *qui vive* by the raids of a single ship. The exploits of Dundonald are well known. It is said that the *Imperieuse*, under his command, found employment for 10,000 of the enemy. Probably that is an exaggeration, but there is no doubt that his proceedings were a constant annoyance to them.

Poker was not invented in those days, but bluffing was frequently used with great effect. At Fort Manack, Java, Lieutenant Lyons landed in August, 1812, with 35 men of the *Minden* and stormed the battery. Finding the Dutch garrison drawn up to receive him, Lyons called out that he had 400 men and would give no quarter, on which the Dutch ran. The *Mindens* spiked the guns and destroyed the fort. The Dutch made an attempt to re-take it, but were driven back; and the British, when their work was finished, re-embarked.

The capture of Banda Neira, in 1810, is a typical case of a successful landing. The following account of the affair is given in James' *Naval History*. Two frigates and a brig were on their way from Madras to Ambozna, with leave to attack Dutch possessions on the way. Their crews were augmented by 100 Madras European troops, and they further embarked 20 artillerymen and two field guns at Penang. Banda Neira is about two miles long and three-quarters of a mile broad. At the time in question the island was defended by 10 sea batteries and two "castles;" one of which, Casteel Belgica, mounting 52 guns, commanded the other and all the sea defences that end of the island. The garrison consisted of about 700 regulars and 800 militia. On approaching the Banda Islands the ships were fired upon, which showed that the Dutch were prepared. The ships had been seen, and a complete surprise was impossible; but, as the night was dark and squally, Captain Cole, who commanded, took his landing-party in the boats and made for Banda Neira, leaving the ships to follow. The total force consisted of about 400 men, but the boats separated in the darkness, and only about 140 seamen and marines, and 40 of the soldiers, arrived at the rendezvous. A heavy tropical rain-squall enabled this little party to land on the beach just under one of the sea batteries, unobserved by the Dutch. The battery was rushed from the rear, the sentry killed, and an officer and 60 men made prisoners without a shot being fired. Captain Cole then made for the citadel, the garrison of which was now alarmed. The outworks were escaladed. The Dutch Colonel and some of his officers lived in a bungalow outside the work. The garrison opened the gate to admit them, and the British rushed in at the same time and took the place. The key of the whole position was now in our hands, and a message was sent threatening to lay the town in ashes if the garrison did not surrender. The ships arrived in the course of the morning. Casteel Nassau and the sea batteries hauled down their flags, and 1,500 Dutch troops and militia laid down their arms.

During the Russian War good work was done by landing-parties in the Sea of Azov, and at Kertch, where great quantities of grain and other stores were destroyed. On the other side of the globe a landing-party from a combined French and English squadron were beaten off with considerable loss. Two Russian ships had taken refuge in the harbour of Petropaulovski. An allied force of three sailing frigates, a corvette, a sloop, and a paddle-wheel steamer, proceeded to attack them. They found the ships protected by batteries, principally armed with the guns landed from the *Aurora*, the larger of the two Russian frigates. The British Admiral shot himself as the squadron was preparing for action. The French Admiral does not appear to have been a strong man. Two days afterwards the frigates attacked the larger batteries, but without making any great impression. The paddle sloop *Virago*, however, silenced a 3-gun battery, and landed a party, who spiked the guns. After three days' consideration, a second attack on the batteries was made, and at the same time 700 seamen and marines from all the ships were landed, with the view of taking in reverse a fort on high ground, which was believed to command the other defences. The information acted upon was incorrect—or, more probably, designedly false. The Russians were prepared for an attack. Many of the landing-party were killed, others taken prisoners, while about half of those who reached their boats were wounded.

This affair bears some resemblance to the attack by the French on the Chinese entrenchments at the mouth of the Tam Sui, and the landing-parties in both cases met the same fate. The following description is abridged from an account which appeared in the *Figaro* :—" The squadron of Admiral Lespes, consisting of *La Gallissonnière*, *Triomphante*, *D'Estaing*, and *Vipère*, arrived off the river Tam Sui on the 1st of October. The two ironclads and the cruisers anchored at a distance, while the gunboat reconnoitred the mouth of the estuary. The river was obstructed by a line of four large junks, loaded with stones, sunk outside the bar, leaving a channel which appeared to be defended by ground mines. On the 2nd a reconnaisance of the coast was made. On the 3rd fire was opened on the forts. The Chinese returned the fire, but at 2 p.m. the forts were silenced. The 4th and 5th were spent in reconnaissances. On the 6th the *Duguay-Trouin*, *Chateau-Renard*, and *Tarn* arrived, the latter bringing the landing-party of the *Bayard*. On the 7th the weather was bad, and the sea too high to admit of landing. On the 8th, at 9 a.m., the landing-parties of all the ships disembarked in a small bay near the mouth of the river and attacked the Chinese position. The Chinese appear to have fought well, as they generally do behind entrenchments. Captain Boulineau 'judged it prudent to stop the advance.' The sea was getting up. The French retreated, leaving their dead behind them. Out of 320 actually engaged 18 were killed and 51 wounded."

