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PAPERS

ON SUBJECTS CONNECTED WITH

THE DUTIES

OF THE

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PREFACE.

This volume contains some information relative to the effects of missiles fired from rifled guns against brickwork, and the Report on the Experiments made by the Prussians at Juliers shews their capability of breaching walls hidden from view, without requiring the enormous amount of ammunition employed in destroying the independent wall built at Woolwich in 1824; but we require proofs of their effects in breaching works more thoroughly protected, and placed so that they would strike them obliquely, and with much diminished velocity, before we can arrive at any satisfactory conclusions.

There are now so many volumes of the Professional Papers that an Index is much wanted to facilitate reference to them; I have therefore prepared an alphabetical list of the subjects of the Papers contained in the volumes published since the index was printed in the 8th Vol. of the Quarto Series, which I trust will be found more convenient than a more lengthy index of contents; and spaces have been left to allow of additions being made to it on the publication of new volumes.

P. J. BAINBRIGGE,
Lieut. Colonel, Royal Engineers,
Editor.

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PROFESSIONAL PAPERS.

PAPER I.

MEMORANDUM ON THE INCREASED POWER OF BREACHING TO BE OBTAINED BY THE USE OF RIFLED ORDNANCE.

BY GENERAL SIR JOHN BURGOYNE, BART., G.C.B., &c.

The capability of effecting a breach by artillery, with the smooth bore and spherical projectiles, was rapidly reduced with increasing ranges; which diminished the velocity of the shot and the precision of the fire.

This imperfection may, for all practical purposes, be said to be entirely removed by the introduction of rifled ordnance.

Up to a range of 1,000 yards, (and probably further trials will carry it some hundreds of yards beyond,) it has been ascertained to give the velocity and precision of practice required to effect breaches, with a small increase of the means necessary for the purpose at much shorter ranges; whereas with the spherical missiles 600 or 700 yards may be deemed their utmost practical limits.

In addition to these advantages of retaining their velocity and their accuracy of fire, they have that of being much lighter for transport, (that is, the guns; for the weight of the missiles remains the same); a quality of peculiar value where the pieces may have to be conveyed through trenches to close positions; and of requiring smaller charges of powder, which not only lessens the expenditure of ammunition, but renders the explosions less injurious to their own batteries; their shells also are capable of containing far more powder, to act as mines within the mass penetrated.

And yet there are drawbacks to the practical benefit derived from some of these items of superiority; viz.,

1. It is only works that have always been considered avowedly defective that are subject to be breached at all, at any influential parts, from a distance; the rule being that all escarps should be well covered, and not liable to be breached

except from the opposite side of the ditch, at which short distance the missile from the smooth bore gun has every required precision, and having a greater *initial* velocity, will strike even a harder blow than that from the rifled gun.

2. As regards the shells, they are not the missiles which make the main impression, and can only at best somewhat accelerate the completion of a breach; and it may be doubtful whether they are of much avail even to that extent, considering the uncertainty of the fuzes in such service.

In considering the operation of effecting a breach, a distinction must be drawn as to the nature and circumstances of the wall, that is, whether it be an escarp wall, with counterforts or buttresses, and perhaps arched in the manner called technically *en décharge*, and backed by solid earth, or whether it be isolated, like Carnot walls, towers, blockhouses, caponnières or magazines, the force required to make a practicable breach in the former being far greater than that which will destroy the latter.

The following are some interesting details, extracted from the Report of the Ordnance Select Committee on experiments made in August, 1860, with Armstrong's rifled guns against a condemned Martello tower on the coast of Sussex.

" The Tower in question (No. 71) was built in the year 1804. It is of brick, able to accommodate 20 men, with magazine space for 80 barrels or 70 cases of powder. Like all the Martello Towers on this part of the coast, it is designed for one gun. The wall on the side fired at is 7 feet 6 inches thick at the level of the ground, and 5 feet 9 inches at the spring of the vault, which is 19 feet from the ground. It is 31 feet 6 inches high, but receives considerable support, at 12 feet above the ground, from the joists of the floor, which radiate from a central pillar, and abut against it. To a certain extent, also, the basement floor, at $2\frac{1}{2}$ feet above the ground, may be regarded as a support. In appearance, the Tower was perfectly sound, the brickwork having been protected by a coating of plaster. The parapet, $5\frac{1}{2}$ feet high and 5 feet thick, was coped with Bramley-fall stone, in blocks containing 7 or 8 cubic feet; a step 2 feet high, round the interior, served the double purpose of a banquette and of a support for the front racers of a rear-pivot traversing platform turning the entire circle. The racer itself was laid on granite curb-stones of about half-a-ton weight each. Thus a great solidity characterised the whole structure. The roof was formed of a bomb-proof vault, supported in the centre by a pillar 4 feet in diameter, turned in three courses of bricks, and surmounted by an equal thickness of ordinary brickwork, giving altogether about 5 feet of masonry over the crown of the arch. The diameter of the whole at the top was 40 feet, and nearly 46 feet at the bottom. (See Plan).

" A broad black line was marked horizontally round the land side of the Tower, at 9 feet from the ground, and three similar vertical lines were marked on the face fired at. As a further assistance to the record, every tenth course of bricks was numbered, in conspicuous figures, in four vertical rows,

" The spot chosen for the position of the battery was a slightly-rising ground beyond the turnpike-road from Eastbourne to Pevensey, on Hoisey Farm, and 1,032 yards distant from the Tower. Here, by an arrangement with the proprietor, a sufficient space was enclosed, and three platforms laid, on which the three following Armstrong breech-loading guns were mounted:—

1. 82-Pounder of 6 inches calibre. Charge for shot, 10 lbs.; for shells, 9 lbs.*
2. 7-inch Howitzer, throwing 100-pounder shells. Charge 9 lbs.
3. 40-Pounder of 4·75 inches calibre, No. 101. Charge, 5 lbs.

The fire was opened at 8 a.m., on the morning of August 7, 1860, commencing with solid shot from the 40-pounder and 80-pounder, and plugged shells from the 100-pounder. 12 rounds were fired, of which 11 took effect.†

" The brickwork was cracked through by the first six shots, and three or four courses were very slightly, but perceptibly started inwards. This was the only effect visible inside the tower, except where the seventh shot had penetrated. The cracks were very fine, scarcely traceable, but extended in two or three irregular lines from three feet above the floor to the spring of the arch, and seem to have been produced by the first and fifth round. (See Plate).

* Reduced at the 20th shell and 99th round to 6 lbs. 12 ozs.

† The latter were as follows:—from the 82-pr. 4 shot and 1 blind shell; from the 7-in. howitzer 2 loaded shells; and from the 40-pr. 3 shot and 1 blind shell.

The extreme penetration of those missiles which struck within 9 feet of the central line (and therefore almost *directly* upon the surface), may be thus defined:—

One 40-pr. shot penetrated 5 ft. 5 in. at course 90.

One 82-pr. shot struck on course 50, on the new brickwork which closed the doorway. This brickwork was laid in cement, and had been finished about six weeks. The shot penetrated the wall, which was 7 feet 6 inches thick, at the junction of the old and new surfaces, which were not bonded together, glancing a little downwards. It broke out about eight bricks on the inside, belonging to three courses, and was lying on the floor. The hole externally was about 2 feet in diameter.

Another 82-pr. shot struck sound brickwork on course 92; passed through the wall 7 feet 6 inches thick, about 2 feet above the springing of the arch, struck the central pier, and lodged itself in the floor at the foot of the pier. The superficial effect did not extend so far as in other instances; the brickwork was broken over an area of 2 feet 9 inches by 2 feet 6 inches; the hole was clean.

A blind shell from a 40-pr. struck course 80, and penetrated 4 feet 2 inches, surface broken over an area of 1 foot 7 inches by 1 foot 6 inches.

A blind shell from an 82-pr. struck course 28, and penetrated 4 feet 3 inches, disturbing twelve courses, and breaking away the bricks over a surface of 2 feet 6 inches by 3 feet.

A 7-in. plugged shell struck course 60, and penetrated 4 feet 3 inches.

A live shell from a 40-pr., (bursting charge 2½ lbs.), struck course 90, penetrated before bursting about 5 feet, making a crater 12 feet wide at the surface, and diminishing to 2 feet at the depth of two or three bricks. Inside the tower the wall was considerably shaken, and seven courses of bricks were broken away.

A live shell from the 82-pr. (bursting charge 5½ lbs.), struck course 68 within the crater of another shell and penetrated about 4 feet.

A live shell from the 7-in. howitzer struck course 48 in sound brickwork, penetrated 4 feet 3 inches, producing superficial injury over 5 feet 9 inches in width and 9 feet 9 inches in height.

The total quantity of brickwork displaced up to this time was estimated at about 9 tons, or 162 cubic feet.

"After taking Photograph No. 2, the firing was resumed with live shells; seven rounds were fired from each piece: one 6-inch shell burst prematurely, as did four others subsequently.

"The Tower was not examined again until after the 27th round, when it was found that the surface was broken from the 70th course to the 110th course of bricks, and over a width of 18 feet; at about the 72nd course, a large opening appeared in the wall, immediately under the spring of the arch, the brickwork of which was visible from the outside. The crater formed by the 7th round, near the doorway, had been much increased, and now extended from the 45th to the 80th course over a width of 8 feet. The 27th round (a 6-inch shell) grazed the nearer side of the embrasure of the west window, and buried itself in the opposite side, where it penetrated 1 foot 6 inches; the explosion, occurring in an open window, did comparatively little damage. The interior, however, was much dilapidated, and daylight was visible through three openings, viz., the one made by the 7th round, a large hole between courses 70 and 80, and a smaller one rather higher up and to the left of it. The next 6 rounds, to the 33rd, were fired in two salvos, and had the effect of enlarging the three openings into a breach about 12 feet 6 inches wide, and 10 feet high externally. The central pillar was fully exposed. A quantity of debris had been carried in, sufficient to cover about one-fourth of the interior; there was a settlement of about 2 inches in the portion of the parapet immediately over it, and besides the two cracks between which this settlement was observable, there was a third crack visible about 3 feet to the left, and the brickwork had started outwards from the granite curb or racer stones between 2 and 3 inches. It was observed, however, that the roof was still undisturbed, the asphalte not even being cracked.