Probably a better instance of how not to do it could not be cited. Suddenness—if possible, surprise—is essential to the success of a landing-party from ships. At the Tam-Sui the repeated reconnaissances taught the Chinese exactly what they had to expect, and gave them time to bring up their men. The French never reached either of the forts, or the entrenched camp; they were checked at an embankment considerably in advance of those works. The French seamen appear to have been entangled in the paddy fields, and to have been shot down by the Chinese from under cover.

As a general rule, the success of a landing-party implies an insufficient garrison, want of vigilance, or want of pluck on the part of the defence. The landing force of a squadron is never large. At our home ports, including all mercantile ports of any importance, the force available for defence against a landing must always be ample to resist any purely naval attack. Unless, indeed, the volunteers are bottled up in fortresses, or employed in throwing up earthworks for the defence of London. However, it is not upon the shores of the United Kingdom that raids are to be feared. If this country retains command of the sea, no enemy's cruiser will run the risk of being caught with half her crew away in boats or on shore. If we lose the command of the sea, the enemy will have other business on hand than looting watering-places. In some of the minor colonies, especially at those places where the English population is small, an enemy's squadron may be in a position to land a force considerably superior to the defence. A naval raid for the purpose of exacting contributions, or destroying shipping and stores, may possibly be made. In these cases vigilance is of supreme importance. Everything depends on bringing the enemy under fire while they are in their boats. The boats must inevitably be crowded with men, and every bullet should tell. The few minutes of confusion inseparable from a landing should also be a golden opportunity for the defence. Coast batteries are occasionally constructed, as at Breandown, with an elaborate gorge defence, but with no obstruction in front, to prevent men landed on the beach walking in over the parapet. Seamen are handy at getting over obstacles, but they also swear on small provocation. Impediments, sufficient to produce objurgation, and thus to prevent surprise, may be easily improvised; and surprise has been generally the principal element of success of landing-parties.

In all cases of naval attack the object of officers commanding coast defences is to impede and annoy the enemy's squadron. Rules for particular cases cannot be laid down, but a careful study of actions beween ships and batteries will give a general idea of the course to be pursued in order to increase the difficulties which are inseparable from sea gunnery, and to make accurate fire from ships impossible. There is, as yet, no accurate range-finder afloat; and though some promising ideas are being worked out, there seems no immediate prospect of a trustworthy instrument. In the absence of means of quickly ascertaining and communicating the range, any rapid movement on the part of the attacking ships is out of the question; or, if carried out, must entail bad shooting and waste of ammunition. The numerous instances already given show that to maintain an effective fire a ship must be at anchor. The excellent practice made by the *Inflexible* at Alexandria may be quoted in opposition to this theory, but the peculiar armament of that ship must be taken into account. The *Inflexible* carried four 16-inch R.M.L. guns, and eight 20-pounder R.B.L. guns. The lighter guns were, therefore, wholly insignificant in comparison with the heavier. The ship carried no secondary armament, in the sense in which the term is now understood. The four heavy guns took some time to load, and their fire was naturally delivered in salvos, with considerable intervals. The policy of keeping the ship moving, and steaming to an ascertained position to fire, seems to have been the natural outcome of her armament. Such a plan would probably not have been followed had she had a secondary armament of 6-inch guns, such as is now usually carried by battle-ships. The object of the defence is, then, to prevent ships from anchoring, by making it so hot for them that they must shift their position or be disabled. Where howitzer batteries exist, this should be a simple operation. The engines and boilers of a ship are protected by a steel deck, which is fairly shell proof; but no such overhead protection is given to the armament. High-angle fire from rifled howitzers should be accurate, and even that of old 13-inch mortars is not to be despised. A howitzer battery cannot be silenced, or even inconvenienced, by the fire of ordinary men-of-war. In the absence of howitzers or mortars —or in conjunction with them—it is a good plan to concentrate all the fire, as much as possible, on one ship, and to drive her out of action. This was done with success at Fort Wagner, the garrison of which work had great experience in dealing with ships.