"Photograph No. 3 was taken at this stage.

"The practice was resumed with the 40-pounder and 6-inch gun. Seven solid shot and 2 shells were fired from the former, and 9 shells from the latter, 2 of which burst within 50 yards of the muzzle of the gun. The 38th shot struck the central pillar and carried nearly half of it away. The 41st shot brought down a large mass of the parapet, exposing the granite curbstones and racers. The practice of the first day terminated at 7 p.m. at the 51st round, of which 47 took effect.

"The appearance of the Tower at this stage is exhibited by Photograph No. 4, which was taken the following morning. The breach was $13\frac{1}{2}$ feet wide on the inside, and 24 feet wide on the outside; the interior was completely open from about 16 feet above the ground to the top, exposing the top of the central pillar, of which less than half remained, the circumference being reduced in one part from 14 feet to 8 feet 4 inches; about 4 feet of the still remaining wall was a mere shell, kept up by the rubbish and debris behind it. The unsound part of the wall extended about a foot and a half on either side, beyond the inner edge of the breach, which was well defined; beyond this distance the wall was almost undisturbed. The opening in the parapet was 15 feet 8 inches wide, one granite racer stone had fallen, two more were only held up by the iron racer, a fourth had started 2 inches, the rest were undisturbed. A coping stone containing 7 cubic feet had been thrown about 20 feet from its position. One 80-pounder shell had entered the doorway of the small stair which is made in the thickness of the sea-wall, about 18 inches below the coping of the parapet, and had exploded on its course through, knocking away the outside stone with a portion of the brickwork. The splinter marks inside the Tower were numerous, but not very deep; one 40-pounder was found buried in the brickwork, which the point had penetrated to a depth of 3 feet 2 inches: the other marks were little more than bruises, and did not weaken the wall to an appreciable extent.

"The practice was resumed under very unfavourable circumstances of weather; the rain falling in torrents, with a strong south-west wind across the range.

"The first 8 rounds carried the breach downwards, but it was not until the 72nd from the commencement that the central pillar was completely knocked away, and so excellent was the quality of the brickwork that it continued to sustain its own weight and that of the centre pivot-stones, with the 6-pounder iron gun which formed the pivot, until the 144th round.

"The 7-inch howitzer was fired again alternately with the other two guns from the 69th to the 136th round.

"The state of the Tower at this stage is exhibited by Photographs, Nos. 5, 6, 7, 8, and may be described as follows:—

"The parapet was demolished for a distance of 63 feet, measured on the exterior circumference. From hence the opening contracted to an external width of about 35 feet at the top of the breach, which was 20 feet above the ground, with a tolerably good ramp. The opening was about 24 feet wide in the clear inside. Very little of the vaulting remained. The interior face and superior slope of the parapet on the sea front, which was taken in reverse, were greatly shattered, but no effect was visible on that side externally, except from the 6-inch shell already referred to, which penetrated the parapet. The few shells which struck the inner surface below had not broken the plaster outside. The effect visible on this surface was the formation of a regular excavation in the wall from one to two feet in depth, where some flues had been formed in the solid, but with no rents or cracks around it. There were also numerous superficial bruises from splinters of shells. It was observable, generally, that the brickwork showed very little tendency to crack, or start, or break away in large masses; some of those strewed over the breach, and derived principally from the vaulting, were, however, large enough to have required breaking up before it could have been prudently stormed. The debris extended about 28 feet to the front; one piece of the stone coping, of about 1 cubic foot, was thrown, by the bursting of a shell, 35 yards from the Tower; another, of 2 cubic feet, 18 yards; fragments of brickwork were found as far as 150 yards from the Tower, and within 80 yards they were numerous. It was calculated that about 6,500 cubic feet of brick and stonework were displaced by the fire, amounting to about 362 tons in weight. This was effected at the expense of 1,200 lbs. of powder in cartridges, and 650 lbs. in bursters for the shells. The weight of iron thrown was 10,850 lbs.

"The precision with which the guns could be directed upon any point it was intended to strike gave them advantages with which no smooth-bored ordnance, firing from such a distance, could compete.

"One 40-pounder shell and five 6-inch shells burst a little way in front of the guns.

"The percussion fuzes employed were too delicate for this service. Many of them exploded with comparatively little effect in grazing or passing through the debris; few, if any, of them penetrated the brickwork before explosion far enough to exhibit their full power. This can easily be remedied by a modification of the fuze, which is at present better adapted for use against ships than masonry. The quality of the brickwork and mortar was first-rate; the resistance of the vaulting more particularly elicited much admiration. It held up, as already stated, long after the supporting pillar was knocked away, and only yielded to repeated direct blows, such as could not have been given at that distance by any other than rifled guns."

Trials were subsequently made to breach a similar Tower, from smooth-bored 68 and 32-pounders, at the same range of 1,032 yards, and the result may be deemed altogether a failure, both accuracy of fire and velocity of the missiles being quite deficient for such a range.

At 500, or perhaps 600 yards, the superiority of the rifled ordnance would probably have been very little, if any.

No comparison can be drawn, as has sometimes been attempted, between the above stated effects produced with the Armstrong gun of large calibre, and given quantities of ammunition, with what is recorded as the expenditure in forming breaches during sieges, because the latter were made with much lighter guns, which at long ranges will make a great difference; and also includes in the expenditure the casualties, irregularities, and waste on actual service, which will create a great excess beyond what is used in deliberate experiments at home; and lastly the practice was against substantial masonry escarp walls, backed with solid earth, which is not to be compared to the destruction of a tower.

The results of recent experiments at Juliers with rifled cannon have confirmed the possibility of breaching Carnot walls, block-houses, &c., even where covered from view by intervening works; but this has been done many years ago at Woolwich with the old ordnance; it can be effected however at greater ranges with the rifled, and with a greater impetus given by each blow, than where the shot and shells, as with the old guns, were necessarily "lobbing" shot fired with very small charges.

This is a practice however that will be of very partial utility in real service, inasmuch as it is blindly executed, without a sight of the object aimed at, or the slightest knowledge of any errors in the firing. At Woolwich and Juliers, &c., the distance from the battery to the wall, and the height and circumstances of the intervening mass, were known to a foot; and after every round, observations of errors in the firing could be, and probably were, made and notified to the battery. Nothing of the kind would be the case at a siege, and therefore it may be held that such effects as were produced at those places, of breaching walls behind covering masses so near as they are represented to have existed at those places, namely, within 60 feet, as at Woolwich, and 100 feet, as at Juliers, assuming that the cover itself was not susceptible of being reduced by the fire,

could not be obtained on actual service; at the same time, where there is a considerable distance between the wall and the cover before it, in the line of fire, such as of a caponnière at the end of the ditch of a work, much less refinement in the fire would be necessary, and the effect might be produced by a reasonable extra expenditure of ammunition; and here no doubt, in most cases, the rifled would have great advantages over the smooth-bored gun by its longer range, and fire at lower angles of elevation.

These are circumstances that will therefore require to be attended to more than has hitherto been thought necessary in the designs for works of defence, where detached masonry constructions are connected with them.

There cannot be a doubt of the over-powering effect of the broadside of a man-of-war which can lay itself alongside of a low, closely concentrated battery on the shore; the effect, however, is produced on the embrasures and parapets, or if the guns are in casemates, on the embrasures; in either case by a great mass of scattered fire directed generally towards the object; a real effective (still less a practicable) breach could hardly be made by shipping in any good escarp wall backed by earth; nor even in a tower or block-house, under any opposing cannonade, even with rifled guns, for want of that absolute stability required to ensure the necessary precision of fire.

Though not coming absolutely under the definition of breaching, an important element in the reduction of works of defence, is the destruction of parapets, traverses, &c., which, being of earth wherever practicable, suffer greatly from shells, in proportion to the quantity of powder they contain to act as mines, and the precision with which they can be directed to the most advantageous depths within their surfaces; and here the rifled ordnance possess very great advantages.

J. F. B.

PAPER II.

On a proposed method of Constructing Fire-proof Brick-arched Floors, devoid of any Lateral Thrust, and without the use of Tie-Rods, capable of carrying the heaviest weights, with suggestions for the application of the same system to the Roofing of Magazines, Bomb-proofs, and Casemated Constructions generally.

By CAPTAIN FRANCIS FOWKE, Royal Engineers.

In the spring of 1858, at the solicitation of the War Department, I undertook to prepare a design for a proposed storehouse on the banks of the Thames at Rotherhithe, to contain the arms and camp and barrack equipage of the army.

As the building contemplated in my design was of considerable extent, and intended for the reception of a variety of articles, all of vital importance in a military point of view, and some of them of a more or less combustible nature; it was necessary that such a building should be constructed in such a manner as to be as safe as it could reasonably be made from the danger of any accident by fire.

Passing over the obvious preparations in the shape of water supply, fire-engines, &c., the primary conditions necessary to effect this safety were, that the building should be constructed throughout of materials difficult of combustion, and that its interior space should be so subdivided by masses of such material as to give the best chance of confining any accidental fire within the smallest possible limits.

To accomplish both these ends it was necessary to have, if possible, a thoroughly efficient system of fire-proof floors throughout the building, and also that these floors should be supported as far as possible upon pillars or supports of incombustible material.

It was thus necessary to avoid the use of iron columns in all situations where they were likely to be surrounded with combustible articles of store—and where-ever iron was indispensable, to case or envelope it within a heat-resisting medium, such as brick or fire-clay.

It became at once apparent that these conditions entirely forbade the employment of the ordinary flooring of parallel girders of either wrought or cast iron, carrying brick barrel vaults and connected with iron tie-rods to sustain the thrust of those vaults; as in case of fire the wrought iron ties would become so lengthened and weakened by the heat that the failure of the vaults would be an almost certain result. The matter would not have been much mended by running these vaults transversely in a long building, so that their combined thrusts might be received by buttresses or other arrangements at the ends, for in that case the failure of any one vault would have been ruin to the whole.

The floor known as Fox and Barrett's, and constructed of wrought iron I shaped joists filled in between with concrete, was thought to be inadmissible, as from the span being too great for a single floor, a large surface of the lower part of the main girders would be exposed to the action of heat; besides which it was probable that the heat generated from the burning of large quantities of inflammable stores would be sufficiently intense to destroy the concrete, upon the integrity of which this description of floor entirely depends.

The problem to be solved was in fact to construct a floor that, with the least possible thickness, should be capable of sustaining the greatest weight; that it should be free from all tie-rods, and that each bay or division in which it might be constructed should be so neutral (if I may use the term) as regards lateral thrust, and so independent of those surrounding it, that the failure of any number of bays would have absolutely no effect upon those in their immediate vicinity.

It so happened that both the length and breadth in feet of the building designed by me were nearly multiples of 16, and as 16 is a convenient length for iron girders, it was decided to divide the floors into squares of which 16 feet should be a side; and that these squares should be carried on brick or stone piers at their angles.

As all these squares were precisely alike, an account of the method in which it was proposed to floor one square will be a description of the entire floor; and as an experiment was immediately ordered to be made upon the peculiar method of flooring then proposed, it will suffice, in describing the method, to give a detailed account of the experiment actually made, with its results.

The portion of floor constructed for experiment is composed of four cast iron girders, in section thus shaped ⅄, (the flanges being downwards), bolted together with four $\frac{3}{4}$-in. bolts at each end, the ends of one pair of girders being shaped to fit against the sides of the other pair, to which they were bolted. (See Plate.)

The depth of the girders in the middle is 1 foot 6 inches over all, and at the ends 1 foot 1 inch, the lower flanges being horizontal and the upper edge curved parabolically. (See Figs. 5 & 6.)

These girders rest upon four brick piers, 2 feet square, having upon them stone blocks 1 foot 11 inches square and 3 inches thick: these blocks are 13 feet apart between faces, giving the girders a clear distance between supports of 13 feet. The stone is prevented from being in contact with the iron by a felt packing.

Between the girders the space is arched over by a 9-in. groined arch, composed of two courses of bricks laid on edge, stretching parallel to the girder from which the arch they compose springs; these bricks are set in Portland cement and are cut to mitre at the line of groin; the versed sine of the arch is 9 inches, or less than $\frac{1}{18}$th of the span, the clear distance between bearings being 13 feet 11 inches, viz., between the opposite flanges of the girders.

The spandrels, or spaces over the haunches, were filled in with concrete to the level of the crown of the arch, forming an even surface all over.

Weight and Method of Loading.

The load was laid on a surface of 64 square feet, or 8 feet by 8 feet, in the middle of the floor.

The first course laid on was composed of Fox and Barrett's wrought iron I shaped joists, which happened to be on the spot at the time: these joists were laid sideways and placed close together 8 feet wide and 8 feet long; across these similar joists 20 feet long were laid to a width of 8 feet, and over and across these, other courses until a weight of 40 tons was obtained, no effect being produced on the arch, beyond the bedding of the flanges of the joists in the concrete.

This weight of 40 tons was allowed to remain on for a week, no further effect being visible.

A weight of 12 tons was then added, more joists and bricks being placed on it: this gave a total load of 52 tons, or 16 cwt. and one quarter, per superficial foot, on the loaded surface, and this caused a bulging out of the two opposite girders, to the extent of $\frac{3}{8}$ths of an inch in each girder in the centre; but on removing the load, which was done after a further period of 48 hours had elapsed, the girders became perfectly straight, and no visible depression appeared in the crown of the arch.

The experimental floor having been constructed within a few feet of a slight iron building, it was thought unadvisable to continue the experiment up to the actual breaking point; from its appearance, when loaded up to the above-named weight, it would probably have stood a very much greater load, and at the height to which the load (of bricks) would have reached, their fall would have been attended with considerable risk to the adjoining building.

The portion of floor to which this severe test was applied was in the most unfavourable position possible for bearing the great strain it successfully supported—that is, it was perfectly isolated, and absolutely unassisted by any such lateral support as would, under all ordinary circumstances, be afforded by the surrounding squares.

Thus we have a floor supported only at four points, and having a bearing between those points of 15 feet from centre to centre.

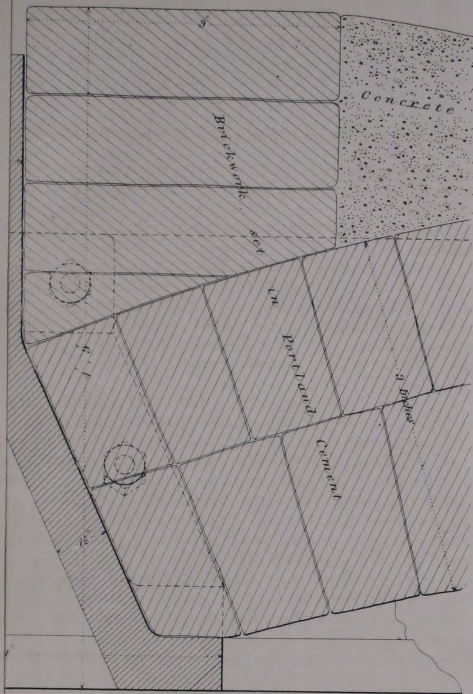
The extreme thickness of the floor is 18 inches, and its mean thickness only 12 inches. It has borne a weight of $16\frac{1}{4}$ cwt. to the superficial foot over its weakest part, and under the most trying circumstances. It is independent of extraneous lateral support in all directions, and it is also free from the defect above-mentioned of depending upon a dangerous system of wrought iron ties.

It is thrown out as a suggestion whether this floor might not be usefully employed, not only for the purposes for which it was originally designed, but also in casemates and in bomb-proof buildings, such as large magazines where, according to the present system of construction, there is so great a sacrifice of valuable space in the massive haunches of the arches and groins.

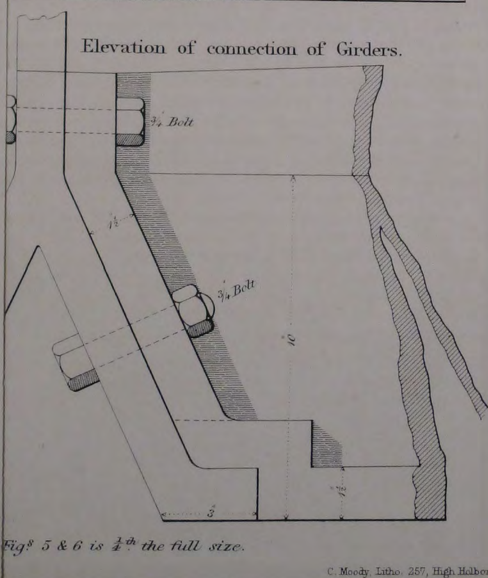
In the case of magazines it would probably be necessary to case the exposed flange of the girder; but this could be done with tiles made for the purpose and hung on the flange itself (see Fig 4).

In carrying out any work on this principle it would not be necessary to use the ⊥ girders; the common ⊥ girder can be used with either Portland stone skewbacks or bricks moulded into the same form. The expense of bolting the girders at the angles might also be avoided by simply casting the bottom flanges with lugs and corresponding recesses alternately, when the girders would keep themselves connected by their own weight and that of their load. In a work of any magnitude the use of moulded bricks would supersede the necessity and expense of cutting to mitre the groins.

F.F.,
27th April, 1860.



Elevation of connection of Girders.



Figˢ 5 & 6 is ¼ᵗʰ the full size.

C. Moody, Litho. 257, High Holborn.

PAPER III.

On the Form of the Voussoirs of a Convergent Arch or Vault.

By the Rev. JOHN F. TWISDEN, M.A.,

Professor of Mathematics in the Staff College.

(Communicated by Lieut. Home, R.E.)

(1.) It is occasionally necessary to construct a casemate with convergent walls, for instance when the casemate is situated at the salient angle of a bastion; * when this occurs the interior surface of the vault ceases to be a portion of a cylinder, and the rules for cutting the voussoirs of an ordinary circular arch are no longer applicable. The object of the following paper is to investigate certain geometrical propositions connected with the form of the vault referred to, and to deduce from them a series of practical rules by which models may be made of any given voussoirs. The writer is not aware that the question has ever before been investigated, and he trusts that the rules he has drawn up may be of some practical value.

(2.) The form of the vault can be thus defined:—There is a semi-circle placed with its plane vertical, there is a vertical line so placed that the plane which contains the line and the centre of the semi-circle is at right angles to the plane of the semi-circle; a horizontal line which moves in such a manner as always to pass through both the straight line and the circumference of the semi-circle will trace out the vault in question. It is obvious that a person who stands inside such a vault will see that the longitudinal joints are horizontal lines, but that they differ from the corresponding joints of a common circular vault in this, that instead of being parallel they converge to a vertical line. Such a vault may be called a convergent vault. It may be added that if the horizontal joints above-mentioned are projected on a horizontal plane, the projections will converge to a point, and in this respect differ from the joints of a semi-circular vault which project on a horizontal plane into parallel lines; the projections on a vertical plane at right angles to the plane of the circle will be the same in both cases.

(3.) To determine the equation to the surface of the convergent vault. Let BDC (Fig. 1) be the circular section, the centre of which is A: draw AO at right angles to BDC, and let OE be the line of convergence; take P any point in DB, and draw the horizontal line PP′ passing through OE, the required surface is the locus of the line PP′; draw PN at right angles to AB, join NO,

* In some works this has been done by building a square casemate; which involves a loss of space at a very vital part of the work.

take p any point in PP′, draw pn at right angles to NO, and na at right angles to OA; denote Oa, an, np by x, y, z respectively, which assumes OE to be the axis of z, OA of x, and a line drawn to the left through O at right angles to both to be the axis of y; also let OA, AP, and PAB be denoted by a, r, and ϕ respectively. Then we have

$$pn = \text{PN or } z = r \sin \phi$$

Also

$$\text{NA} : \text{AO} :: na : a\text{O}$$

or

$$r \cos \phi : a :: y : x$$

$$\therefore \frac{ay}{x} = r \cos \phi$$

$$\therefore z^2 + \frac{a^2 y^2}{x^2} = r^2$$

The required equation.

(4.) To determine the equation to the section of the convergent vault made by any vertical plane parallel to the circular section.