If the object of the enemy is to force the passage of a channel, obstructions must be placed in his way. Artillery fire, in this case, should be regarded as auxiliary—a most important auxiliary no doubt, but unable alone to prevent an enemy from passing. Passive obstructions, to be effective, must be practically immovable. Floating booms are, as a rule, destroyed without great difficulty.

A channel was cleared at Obligado, and at the forts below New Orleans, where ships chained together were moored across the stream; on the other hand, at the second attack on the Peiho, where the river was staked as well as otherwise obstructed, our vessels were stopped, and sustained a disastrous defeat. Difficulties of navigation should in all cases be taken every advantage of by the defence. A bend in the channel where ships must turn may be sufficient to impede a squadron, if means are taken to obstruct the view of the Captains and pilots of the ships. Smoke is useful in such places, and as we are within measurable distance of smokeless powder, other means of producing it may have to be used. The fires on the banks of the Mississippi at Port Hudson were primarily intended to show up the enemy by their light. As it turned out, their smoke proved more effective than the projectiles from the batteries. The days of fire-ships ended with the universal adoption of steam; perhaps, in attacks on forts, smoke ships may take their place. Navigation in narrow water, under ordinary circumstances, requires great care and constant attention. No great effort of imagination would seem to be necessary to picture the position of the Captain of a ship when, in addition to all ordinary difficulties of pilotage, his view is obscured by smoke, landmarks are invisible, and the compass is useless, owing to the concussion of the ship's guns. Surely these are sufficient to bother a man of average capacity, without calling in the aid of artillery fire. Yet the possibility of ships running through such a channel as the Narrows at Bermuda, with the buoys removed or misplaced, by simply observing the colour of the water, has been gravely maintained.

Since the defences of Alexandria and of Foo-Chow were attacked, gunmakers and artillerists have advanced in two directions. The first of these—the development of quick-firing guns—is temporarily in favour of naval attack. According to the theory advanced in this paper, ships never effect anything against works or guns, but only against gunners. Any invention which increases the rapidity and accuracy of fire is of more importance to seamen than an invention which increases the power of guns. The method of mounting quick-firing guns has greatly improved the shooting from a moving platform. Rapidity of fire has, of course, been increased by their adoption. All naval Powers have recognised these facts, and have mounted large numbers of quick-firing guns in newly-fitted ships. These guns are in no case placed behind armour; if protected at all, their shields are only proof against machine-gun bullets. Their fire should, therefore, easily be kept down by similar guns mounted on shore, the detachments of which would be far better protected than their adversaries afloat. The advantage that this invention has conferred on ships is, therefore, merely temporary. The fact is that the ships have the guns and the forts have none.

The other point referred to is the adoption of high explosives for the bursting charges of shell. This is altogether in favour of the defence. Whether these shells are to be fired with slow-burning powder or by compressed air matters little. The universal introduction of high explosive bursting charges will probably have the same effect on the question of ships *versus* forts that the introduction of shell produced in the days of wooden vessels. Special ships will, more than ever, be required to attack coast defences.

If it be admitted that no serious naval attack on a fortress can be attempted, except by a Power possessing uncontested superiority at sea, it follows that this country is less liable than any other to such attacks. The increased speed of war vessels has in no way affected the question as regards organised attacks, though it has, perhaps, made a sudden raid a more feasible operation than in former days. If so, it has to an equal extent enhanced the chance of a cruiser being intercepted while engaged in a raid.

As far as the United Kingdom is concerned, a raid on an undefended port is possible, but any organized naval attack on a fortress is out of the question. Coaling stations abroad, especially those of secondary importance, such as St. Lucia or Thursday Island, are more open to attack; for at these distant stations it is possible an enemy may, in a particular locality, be temporarily superior to us at sea.

Coast fortifications are essentially the defence of a weak against a strong naval Power. By Great Britain they should be regarded as a necessary evil—necessary so far that our arsenals at home and abroad must be secured against naval attack, and our coaling stations and great mercantile ports must be protected against raids—an evil, because every shilling spent in works of defence represents an equivalent reduction in our aggressive strength, and every gun mounted in a fortification takes 50 men from the fighting line.