Let x have any particular value x_1, then y and z are the co-ordinates of any point of this section, and therefore its equation is

$$\frac{z^2}{r^2} + \frac{y^2}{\frac{r^2\, x_1^2}{a^2}} = 1.$$

Suppose (Fig. 2.) the plane of the paper to be the horizontal plane through O; take BA = AC = r; OA at right angles to BC equal to a, $Oa = x_1$ and draw bac at right angles to AO; then

$$ba : aO :: \text{BA} : \text{AO}$$

or

$$ba = \frac{r x_1}{a}$$

Hence the required section is an ellipse of which the principal semi-axes are r, and ba: if a is between A and O the vertical axis (r) is the major axis, and the horizontal axis (ba) is the minor axis; on the other hand if a is beyond A, the vertical axis (r) is the minor axis, and the horizontal axis (ba) is the major axis.

(5.) To obtain a practical rule for drawing the elevation of any vertical section of the vault made by a plane parallel to the circular section.

Draw (Fig. 3) BACO as in Fig. 2, and let it be required to draw the elevation of the section which is situated at a distance Oa from O; take ad equal to AB and draw the ellipse bd.* Next to draw the edges of the voussoirs; let PQ be one of the edges of a voussoir in the circular section; draw PN at right angles to BA, join NO, cutting ab in n; draw np at right angles to ab cutting the elliptic arch in p; then p is the point corresponding to P: finally at p draw pq a normal to the curve at p; this will be the edge of the voussoir in the elliptic section corresponding to the edge PQ in the circular section. Of course the normal in the case indicated can be drawn as follows: with centre b and radius

* It is plain from this that to form the centering of the vault a sufficient number of the curves should be drawn by the above rule; if these are constructed on wood and placed at the proper distance apart the required centering is at once obtained.

ad describe a circle cutting AO in *s* and *s'*, these are the foci of the ellipse; join *sp*, *s'p*, and bisect the angle *sps'* by the line *qp*, this line is the required normal.

(6). Practical rule for forming the model of the front and back faces of any voussoir.

The rule in the last article will enable us to determine the form of the front and back ends of any voussoirs; let them be EFGH, KLMN, in Fig. 4, and suppose them to be cut out in planking; it remains to fasten them together in the proper relative position; the rule for this is somewhat difficult to enunciate, but the thing itself is not hard to do. Draw (Fig. 5) ABD, AO, BO, as before; let QPP_1Q_1 be the circular face of the voussoir corresponding to EFGH and KLMN; draw PN, P_1N_1 at right angles to AB, join ON, ON_1; let A*a*, Aa_1, be the distances of the faces of the required voussoir from the circular section; draw *ab*, a_1b_1 cutting ON, ON_1 in *n*, *m*, and n_1, m_1 respectively; produce *ba*, b_1a_1, and nail together three pieces of plank so as to form a triangular prism whose plan is *rstu*, and elevation RST,—it should however be made shorter than aa_1 by twice the thickness of the plank from which EFGH and KLMN have been cut; if these are nailed on to the ends of this prism they will be at the right distance apart. Nail EFGH on to one end, it only remains to nail KLMN on to the other end in the right relative position; one way of doing this is shown in Fig. 6: draw on a horizontal table the lines *an*, a_1m, *nm*, n_1m, aa_1 the same as in Fig. 5. Place EFGH in such a manner that the point F is at *n*, and G vertically over n_1; if its plane is kept vertical by being supported against a vertical board YZ, whose horizontal edge XY coincides with *an*, the prism USTR will be in a position fitted to receive the piece KLMN, which must be placed against it as indicated, the point L coinciding with *m*, and M vertically over m_1,* and if when in this position it is nailed to the end of the prism, the model is completed so far as the form and position of the two ends are concerned; it remains now to form the model of the *sides* of the voussoirs.

(7.) To determine the equation to the surface of contact of two continuous voussoirs.

Produce (Fig. 3) *qp* to cut *bc* or *bc* produced in G; suppose the ellipse to be turned upward round *bc* through an angle of 90°, it is evident that the surface in question will be the locus of the line *q*G; hence take H any point in it, draw HK at right angles to *bc*, denote O*a*, *a*K, KH by x, y, and z respectively; we are to find the relation between x, y, and z. Now in the ellipse

$$aG : an :: ad^2 - ab^2 : ab^2$$

but $$an = \frac{xr\cos\phi}{a}$$

and $$ab = \frac{xr}{a}$$

* It may be of use to remember that the height of M and G above m_1 and n_1 is the same as the *vertical* height of P_1 above P. It would also (probably) be found convenient to *steady* the two ends between *two* vertical boards: it might even be found convenient to fasten the ends temporarily to two such boards and then to introduce the prism between them; but this can be safely left to the workman.

therefore $aG = \frac{ar \cos \phi}{a} \times \frac{a^2 - x^2}{x^2}$

again $pn : nG :: HK : KG$

or $r \sin \phi : \frac{rx \cos \phi}{a} + \frac{xr \cos \phi}{a} \times \frac{a^2 - x^2}{x^2} :: z : y + \frac{xr \cos \phi}{a} \times \frac{a^2 - x^2}{x^2}$

or $r \sin \phi : \frac{ar \cos \phi}{x} :: z : y + \frac{r \cos \phi}{a} \cdot \frac{a^2 - x^2}{x}.$

therefore $z = \frac{xy \tan \phi}{a} + \frac{a^2 - x^2}{a^2} r \sin \phi \ldots\ldots\ldots\ldots\ldots\ldots (1)$

is the required equation.

(8.) Now in order to make a model of the surface of contact of two contiguous voussoirs, we have to make a model of that portion of the surface (whose equation is (1)) *above* the horizontal line drawn through Pp. But if we obtain the curve of intersection of this surface with any plane and place it in a proper position relatively to the line Pp, and then draw from each point of it a line at right angles to Pp this will give the surface required; the best plane of intersection seems to be one passing through Q (Fig. 3) at right angles to QP.

It is evident that this plane is at right angles to the plane yz; consequently its equation will be identical in form with that of a line at right angles to AQ, or if AQ $= r'$, it will be

$$y \cos \phi + z \sin \phi = r' \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2).$$

(9.) To determine the equation to the line of intersection of the plane (2) with the surface (1) referred to axes in the cutting plane.

Since the equation to the surface is

$$z = \frac{xy \tan \phi}{a} + \frac{a^2 - x^2}{a^2} r \sin \phi$$

by eliminating z we obtain the equation

$$r' = \frac{xy \tan \phi \sin \phi}{a} + \frac{a^2 - x^2}{a^2} r \sin^2 \phi + y \cos \phi \ldots\ldots (3).$$

This is the equation to the projection of the line of intersection on the plane of xy. Let (Fig. 7) Ox, Oy, Oz, be the axes of x,y,z, and $x'y$ the cutting plane, let it cut zx in O$'x'$, and zy in O$'y$; and take these lines as the axes of coordinates in the plane; let P$'$ be a point in the curve of intersection, draw P$'$N$'$ at right angles to O$'x'$; then if we call O$'$N$'$, N$'$P$'$, x' and y' respectively we have to find the equation which connects x' and y'; draw P$'$P at right angles to the plane xy, and PN at right angles to Ox then ON and NP are the x and y of equation (3). But the angle y O$'$O equals ϕ, hence we have

$$x = x'$$
$$y = y' \sin \phi$$

and the required equation is

$$r' = \frac{x'y' \tan \phi \sin^2 \phi}{a} + \frac{a^2 - x'^2}{a^2} r \sin^2\phi + y' \sin \phi \cos \phi$$

or suppressing the accents for the sake of convenience

$$x^2 r \sin^2 \phi - xy\, a \tan \phi \sin^2 \phi - y\, a^2 \sin \phi \cos \phi + a^2 (r' - r \sin^2 \phi) = 0 \quad \text{.. (4).}$$

This equation is evidently that to a hyberbola; it may be written in the form

$$Ax^2 - Bxy - Cy + D = 0 \quad \text{........................ (5).}$$

where $A = r \sin^2 \phi$, $B = a \tan \phi \sin^2 \phi$, $C = a^2 \sin \phi \cos \phi$; and $D = a^2 (r' - r \sin^2 \phi)$. It remains to discuss this equation.

(10.) To find the asymptotes to equation (5).

Write it in the form

$$y = \frac{Ax^2 + D}{Bx + C}$$

Then it is plain that the equation to one asymptote is

$$x = -\frac{C}{B}$$

Also the above equation can be written

$$y = \frac{Ax + \frac{D}{x}}{B(1 + \frac{C}{Bx})}$$

$$= \frac{Ax}{B} - \frac{AC}{B^2} + \frac{D}{Bx} + \cdots\cdots$$

Therefore the equation to the other asymptote is

$$y = \frac{Ax}{B} - \frac{AC}{B^2}.$$

The co-ordinates of the point of intersection of the asymptotes *i.e.* of the centre of the curve, are

$$x = -\frac{C}{B} \text{ and } y = -\frac{2AC}{B^2}.$$

and if θ is the acute angle between the asymptotes

$$\text{Cotan } \theta = \frac{A}{B}.$$

or

$$A \sin. \theta - B \cos \theta = 0.$$

(11.) To determine the equation to the curve (5) when the asymptotes are axes.

(*a.*) Transfer the origin of co-ordinates to the centre *i.e.* for x and y write

$x - \frac{C}{B}$ and $y - \frac{2AC}{B^2}$, then we obtain

$$A\left(x - \frac{C}{B}\right)^2 - B\left(x - \frac{C}{B}\right)\left(y - \frac{2AC}{B^2}\right) - C\left(y - \frac{2AC}{B^2}\right) + D = 0.$$

or
$$Ax^2 - Bxy + \frac{AC^2 + B^2 D}{B^2} = 0.$$

(*b.*) Transform the axes to the asymptotes.