Coast fortifications should, then, be strictly limited to what is absolutely necessary, and every tendency to exceed this limit should be resisted. Disappearing guns and rifled howitzers—neither of which can be silenced by men-of-war—long-range guns, high explosives, and submarine mines, have enormously increased the difficulties of naval attack, and have rendered gigantic armaments unnecessary. Let it always be remembered that the sole *raison d'être* of the coast defences of the Empire is to allow the navy and army to act on the offensive, and fight out a quarrel on the high seas, and in a hostile country, rather than on British soil.

PS VERSUS FORTS

From Kinglake's Crimea
(Blackwood)

PAPER VIII.

A VISIT TO BAIRAM ALI AND THE WORKS AT SULTAN BAND.

By Lieut.-Colonel H. L. Wells, R.E.

On the 21st of November, 1889, after a pleasant three days at Amu Daria, I decided to visit Bairam Ali, the site of ancient Merv. A waggon, fitted up as a carriage by putting in partitions, etc., so as to afford lavatory and servant's bunk, a couch, stove, etc., had been placed at my disposal by General Anneakoff, and being attached to an ordinary train, the $134\frac{2}{3}$ miles from the Oxus to Bairam Ali were traversed in 12 hours. There was some difficulty in obtaining food at the last-named place, and the cold experienced during the night in a waggon standing on the siding in the midst of the steppe was very severe.

On the morning of the 22nd, the acquaintance of Captain Zaveecha, of the Russian Engineering Corps, was made, and, thanks to his kindness, a guide and ponies were supplied to visit the ruins of ancient Merv, which, scattered as far as the eye could reach northward and westward, give a depressing aspect to the, at the best of times, dreary steppe.

The impression conveyed by Bairam Ali and its surroundings, as well as a sketch of the reasons which led to the abomination of desolation running riot there, is given in the Hon. George Curzon's admirable book, *Russia in Central Asia.*

The Trans-Caspian Railway will soon alter the aspect of this country, and it will probably ere long be a smiling oasis.

The morning of the 22nd was spent in visiting the ruins, and in the afternoon going over the works, which are under the charge of Captain Zaveecha, and which well repaid the trouble.

Substantial buildings are rising in considerable numbers ; these will be the dwellings of the officials who are to administer the new province, which is to spring up as soon as the Murghab shall have been turned on to the steppe, and its waters again have fertilized the site of the once fruitful "Queen of the world."

For lack of timber, the metals of the Decauville Railway are used as scaffolding. The buildings are constructed in brick, the earth here, and apparently throughout the Central Asian steppe, being admirable for brick-making. Arched roofs are to be used wherever possible, as the white ant is rampant in these parts. The bricks are extremely large, $14'' \times 7'' \times 3\frac{1}{2}''$, and are mostly burnt in a kiln of a Chinese pattern, the designs for which were brought from Kulja, on the Chinese frontier, by Colonel Poklefski, the engineer in charge of Sultan Band, *i.e.*, the dam which is in course of construction on the Murghab river. The kiln is dome-shaped, and there are four chimneys placed at equal intervals around the circumference of the dome, so as not to interfere with either the aperture for charging the kiln or the grate by which it is heated. These chimneys, constructed in the thickness of the walling of the dome, emerge from the interior of the kiln at about $2\frac{1}{2}$ feet from the floor. The half of the kiln is built in excavation, the grate being reached by a sloping way. The aperture for charging the kiln is on a level with the surrounding country. The brick-burner arranges that the heat shall reach all portions of his kiln by regulating the draught of his four chimneys—opening one, closing another, and so on—and certainly most magnificent bricks are produced ; 150,000 go to a charge.

When the bricks are just burnt, the custom is to open an aperture which is left in the brickwork of the crown of the dome, pour in water, and then to immediately reclose it ; by doing this the bricks seem to be silicised, or chemically hardened, in some manner, and when so treated they have a light olive green colour, and are certainly far more durable. The brick of Central Asia is of a light straw colour when burnt in a kiln of European pattern. Burnt bricks cost three roubles per 1,000, and unburnt 2·50 roubles, a rouble being worth two shillings nearly.

A cement was seen in course of preparation both here and at Sultan Band, its manufacture having been instituted by Colonel Poklefski, the engineer in charge of the last-named work. Lime produced in the neighbourhood of Askabad is brought thence by rail to Bairam Ali, and mixed in proportion of one to five with earth from the steppe, and ground in a mortar mill. Bricks are made of this mixture and burnt in an ordinary flare kiln. The bricks are then broken up and ground down, and form an hydraulic cement, for which properties as good as the Portland cement are claimed.