Let Hx, Hy (Fig. 8) be the rectangular axes through the centre of the curve *after* the transformation in the last section, these are parallel to the original axes; draw x'H in such a manner that x'H$y = \theta$; take P any point of the curve and draw PN′N parallel to Hy, then PN′, N′H, are the new co-ordinates of P, and PN, NH are the old co-ordinates; or the transformation will be effected by substituting in the equation of the last section $x \cos\theta$ for x, and $y + x \sin\theta$ for y. When this is done the required equation can be written

$$x^2 \sin\theta\,(A \sin\theta - B \cos\theta) - Bxy \sin\theta + \frac{AC^2 + B^2 D}{B^2} = 0.$$

But by Art. (10)
$$A \sin\theta - B \cos\theta = 0$$

Therefore
$$\sin^2\theta = \frac{B^2}{A^2 + B^2}$$

and therefore the equation required is

$$xy = \frac{(AC^2 + B^2 D)\sqrt{A^2 + B^2}}{B^4}$$

(12.) Hence substituting for A,B,C,D we obtain

(*a.*) For the asymptotes referred to the original co-ordinates

(1.) $$x = -\,a \operatorname{cotan}^2\phi$$

(2.) $$y = \frac{r \operatorname{cotan}\phi}{a}\,x - r \operatorname{cotan}^3\phi$$

(*b.*) For the curve referred to the asymptotes, we obtain after reduction

$$xy = \operatorname{cosec}^2\phi \operatorname{cotan}\phi\,\{\,r' - r + r \operatorname{cotan}^2\phi\,\}\sqrt{r^2 \operatorname{cotan}^2\phi + a^2}$$

(13.) To draw on the cutting plane the projection of the horizontal edge through Pp (Fig. 3).

Let (Fig. 9) ABD be the circular section, PP′ the horizontal line whose projection on the cutting plane it is required to find, produce AP to meet the cutting plane in Q; this will be one point in the projection and its position is fixed by the fact that on equals a, and nQ equals r' cotan ϕ. Draw $P'Q'$ at right angles to oy, then Q' is another point in the projection and it is evident that oQ' equals $OP' \cos \phi$ which equals $(r' \operatorname{cosec} \phi - r \sin \phi) \cos \phi =$

$$r' \operatorname{cotan} \phi - r \sin \phi \cos \phi.$$

This gives the position of Q' on the plane, and therefore the position of the required projection is known. The method of using the equations now obtained will be best understood by discussing a particular case.

(14.) Given a casemate 20 feet wide, radius of front arch 20 feet (so that the arch is an arc of 120° and the smallest value of ϕ is 30°) the depth of the casemate 30 feet, the distance of the line of convergence from the circular section 50 feet. It is required to draw the curve and the projection of the horizontal line (of Articles 12 and 13) when $\phi = 45°$, the height of a circular voussoir being 2 feet (Fig. 10).

Here we have $a = 50$, $r = 20$, $r' = 22$, $\phi = 45°$.

Hence the equations to the asymptotes are

$$x = -50 \text{ and } y = \frac{2x}{5} - 20.$$

Take Ox, Oy at right angles, measure $Oh = 50$, draw hl parellel to Oy this line is the one asymptote; take $Ok = 20$ this will be one point in the other asymptote and $On = 50$ this will be another point in it; join nk and produce it to meet hl in l, nl is the second asymptote, and l is the centre of the curve.

Next to draw the curve, its equation becomes on substitution

$$xy = 2369{\cdot}5.$$

From this we can determine as many points as we like; in the diagram the following have been taken:

$$x = 48{\cdot}86,\ 50,\ 60,\ 70,\ 80,\ 90,\ 100,\ 110,\ 120,\ 130,\ 140,\ 150,$$

and the corresponding values of y are found to be

$$48{\cdot}86,\ 47{\cdot}4,\ 39{\cdot}5,\ 33{\cdot}9,\ 29{\cdot}6,\ 26{\cdot}3,\ 23{\cdot}7,\ 21{\cdot}6,\ 19{\cdot}7,\ 18{\cdot}2,\ 17,\ 15{\cdot}8,$$

the curve is then drawn as indicated.

Finally, to draw the projection of Pp, we have:—$On = 50$, and $nQ = r' \cos \phi = 22$, which gives the point Q of the projection, situated in the curve as it plainly ought to be; and next $OQ' = 22 - 10 = 12$, gives the second point of the line.

If we take $nm = 30$ the depth of the vault, and draw pgm parallel to Qn, the portions of the curve and line required are Qp, and Qq. A similar construction must be made corresponding to every joint of the circular arch.

(15.) Method of constructing a model of the surface of contact of any two contiguous rows of voussoirs.

Take two planks (Fig. 11) and make the edge of one of them, AB, perfectly straight, and draw on that plank the curve BD which is the same as the curve

Qp in Fig. 10, making also the angle at A the same as the angle Qqp; take an exactly similar piece of plank A′C′ and draw the same curve D′B′ upon it, and then cut away the part indicated, leaving the curve D′B′ as the edge. Now place the latter over the former at the requisite distance $r' - r$, which in the present case is two feet, as shown in Fig. 12, the edge D′B′ being placed so as to be exactly vertically over the curve DB. Fasten a number of thin straight pieces of wood to these two edges, as shown by pq, $p'q'$ $p''q''$.... and they will give the exact surface if sufficiently narrow and sufficiently close together; the exact position of any one (pq) is indicated by the lines pn, nq, where pn is at right angles to the board ABC, and makes with AB an angle A.

(16.) Hence we can complete the model of the voussoir described in Article 6. Suppose Qp (Fig. 10) to be the curve corresponding to edge P_1 Q_1 of Fig. 5. Take na and na_1 in Fig. 10 equal to Aa, and Aa_1 in Fig. 5; draw asr, $a_1s_1r_1$, parallel to nQ; cut out in plank the curve rr_1 and the straight line ss_1, and fasten them together in the proper relative positions, as described in the last article. Then, having made allowance for the thickness of the planking, place this between KLMN and FGH (Fig. 6) in such a manner that s and s_1 come to G and M, and r and r_1 to H and N; if thin and straight pieces of wood are then nailed on to rr_1 and ss_1 as before described, that face of the model will be completed. The other face is made in exactly the same manner, except that the concave curve must be used instead of the convex.

NOTE.—The investigation is now complete; but one or two subsidiary points remain to be noticed. It will evidently be a great simplification if we can treat the curved line rr_1 as a straight line (Fig. 10). The object of the following articles is to ascertain when this can be done; we shall effect this by discussing more particularly the relation between the line Qq and the curve Qp; it must be remembered that though reference is still made to Fig. 10, the reasoning supposes that the angle ϕ has any value, and is not limited to the particular value $\phi = 45°$.

(17.) To determine the equation to the tangent to the curve, and to determine the point (T) in which the tangent drawn to Q cuts Oy.

Taking the equation to the curve referred to, Ox, Oy, we have (Eq. 4)

$$F(xy) = x^2 r \sin^2 \phi - xy\, a \tan \phi \sin^2 \phi - y a^2 \sin \phi \cos \phi + a^2 (r' - r \sin^2 \phi) = 0$$

∴ Differentiating,

$$F'(x) = 2xr \sin^2 \phi - ya \tan \phi \sin^2 \phi$$

$$F'(y) = - xa \tan \phi \sin^2 \phi - a^2 \sin \phi \cos \phi.$$

and therefore the equation to the tangent at any point (xy) of the curve is

$$(y' - y)(xa \tan \phi \sin \phi + a^2 \cos \phi) = (x' - x)(2xr \sin \phi - ya \tan \phi \sin \phi)$$

Now the co-ordinates of Q are (Art. 13) $x = a$, and $y = r' \cot \phi$. Whence the equation to the tangent to the curve at the point Q is, after reduction,

$$(y' - r' \cot \phi)\, a = (x' - a)\,(2r - r') \sin \phi \cos \phi.$$

Now OT is the value of y' derived from this equation by writing $x' = 0$.

$$\therefore \quad OT = r' \cot \phi - (2r - r') \sin \phi \cos \phi.$$

Cor. But $OQ' = r' \cot \phi - r \sin \phi \cos \phi$ (Art. 13).

Hence subtracting $\quad Q'T = (r' - r) \sin \phi \cos \phi = \frac{1}{2} (r' - r) \sin 2 \phi$

a very important conclusion follows from this: $Q'T$ equals zero when $\phi = 0$, and also when $\phi = 90°$, in both cases QQ' coinciding with the tangent to the curve at Q, or rather with the curve itself, which for those values of ϕ degenerates into a straight line. Next $Q'T$ is greatest when $\phi = 45°$, and is then equal to $\frac{1}{2}$ $(r' - r)$ which is in all cases very small. Hence the line $Q'Q$, though very nearly coinciding with the tangent, will always cut the curve in Q, and therefore in some other point.

(18.) To determine the points of intersection of the line QQ' and the curve. From Art. 13. It is evident that the equation to QQ' is

$$y - (r' \cot \phi - r \sin \phi \cos \phi) = \frac{r \sin \phi \cos \phi}{a} x$$

If we substitute the value of y in the equation to the curve the roots of the resulting equation will give the values of x corresponding to the points of intersection; this equation is

$$x^2 r \sin^2 \phi - x^2 r \sin^4 \phi - ax \tan \phi \sin^2 \phi (r' \cot \phi - r \sin \phi \cos \phi)$$
$$- xar \sin^2 \phi \cos^2 \phi - a^2 \sin \phi \cos \phi (r' \cot \phi - r \sin \phi \cos \phi)$$
$$+ a^2 (r' - r \sin^2 \phi) = 0 \quad .$$

which on simplification becomes

$$x^2 r \cos^2 \phi - ax (r' + r \cos^2 \phi - r \sin^2 \phi) + a^2 (r' - r \sin^2 \phi) = 0,$$

or $\quad xr \cos^2 \phi (x - a) - ar' (x - a) + ar \sin^2 \phi (x - a) = 0.$

whence the values of x corresponding to the points of intersection are

$$x_1 = a$$

and

$$x_2 = \frac{a (r' - r \sin^2 \phi)}{r \cos^2 \phi}$$
$$= a\left\{\frac{r'}{r} + \frac{r' - r}{r} \tan^2 \phi\right\}$$

consequently x_2 is always greater than x_1 or the second point of intersection is always *beyond* the circular arch; and the distance between the points of intersection equals

$$\frac{a (r' - r) \sec^2 \phi}{r}$$

(19.) Rule for the position of the circular arch.