Nursery gardens of tens of thousands of young trees were seen in a flourishing condition ready for planting out as soon as the Sultan Band shall be completed. Hot-houses, too, in a small way, are used for experimenting on vegetable products with a view to acclimatizing them.

Captain Zaveecha and young Poklefski, son of the engineer already mentioned, kindly offered to arrange for my visiting the last-named work, and telephoned to Poklefski, senior, to know if there was any objection to my coming to visit him. Colonel Poklefski had for some time been seriously ill, and it was feared that perhaps he might not be able to receive me ; however, though still very ill, he kindly consented to do so, and on November 23rd a troiga, drawn by three sturdy Russian horses, and driven by a blue-eyed, sandy-haired Russian "Moujik," were in waiting at the siding on which my waggon was shunted. Taking a small Gladstone bag and some blankets, and leaving at 9.10 a.m., we drove across the steppe in a southerly direction, reaching our destination at 1 p.m., having covered, I calculate, 36 miles in the interval.

It was some time after leaving Bairam Ali ere the ruins of the ancient cities were lost to view, and the long disused irrigation channels were seen intersecting the plain on both sides of the road. At about 18 miles from Bairam Ali, the Kabitka (felt tent) of a Russian officer, who was evidently engaged in taking levels, was passed, and then at, say 20 miles, a large Aoul, or collection of Turcoman tents, was seen in the neighbourhood of depressions leading into the Murghab river ; at 28 miles the river itself was seen, and its banks followed to the site of the Band.

It is little more than a century since the then rich city of Merv, which occupied the present site of Bairam Ali, was attacked by the Bokhariots, who, in order to reduce the town and ruin its inhabitants, cut the earthen band of Sultan Sunjar, which provided for the irrigation of the plain of ancient Merv, and for the distribution of the water supplied by means of the Band. The irrigation channels still exist, and will be again utilised.

The cutting of the Band had the desired effect ; Merv yielded, and its inhabitants were carried into captivity, the country being given over to desolation and the Turcomans, and the site of ancient Merv remained uninhabited till now.

The original Band was of earth, as the new one is to be, and had a masonry waste weir also like its successor.

By comparing plans, *Plates* I. and II., it will be seen that the new dam will occupy the identical position of the old one, and the new sluices and waste weir will be but a short distance from the old weir, in fact, only 160 sagines = $373\frac{1}{3}$ yards to the south-east, or up-stream from it.

A short cut will lead from the new sluices into the ancient canal, or Sultan Ab.* It is little more than a year since the project was fairly taken in hand of renewing the ancient Sultan Band, the Emperor himself granting the money for its execution from his private purse.

Colonel Poklefski Koziell, a Polish engineer, is in charge of the work. This energetic officer was at one time an Instructor in a Military College in St. Petersburg; then a proscribed rebel in the Polish insurrection of 1860; a General of Brigade in Bourbaki's army; a prisoner in Siberia; till sent as a simple Cossack to Kulja, where his engineering ability becoming evident it was turned to account, and he became *ipso facto* chief engineer of the province.

Seventeen years devoted to the study of irrigation in Central Asia has, apparently, made him a great authority on the subject; at all events, he was especially selected for the present work by H.I.M. the Czar. Exposure endured in acquiring this knowledge has, I fear, undermined his constitution. The whole organisation of the work, and the workmen, show that a capable man is at the head of affairs. He is ably assisted by two younger engineers, and there are several students and cadets attached to the staff for the purpose of learning their profession.

The labour is almost entirely performed by Turcomans. No contractors are allowed, nor are there any gangers or middlemen. The Turcomans work in small squads of four or five, and are paid by piece-work, the engineers measuring up the work done whenever required. Squads of Russian soldiers, who have been allowed to come here from the garrison at Merv to earn working pay, occupy the buildings marked "temporary barracks" on *Plate* I. They have no arms with them, and are principally employed in making

* Sir Henry Rawlinson, G.C.B., published an account of this work in the *Quarterly Review* some few years ago.

the fascines and placing them in position. There is not an armed man in the place.

The Turcomans are supplied with food at cost price, as otherwise they would have to go far for provisions. No liquor is allowed on the premises, and, there being no shops, none can be obtained. It is this fact, no doubt, which accounts for the happy immunity from disturbances, brawls, etc., that has been experienced, as well as for the absence of sickness.

On *fête* days the Turcomans are regaled on mutton and rice, and the soldiers with an allowance of vodka. The latter were gaily singing at their work on the frosty morning of November 24th.

Plate I. is the site of the dam.

Plate II. shows the dam and all the proposed works. The masonry and brickwork are shown shaded in, and the earthwork and its artificial slopes are shown in thick lines. It will be seen that there are to be two canals, one flowing from the right bank to Bairam Ali, the other from the left bank in the direction of Merv; the latter is marked Q in the plan.

Plate III., Section α, shows the longitudinal section of the dam. Section β shows the level, etc., along the course of the waste weir and the channels leading from it.

Figs. γ and δ show details of the frame for staging to form a temporary bridge for casting in earth and fascines in constructing the dam.

Plate IV., Section η, shows a scheme for the waste weir, which, however, has not been adopted.

Fig. θ is looking north, and explains itself, showing the travelling crane for raising the doors of the waste weir and sluices.

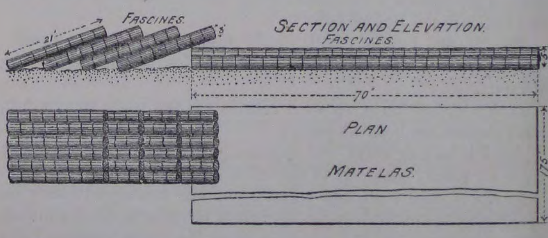
Figs. ι, κ, and λ explain themselves; the last-named shows an opening, or species of lock-gates, to allow of steam launches and such like craft plying on the canal reaching the upper waters of the Murghab.

Plate V. shows a more detailed plan of the waste weir and sluices, with the rails for transporting the travelling crane, by which the sluice and waste weir doors are to be raised, a detailed drawing of one of which is also shown at *Fig.* μ.

On approaching the site of the new Band, the masonry barracks, as they are termed on *Plate* I., but which are really a set of new quarters for the staff of engineers and upper subordinates, attract the attention, not that they are spacious or lofty, for, on the contrary, they are very simple, and scarcely commodious enough for comfort, at all events during the hot weather; however, they are pleasantly situated above the river, and from the windows of Colonel Poklefski's quarters the greater part of the work can be seen. The quarters remind one very much of a coastguard station on some low-lying shore of the English Channel.

On a lower level of the slope to the river are the temporary barracks, built in excavation from the side of the slope, and half, as it were, buried in it. These are used partly as stores and partly as barracks for the soldiers who come from Merv to earn working pay; on the river is a bathing hut, from which a delightful plunge and swim can be had.

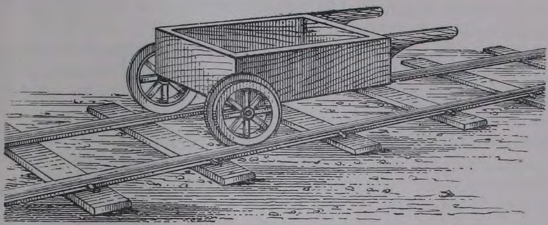
The dam is being built in the following manner. First of all frames in timbers of the description shown at *Fig.* 8, *Plate* III., have been arranged as a staging, along which a line of Decauville rails is laid, forming a temporary bridge. Then a series of fascines are thrown in, anchored with stone until a "matelas," five feet thick, of these materials is arranged down stream from the stage or bridge, and across the bottom of the whole width of the river bed, viz., 175′ × 70′.



Then fascines, 21 feet long by 3 feet diameter, bound with wire, and weighted with stones placed in their centre up to a weight of 250 lbs. for each fascine, are dropped into the stream and arranged as shown in the above section and plan. Earth is thrown in from the staging and collects behind the fascines as the layers are built up, each layer of fascines being pegged to the one beneath it.

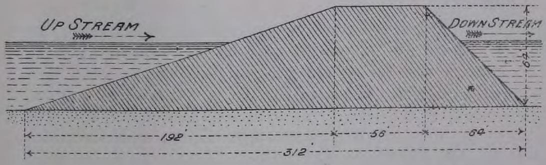
The earth to form the dam is obtained from both banks of the river, and brought to the staging by trucks running on the Decauville lines or handbarrows arranged with double wheels to run on the lines.