If the height of the front arch of the casemate equals half its width, the circular arch must be in front and no alternative is left; but if the height is less than half the width, the circular section may occupy any position beyond that section, in which the width of the casemate is diminished to the double of the height of curve;* for of course there is no reason why the circular section should be a semi-circle, and consequently the only limit on the position of the circular section is that it cannot be on this side of that section for which the width is twice the height of the curve. It would seem that the best position for the circular section is that in which the section is a semi-circle—*i. e.* in which the circular section is as near as possible to the line of convergence; for it is obviously desirable that the voussoirs should be as little *skew* as possible; in other words, that the curve Q p should as nearly coincide with Q q as possible. Now on this side of the circular section, the tangent to the curve at Q is between the curve and Q q, but *beyond* the circular section the curve is at first between Q q and the tangent—*i. e.* up to the second point of intersection—and afterwards Q q is between the curve and the tangent, consequently the curve and the line Q q are much nearer coincidence beyond the circular section than on this side of it.

It might be thought, at first sight, that there would be objection to using an arch in which ϕ may be very small, since then the right-hand side of Equation (b), in Article 12, becomes very large, and it might be feared that the curvature of the hyperbola would become considerable; but then it will be observed (see Art. 12) that the point of intersection of the asymptotes, *i. e.* the centre of the curve, goes off to a great distance, and consequently the part of the curve required will be very remote from the centre, *i. e.* it will very nearly coincide with a straight line. On other grounds it is obvious that when $\phi = 0$, and $\phi = 90°$, the curve must degenerate into a straight line.

(20.) To determine the greatest distance between the curve and a chord drawn through any two points of it.

Let Ox, Oy be the asymptotes of the curve whose equation (Art. 12 b.) we will write for shortness. (See Fig. 13.) $xy = m$.

Let P_1, P_2, be two points whose co-ordinates are (x_1, y_2,) (x_2, y_2) the equations to the chord drawn through them is

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1} (x - x_1)$$

or

$$y - \frac{m}{x_2} = - \frac{m}{x_1 \ x_2} (x - x_1)$$

* Geometrically this is not a limit; the limitation simply results from the fact that an arch of more than 180° would be inadmissible. It may be remarked that the term "beyond a section" means farther from the line of convergence than that section; while the term "on this side of a given section" means nearer to the line of convergence.

Since (x_1, y_1) (x_2, y_2) are points on the curve. Now let y' correspond on the *curve* to the abscissa x.

Therefore $$y' = \frac{m}{}$$

and therefore $$y - y' = \frac{m}{x_1} - \frac{}{x} - \frac{m}{x_1 \ x_2}(x - x_1) = \frac{m\,(x_2 - x)\ (x - x_1)}{x\ x_1\ x_2}$$

x being intermediate to x_1 and x_2. In the figure PP′ represents $y - y'$; it is plain that $y - y'$ will be maximum when

$$0 = \frac{m}{x^2} - \frac{m}{x_1 \ x_2}$$

or when $$x^2 = x_1 \ x_2$$

Therefore the greatest value of $y - y'$ is $\frac{m}{x_1 \ x_2}(\sqrt{x_2} - \sqrt{x_1})^2$

Now suppose x_1 and x_2 to correspond to the extremities of any voussoir, then if this value is less than a fraction of an inch, the upper edge of the voussoir may be treated as a straight line, and this circumstance will greatly facilitate the cutting of the voussoir, as well as the construction of the model. For instance, if, in Fig. 10 (Art. 14), we suppose a single voussoir to occupy the whole space between the dotted lines 80 and 90—and therefore to be nearly 10 feet long—the greatest value of $y - y'$ will be $\frac{2369 \times (\sqrt{90} - \sqrt{80})^2}{80 \times 90}$ which is equal to 1·16 inches; the curvature in such a case could not perhaps be neglected. If we took the part of the curve that lies beyond the circular section, and between the ordinates 130 and 140, we should find that the greatest value of $y - y'$ is 0·3 of an inch. It is evident from this that the curvature of the upper edges of the voussoirs will never be very large, and in most cases can be neglected; and consequently that the main use of the curve drawn in Figure 10 will be to fix the relative positions of the upper and lower edges of the voussoir. It may perhaps be added that the curvature of a voussoir when near the line of convergence may be considerable, it will therefore be unsafe to treat any portion of the curve (such as that represented in Fig. 10) as a straight line without trial, but if we suppose all the voussoirs to be of equal length, and if we find that the curvature of one of them can be neglected, then, *à fortiori*, the curvature can be neglected of all those which are more remote than it from the line of convergence.

It is manifestly quite essential that the curves (like that in Fig. 10) corresponding to each joint of the maşonry, should be drawn on a considerable scale and with great accuracy.

APPENDIX.

The following article is a generalization of what has gone before, so far as the purely geometrical portion is concerned: as at least one application may easily be suggested by practice, it has been thought well to make the present addition.

(1.) The annexed figure 14 corresponds to fig. 3, and therefore need not be particularly described.

Let OA $= a$, AN $= h$, NP $= k$, and let the equation to the curve BD be

$$f(h, k) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Let O$m = x$, $mn = y$, $np = z$,

then $\qquad z = k,$

and $\qquad \frac{y}{x} = \frac{h}{a};$

Therefore $\qquad f\left(z, \frac{ay}{x}\right) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$

is the equation to the convergent vault in its most general form. If we suppose Om to have any particular value b, the equation (2) is that to a parallel section. Hence the equation to the curve bd is

$$f\left(z, \frac{ay}{b}\right) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

It is evident that (1) and (3) are curves of the same order.

Next, to determine the equation to the surface of contact of two contiguous voussoirs.

Draw the normal pq to the curve ad at p; this is the line which traces out the surface in question. Draw PQ a normal to the curve BD at P, and let the angle PGB $= \phi$, then we have

$$f'(k) - f'(h) \tan \phi = 0$$

by the properties of the normal; also the equation to pq is

$$z' - z = -\frac{dy}{dz}(y' - y);$$

But from equation (3)

$$f'(z) + \frac{a}{b} \cdot f'\left(\frac{ay}{b}\right) \cdot \frac{dy}{dz} = 0.$$

Therefore the equation to the normal is

$$z' - z = \frac{b}{a} \cdot \frac{f'(z)}{f'\left(\frac{ay}{b}\right)} (y' - y).$$

Now, $f'(z) = f'(k)$ and $f'\left(\frac{ay}{b}\right) = f'(h)$. Therefore the equation becomes

$$z' - k = \frac{b}{a} \tan\phi \left(y' - \frac{bh}{a}\right).$$

Hence, suppressing the accents, and writing x for b, the required equation is

$$z - k = \frac{xy \tan\phi}{a} - \frac{x^2 h}{a^2} \tan\phi.$$

which can be easily shown to be the equation to the hyperbolic paraboloid. We thus obtain the remarkable theorem that "*if a convergent vault is cut by* "*planes parallel to its front, and normals are drawn to those points of the resulting* "*curves which are in the same generating line, the locus of the normals will be a* "*Hyberbolic Paraboloid whatever be the form of the front of the vault.*"

If we suppose the point O to be removed to an infinite distance, we have the limit of $\frac{x}{a}$ equal to unity, and consequently the equation to the surface degenerates into

$$z - k = \tan\phi (y - k).$$

The equation to a plane passing through PG at right angles to the front of the vault; which, since the vault in this case becomes a cylinder, is obviously the result that should be obtained.

(2.) The practical case alluded to at the beginning of the appendix is the following:—

Suppose the line of convergence not to be opposite to the centre of the front of the vault: *Eg.* Suppose the circular section to be BDB′ and the point O of convergence to be opposite to the point A, which is not the centre of the circle. In this case if G is the centre of the circle, and AG = c, we have for the equation to the circle

$$y^2 + (x - c)^2 = r^2,$$

and for the equation to the vault

$$z^2 + \left(\frac{ay}{x} - c\right)^2 = r^2,$$

and for the equation to the section bd,

$$z^2 + \left(\frac{ay}{b} - c\right)^2 = r^2.$$

Now this may be written,

$$\frac{z^2}{r^2} + \frac{\left(y - \frac{bc}{a}\right)^2}{\left(\frac{br}{a}\right)^2} = 1.$$

whence bdb' is an ellipse, whose axes are respectively bb' and r, its centre being in the middle point of bb'. Hence in this case the rules for the construction of the centring, and of the fronts and backs of any voussoirs, are the same as those above given. The equation to the surface of contact of two contiguous voussoirs

will be $$z - r\sin\phi = \frac{xy\tan\phi}{a} - \frac{x^2(r\cos\phi + c)\tan\phi}{a^2};$$

and if we suppose this to be cut by a plane which is perpendicular to GP, and at a distance r' from G, the equation to the curve referred to the analogous axes will be obtained as before; viz.,

The equation to the cutting plane is,

$$z\sin\phi + y\cos\phi = r' + c\cos\phi.$$

The equation to the projection of the curve on the plane xy is,

$$\frac{x^2(r\cos\phi + c)\sin\phi\ \tan\phi}{a^2} - \frac{xy\tan\phi\sin\phi}{a} - y\cos\phi + r' - r\sin^2\phi + c\cos\phi = 0.$$

And the required equation,

$$\frac{x^2(r\cos\phi + c)\sin\phi\tan\phi}{a^2} - \frac{xy\sin^2\phi\tan\phi}{a} - y\sin\phi\cos\phi + r' - r\sin^2\phi + c\cos\phi = 0.$$

And as this equation is of the form,

$$Ax^2 - Bxy - Cy + D = 0,$$

it admits of the same discussion as in the former case, the same inferences will follow from it, and the same rules be founded upon it.

The equation to the projection of the horizontal joint through P on the cutting plane will be

$$ay = x(c + r\cos\phi)\sin\phi + a\{(r' + c\cos\phi)\cot\!an\,\phi - r\sin\phi\cos\phi\}.$$

The above equations will, of course, reduce to those discussed in the text if we write $c = 0$.

J. F. T.

Erratum.—Page 12, line 12, omit the words "at right angles."

PL. 1.

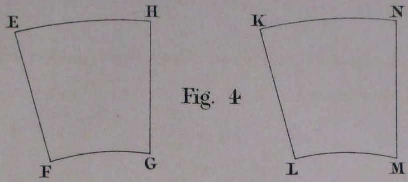


Fig. 4

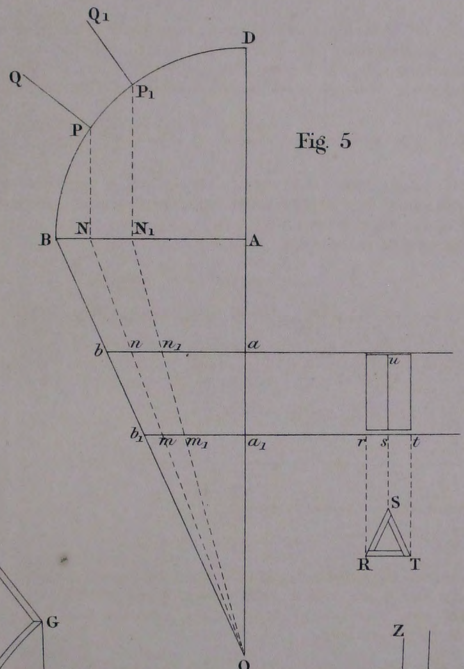


Fig. 5

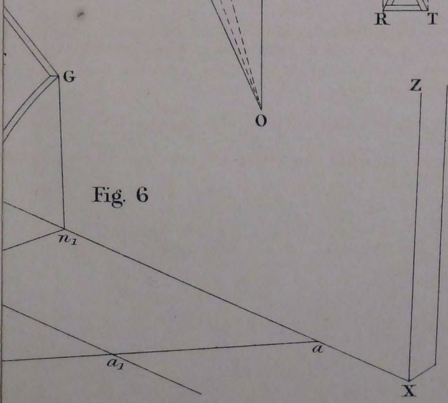


Fig. 6

PAPER IV.

Notes upon the Construction of Buildings at Gibraltar with Tapia.

Compiled by HENRY C. JAGO, Clerk of Works, R.E.D.
Forwarded by COLONEL STEHELIN, C.R.E., Gibraltar.

In the empire of Morocco the walls of fortifications and other substantial buildings, and even those of dwelling houses, are made of a composition known by the name of "tapia," which is extremely durable, not liable to splinter, and consequently well adapted as a substitute for masonry in works of defence.

The Moorish Castle at Gibraltar is a good specimen of this style of building, having stood for upwards of 1,100 years with little sign of decay from age. It was moreover exposed to the fire of the enemy's batteries for three years, during the great siege, without injury to the walls, except the small indentations made wherever a shot struck.

The real art of making tapia has apparently been lost in Gibraltar, for the modern attempts have produced a very inferior composition, scarcely better than well-rammed earth.

Under these circumstances, application was made to the Emperor of Morocco, to send masons to Gibraltar to instruct the Engineer Department in the true composition and manufacture of tapia, and the method of building with this material; and the Emperor, as will be seen by the annexed letters, sent two of his best workmen over to the garrison, under whose instructions a traverse, (33 ft. 10 in. by 13 ft.) and the merlon of a battery were constructed; and the process is explained in the accompanying memorandum.

Memorandum relative to the Preparation of, and Mode of Building with Tapia, as executed under the immediate direction and superintendence of Moorish Masons, in the erection of a Traverse at the Grand Battery at Gibraltar: compiled by Mr. Henry C. Jago, Clerk of Works.

Materials used.—Surface soil, sand, and pure clay are rejected as useless. Marl of a dark red colour, containing oxide of iron, gypsum, volcanic lime, sand and some salt not clearly ascertained by the tests used, as found in the red sand pits at Gibraltar, was in this case the material selected, which, with lime, finely slacked, and broken stone, or loose shingle from the quarries, were used by the Moorish masons in the composition of tapia. Round pebbles or beach shingle are inapplicable. The debris arising from the destruction of old masonry walls, and the refuse of the mortar yard or lime kilns, are good and useful materials.

PROPORTIONS.—About 25 cubic yards were mixed at once, and in the following proportions: viz.

Marl	cubic yards	13
Shingle	"	3
Lime-refuse	"	2½
Lime	"	6½

Should the lime-refuse not be available 2 cubic yards of shingle and half a yard of lime may be used instead.

PREPARATION.—The marl, shingle, and lime-refuse are spread in a bed about 1 foot 6 inches in depth; the lime, having been carefully slacked, is then evenly spread over the surface of the mass, and a *considerable quantity* of water is poured over the whole, after which the workmen commence at one or more sides of the heap or bed, and cut and turn it over with picks and shovels. Should any portion appear dry, more water is added; and this process of turning over and watering is continued until the whole of the ingredients are thoroughly mixed. The requisite amount of water and the state of the tapia are tested by compressing a portion in the hand; if with moderate pressure it will afterwards maintain its form, it is fit for use, but if it fall to pieces it is too dry, must be again turned over, and more water added; if, however, it gives too readily to the pressure of the hand, it will be too soft, and more dry material must be added to stiffen it. About 1,000 gallons of fresh spring water were found necessary to mix the 25 yards of tapia. After being thus prepared, the whole mass must be allowed to stand for a day or two, and on no account is it to be used until the lime is completely cold.

EXECUTION.—In the erection of buildings composed of tapia, the work is carried up in coffers, or casings of 3-inch planking, the sides being placed as far apart as the thickness of the walls is proposed to be. These coffers in the present instance were kept together by framework, composed of sleepers, uprights, and caps, all of deal 4½ inches wide by 1¼ inch thick, morticed and tenoned, placed at distances of about 2 feet 9 inches apart. Care must be taken that the sills of these frames are set perfectly level, and the uprights perpendicular, or difficulty will arise in carrying up the succeeding courses.

The sides or casings of the coffers were of 3-inch deal, 9 inches wide, wrought on the inner faces, and the edges shot; three of these in depth were bolted together with ½-inch round iron bolts, placed at distances of about 5 feet apart, to form each side. The bolts bind the deals together and prevent their warping.

In laying the sleepers for the first course of tapia, each sleeper being placed perfectly horizontal is cased with rough stone-work, forming a rough drain, to take the pressure of the tapia off the sill or sleeper, and leaving them free for removal to an upper course. After the first course, grooves are cut in the upper surfaces of the courses of tapia, as the work proceeds, to receive these sills or sleepers, and small flat stones are laid over them to facilitate their removal. To cut the grooves a miner's pick with a curved head, 1 foot 6 inches long, and a helve 2 feet long, is used. Old pick-axes were altered for this purpose, and were found to answer extremely well.

The framework having been thoroughly secured, the prepared tapia is thrown in between the planking in layers about 9 inches thick, and as many men as can get into the space between the planking (being each provided with a rammer) commence ramming the material. Ordinary field-work ramming is altogether useless. The rammer is raised nearly to the level of the shoulder and brought down with all the force the man is capable of exerting. The ramming is done by word of command, so that all the rammers come down at the same time, the words used by the Moors being, " Y Allah, zah ! " (Y Allah means " To God," or " O, God," and zah, used in bringing down the rammer, means " strike together.") This is found to be the most laborious part of the work, and must be strictly attended to. After the ramming has been continued some time, the tapia will have been worked into a soft paste; a small quantity of coarse broken stone is then evenly spread over the surface, and the ramming again proceeded with; this ramming and supplying broken stone is continued until the mass has become tough, and no longer adheres to the rammer; another layer of tapia is then spread, and so on, until it has reached the top of the casing or coffer.

To the 25 yards of tapia originally prepared, 3 yards additional of coarse stone were used during the ramming.

The compression of the material was about three inches in the original depth thrown in of 9 or 10 inches.

Two days should elapse before the frames are removed ; an earlier removal may injure the whole work. After the framework has been taken away the filling in of the centre of such a construction as a traverse may be proceeded with at once; for this purpose earth, debris from old buildings, and coarse shingle are used, having about half a cubic yard of lime riddlings, mixed with 9 cubic yards of earth ; this is first prepared by turning and watering, similarly to the preparation of the tapia, and is afterwards filled in and rammed in a similar manner.

The eaves-course of the traverse was formed of three courses of Malaga bricks, laid in mortar, and projecting 3 inches from the face of the traverse.

The top was formed roughly with the tapia, and covered with about 3 inches of common mortar, into which small dry shingle was beaten until it became of considerable rigidity.

The whole surface of the traverse was afterwards plastered with a thin coat of plaster prepared as follows :—Lime, taken fresh from the kiln, was carefully slacked and sifted through a fine sieve, great care being taken that no particles remained unslacked, and was mixed with clean sharp sand finely sifted, in the proportion of one of sand to ten of lime, with as much water as worked them into a very stiff paste, in which state it was left for at least four or five days before it was used.

The mode of treatment and the materials and utensils used in the construction of erections in tapia are so similar to those used in the erections of " pisé," that attention is directed to the article on " Pisé," in " Nicholson's Architectural Dictionary." London : J. Barfield, 1819.

R. E. Office, Gibraltar,
16th May, 1860.

PAPER V.

Account of the Operation of Blasting with Large Charges at the Quarries at Holyhead in November, 1860.

By COL. HAMILTON, Royal Engineers.

Minute by the Inspector General of Fortifications.

In Vol. II of our Professional Papers, New Series (1852), will be found a long account of the mining in the Holyhead quarries up to that period.

Similar operations have been carried on there ever since, with much judgment and effect, by the Contractors, Messrs. Rigby, aided by their efficient Resident Engineer Mr. Cousens.

Through their polite attentions, Colonel Hamilton, Royal Engineers, was enabled to witness a recent large explosion, and to collect information which is well worthy of being recorded, and which he has embodied in the following report.

Report on the Explosion of 12,000 lbs. of Gunpowder in the Quarries at Holyhead, on the 24th November, 1860.

By COLONEL HAMILTON, R.E.

Royal Engineer Office,
Manchester, 30th November, 1860.

Sir,

In accordance with the instructions conveyed in your letter dated 22nd inst., I attended to witness an explosion of gunpowder at the quarries of the harbour-works at Holyhead on the 24th inst., and have the honour to report, in reference thereto, as follows, viz. :—

The quarries, opened and worked by Messrs. Rigby, Contractors for the harbour-works, are situated on the declivity of the Holyhead Mountain, at about 1,500 yds. distance from and in rear of the land end of the breakwater the portion thereof, 120 feet by 40 feet, and 90 feet in height, on this occasion operated on, was formed of quartzose schist, extremely hard and weighing about

$1\frac{3}{4}$ cwt. to the cubic foot, stratified in lines extending from N.E. to S.W., a little overhanging to S.E., but nearly vertical, with numerous joints in that and other directions throughout the whole mass.