On November 23rd, in addition to earth tipped in from the main staging, a lot of runs of Decauville metals had been arranged, and earth was being dug from the high ground marked Z on *Plate* II.,



and carried out on light staging and tipped into the river behind the fascines, which had apparently risen to about 14 feet from the "matelas," and the river was pouring over the fascines in a picturesque cascade, far too powerful to look pleasant.

The dam is eventually to have the section shown below.



It is stated that the water will be raised 42 feet to the sills of the sluices and waste weir, and the remaining 22 feet will be the extra height that will bring the top of the dam and the roadway thereon to a level with the roadway over the waste weir and sluices, and will enable water to be stored up to the top of the sluices, etc.

Colonel Poklefski says the lake caused by the dam will be 18·6 miles in length, and there will be 6,860 million cubic feet of water stored up; 2,744 million will be available in time of scarcity, that is, can be stored by the doors being let down, and let run out, by opening them, as may be deemed necessary. Not being an irrigation engineer, I felt incompetent to criticise the work, but asked how the dam was to hold water without a puddled trench. The reply was that the nature of the earth of which the dam was being composed was so clayey, and experiments had shown it so impervious to water, that no puddle trench or anything of the kind would be necessary.

From the dam, the cutting leading from what will be the reservoir to the waste weir and sluices was visited and found almost completed. The brick and cement-making for the brickwork of the above weir, etc., were going on here. Persian wheels were used to raise water to the brickfield and concrete platforms, and excellent machinery, driven by a first-rate engine, was in position for mixing the concrete and tipping it into trucks, by which it will be run to the site of foundations.

The old waste weir of Sultan Sunjar was visited, and is of magnificent material. The brickwork and cement are of such excellent quality that dynamite has to be employed to move them. The *débris* is used in making concrete for the foundations of the new structures; broken brick will be used for the balance of concrete required.

The new waste weir and sluices had not been commenced. The design for them will be learnt from *Plates* IV. and V. The waste weir will have 15 openings, $7' \times 14'$, not including the semi-circular arch turned over the top of the opening, and will be closed by iron doors, the details of which are shown at *Plate* V., *Fig.* μ, as is also the arrangement for holding the doors at any required level, which seems to be clumsy. The fact of no runners being placed at the back of the waste weir and sluice doors, a plan adopted by Mr. L. B. Wells, and which has met with such success at Dutton, on the Weaver navigation, necessitates a powerful crane being employed to raise them. Colonel Poklefski had not heard of the last-named method, and regretted that it was too late to employ it, as the doors for Sultan Band were already partly constructed. (There seems to be no arrangement for forcing the doors down in case of their jamming with pressure from water).

The water from the waste weir will flow into the river bed along the channel O P, *vide Plate* II. and Section β, *Plate* III., and will descend to the river level in three steps in brickwork, with flooring of stone laid on fascines, not in two steps, as shown at Section β, *Plate* III., Section η, *Plate* IV., and on *Plate* II., in plan.

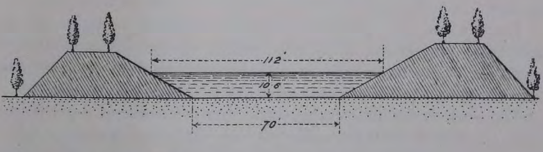
The first fall, or step, will occur at the sluice, and be 21 feet, the second only three feet, and the third 14 feet; the remainder of the fall will be obtained in the slope of the channel.

The sluices will be nine in number for the main, or north-east, channel, with openings of $7' \times 10\frac{1}{2}'$, not including the semi-circular arch turned over the top of the opening.

No details of the sluice gates, or doors, were gathered, nor of the manner in which it is proposed to close the opening, 14 feet in width, intended to be made in the sluice dam to permit steamers entering and leaving the reservoir, and, in fact, to enable water traffic to be carried on between the upper course of the Murghab river and irrigation channels. An elevation of this opening, and the swing bridge to span it, is shown at *Fig.* λ, *Plate* IV.

Turbines to the power of 3,000 horses are to be worked by the flow of water at the sluices, and will provide motive power for mills, electric lights, etc., etc.

No details as to the sluices for the canal at Q, *Plate* II., were gathered. The main canal going to Bairam Ali will have the following dimensions, though the extreme height of the banks on either side was not learnt :—



The following are Colonel Poklefski's figures :—

He calculates that 4,116 cubic feet per second will flow along this channel when the water is at its normal height of $10\frac{1}{2}$ feet. The slope is $\frac{3}{10000}$.

That the canal at Q, flowing to the north-west, will convey 5,145 cubic feet per second.

That the Murghab is at its fullest during March, April, and May, when, he says, its flow varies from 5,145 to 10,290 cubic feet per second. In June, the water supply decreases, and in July, August, September, and October there is little water, but there will always be 1,372 cubic feet per second, which would be sufficient to water 80,000 hectares, or 197,688 acres of garden, not counting 2,744 million cubic feet in reserve.

The spring supply, which is what is principally wanted, as it is at that season that the crops will be coming up, will be sufficient to irrigate 600,000 hectares of land, or double what is available on the Murghab. Moreover, the present project only contemplates the irrigation of 120,000 hectares, *i.e.*, 296,532 acres, or well within the margin of the water supply in spring, and leaving only 40,000 hectares unirrigated in summer.

Colonel Poklefski is very confident of the success of his undertaking; he is certainly of a very sanguine temperament.

As already stated, experiment has proved that the soil of the Merv steppe is very impermeable to moisture, so that the canals can be carried above the surface of the surrounding country, as shown in the sketch at p. 245.

The smaller channels will all be laid out with careful regard to—

(1). The absolute regularity of supply so that the ground shall neither get too much or too little water.

(2). The climate of the country.

(3). To the very impermeable nature of the soil.

(4). The nature of crops it is proposed to grow.

(5). The customs of the natives and colonists who will till the ground.

The cost of the project for 120,000 hectares is estimated at 4,000,000 roubles, or £400,000 nearly, at the present rate of exchange. The cost would be, probably, double, were it not for the great number of ancient channels still available and fit for use.

The work is certainly being carried out at a marvellously cheap rate, *i.e.*, from 5 to 10 times cheaper than similar work was executed on the Trans-Caspian Railway. Earthwork costs only 1·93 roubles per square sagine, or 1s. $1\frac{1}{2}$d. per 100 cubic feet. Bricks of the large Russian pattern, $4'' \times 7'' \times 3\frac{1}{2}''$, unburnt, cost 5s., and burnt, 6s., per 1,000. Brickwork finished and in position costs 40 roubles per cubic sagine, equals £1 3s. 4d. per 100 cubic feet, nearly. Concrete in hydraulic mortar, 50 roubles per cubic sagine, equals £1 9s. 2d. per 100 cubic feet, nearly. Daily labourers receive from $7\frac{1}{5}$d. to $9\frac{3}{5}$d. per diem.

It is proposed to keep the main canals free from silt by discharging compressed air from tubes in the bottom of a steam launch, and the silt thus stirred up will flow away and be distributed over the fields irrigated.

It is proposed to collect large stores of forage and straw in readiness for the support of both colonists and their cattle on their arrival at Bairam Ali; "silos" are to be extensively used for the purpose.

It is calculated that should the whole 300,000 hectares of land on the Murghab be irrigated, it would sustain at least a million men. Colonel Poklefski considers that there are more than 6,000,000 nectares of land capable of irrigation in Russian Central Asia, with plenty of water to hand for their irrigation, in addition to the land on the Murghab, *i.e.*, territories five times that of Egypt in combined extent, with a climate and soil capable of producing as good grain, cotton, and tobacco, as that of the last-named place.

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P.S.—It will be seen by the date given at the commencement of the above paper that it treats of what was seen nearly a year ago, and the paper itself was written in January last.

When in the Caucasus, at the commencement of the present month, I heard rumours of the Band on the Murghab having proved a failure, and that it had been carried away by a flood whilst still in an incomplete state.

Another rumour was that the waters of the Murghab had not come up to the amount estimated by Colonel Poklefski, and that this was the cause of his having been dismissed from his post at Sultan Band.

For the truth of any of these reports I cannot vouch, and no definite and exact news as to what had happened could be gathered.

A copy of the *Times*, seen at Batoum on October 5th, showed that Colonel Sir C. Scott-Moncrieff was *en route* for Central Asia, his services having been placed at the disposal of H.I.M. the Czar for the purpose of assisting in irrigation works in that part of His Majesty's dominions.

All this news made me hesitate to print the foregoing pamphlet, but further consideration has led me to think that it may still have interest, though it may prove to treat of a project which ended disastrously for the engineer who drew it up, and as it will show what Sir Scott-Moncrieff may be called on to perform.—Yours faithfully,

H. L. WELLS.

J.U.S. Club, October 25, 1890.