An entrance gallery, 5 ft. 6 in. by 3 ft. 6 in., was driven from the face of the rock, commencing at a height of 12 feet above its base, with a view to gain an efficient line of tamping resistance, a favourable joint in the line of strata having been taken advantage of to the extent of 34 feet, where a shaft, 3 ft. 6 in. by 3 ft. 6 in., was sunk to the depth of 14 ft. 6 in.; from this level galleries, 5 ft. 6 in. by 3 ft. 6 in., were driven right and left, the former to the extent of 49′ 9″ and the latter 56′ 6″, with a length of 43′ 6″ of headings and chambers of similar dimensions, as illustrated in the accompanying plan and elevation. The galleries, shafts, &c., were worked out by blasting, necessitated by the hard nature of the rock; and the increased size given to these communications above that generally adopted was with a view to enable the miners to strike with more freedom and effect, the extra excavation being more then compensated by the facility of working. The chambers were formed by slightly enlarging the short return-headings, and were placed from two to three feet below the level of the ground or rail line in front of the quarries, to ensure the bottom of the face acted upon being well lifted, as want of attention to this particular before a former explosion led to considerable subsequent labour in removing a portion of stone left standing.

The gunpowder used was similar to the fine grain government powder, its strength having been previously tested by projecting with a $1\frac{1}{2}$-oz. charge a 68-lb. shot from a mortar at an angle of 45° to the distance of 480 feet; the charges were placed in canvass bags well coated with tar, 2,000 or 3,000 lbs. in one bag, and the remainder in smaller bags, and so respectively lodged in each chamber.

The tamping was executed throughout with a sort of stiff red clay obtained in the vicinity, used in a slightly moist state, well rammed up to the entrances of the chambers, and close to the bags of gunpowder, merely leaving a small air space round the latter, and was continued to the mouth of the gallery in the face of the rock: it apparently answered its intended purpose admirably.

The battery employed to fire the charges was that known as Grove's. It had 32 cells, and platinum plates, 8 in. by 6 in., in nitric acid, in porous cells surrounded by diluted (6 to 1) sulphuric acid; it was placed on the top of the cliff, and directly in rear of the line of chambers, 300 feet distant from the upper edge of the former; two copper wires connected the battery with each charge, extending from the latter through the galleries directly up the face of the cliff and on to the cells, where the four positive were united, as well as the four negative. This method is considered by the Resident Engineer of the works much safer than using only one positive wire through all the charges and one negative in return. To the extremities of the copper wires at the charges were attached platinum wire about $\frac{1}{8}$ inch in length, protected by a wooden block, round which block a small bag of fine or sporting powder was tied and introduced into the large bags of powder before-mentioned.

The total quantity of powder used in the explosion was 12,000 lbs. placed in four charges amounting respectively to 4,000, 3,000, 2,300, and 2,700 lbs., with lines of least resistance 29 feet, 32 feet, 22 feet, and 24 feet 6 inches, as shown on the drawing; these respective charges were not calculated by any specific formula founded on the lengths of the lines of least resistance, but a certain number of pounds of gunpowder per ton of rock to be removed was allowed, according to the particular features and tenacity of the portion to be acted on (in the present instance 1 lb. of gunpowder to 3 tons of rock); this calculation was based upon the experience gained from numerous previous explosions of a similar character carried out at different parts of the quarries. In some cases 1 lb. of gunpowder was found sufficient to remove only two, in other cases it has proved adequate to displace four tons of stone.

Shortly after the hour appointed (12 o'clock) the mines were fired by the Contractor's Resident Engineer, who remained at the battery, on a signal from Mr. Rigby, with most successful results: the rock a little above its base was seen to bulge slightly outwards and then tumble to pieces, emitting much smoke, and the superincumbent mass gently sliding down, separated into various sized blocks; a perfect volley of small stuff, mostly the tamping, shot horizontally along, close to the ground, directly in front of the face of rock to a distance of about 250 feet, covering the surface with a coating of fine damp clay separated into small particles like sand; no stones of any magnitude were thrown out beyond the general debris, which was confined to a width of 125 feet from the original face of the quarry, as shown in the section.

The total quantity of rock removed was about 40,000 tons, which gives $3\frac{1}{3}$ tons to the pound of gunpowder used.*

The miners were but little impeded by wet or damp, the gallery was driven with a slight inclination upwards, to allow any water met with to find its way out: whenever damp holes had to be fired, pitched bags or cases, capable of holding 3 to 5-oz. charges, were used; the smoke from the firing of the blasts and foul air were removed by a rotatory blower worked by a boy at the mouth of the heading, and a canvass pipe conveyed the fresh air to the chambers.

The powder was brought to the mouth of the gallery in casks (containing from 50 to 100 lbs.) and there emptied into canvass bags capable of holding 50 lbs.: these bags were then passed from hand to hand by men placed at intervals in the galleries, to the respective chambers, where they were discharged into larger bags previously lodged there, to the extent required, after which some old powder cask sackings were thrown round and over them.

*The report on the effect of a similar explosion in January, 1857, printed at page 140, Vol. VI. of this Series, shows that $7\frac{1}{2}$ tons per pound of gunpowder were then brought down, or nearly double the quantity removed by each pound on this occasion; and on reference to the accompanying plan it will be observed that if, instead of the charge of 4,000 lbs., a smaller one had been employed, the effect would probably still have extended as far as the joint at that end, and also that a slight addition to the charge of 2,700 lbs. at the other end would have caused the fall of all the portion as far as the recess, which is described as "much shaken." It may also be remarked that the cliff brought down in January, 1857, was 25 feet higher than that here described, also that the strata of the former were horizontal, whilst those of the latter were vertical, and, on the other hand, that the blocks forming the debris of the latter were smaller, and more suitable for building, than those of the former: it is evidently therefore difficult to fix any rules for determining the quantity of powder required, especially where hidden joints exist which limit its effects.—ED.

The clay for tamping was brought to the mouth of the main gallery in waggons, and wheeled through it on planks to the shaft, where it was thrown down, and conveyed from the bottom thereof in a similar manner to the headings. This method was found to require less time and labour than any other known to the Engineer. The whole of the tamping was performed in 42 hours by 25 labourers.

The copper wires leading from each charge were, throughout their course in the tamping, lapped round with calico and tar bands, great care having been taken when tamping about them. This method was preferred to that of using wooden casings, and gave much freedom and ease in turnings at the angles and bends in the headings.

The cost of the powder (12,000 lbs.) used in the charges amounted to £300, and that of the canvass bags in which it was placed, including the tarring thereof, to £4 4s. The cost of the battery was £41 10s., and that of the wires connecting it with the charges £10 10s., made up as follows, viz.:—

GROVE'S BATTERY.

	£	s.	d.
32 porous cells at 2s. 8d.	4	5	4
32 zinc plates at 2s. 6d.	4	0	0
32 platinum ditto at 15s.	24	0	0
32 gutta percha troughs at 2s. 6d.	4	0	0
Mahogany case for box, quicksilver, poles, &c.	2	14	8
$2\frac{1}{2}$ gallons nitric acid to fill the cells at 18 8d.	2	6	8
$\frac{1}{2}$ gallon sulphuric ditto at 6s. 8d.	0	3	4
	£41	10	0

WIRES.

8 copper wires from the battery to the charges, including calico lapping and tar bands:—

8×500 ft. = 4,000 ft., and 800 ft. of wire weighing 28 lbs.,
4,000 ft. = 140 lbs., at 1s. 6d., cost £10 10s.

The time occupied in driving the galleries, shafts, &c., was about 9 months, the rate of progress averaging 1 foot per day of 24 hours, and 8 miners working; the cost being as hereafter detailed, viz.:—

	£	s.	d.
25s. to 26s. per foot of galleries driven, according to hardness of rock, 210 feet, at 25s. 6d.	267	15	0
Smith and labourer (1 day per week) keeping tools in order, equal to 36 days, at 10s.	18	0	0
Powder used in blasting (3 lbs. per foot), $210 \times 3 = 630$ at 6d.	15	15	0
1 inch of fuze per foot = 210 at 4d.	3	10	0
6 lbs. of candles per week, $36 \times 5 = 216$ at 8d.	7	4	0
30 bags or tarred cases at 9d.	1	2	6
	£313	6	6

Thus it would appear that 40,000 tons of stone were procured at an expense of £669 10s. 6d., or about 4d. per ton.

I witnessed the explosion from a point 150 yards in front of the cliff: the report was not loud, it resembled the sound of very distant thunder. On the whole the operation was a satisfactory one to Mr. Rigby and his assistant engineer, Mr. Cousens, to both of whom I am much indebted for the free and unreserved information they readily afforded me. The latter gentleman favoured me with the plan and elevation already referred to in this report.

I have the honour to be,

SIR,

Your most obedient humble servant,

R. G. HAMILTON,

Colonel, Com. Royal Eng.

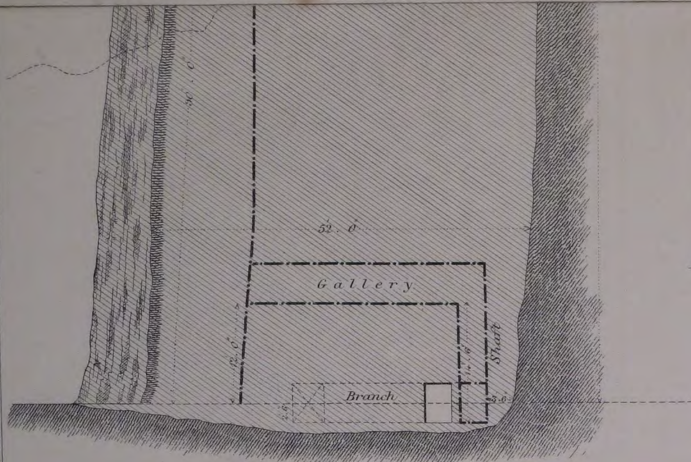
REMARKS BY THE INSPECTOR GENERAL OF FORTIFICATIONS.

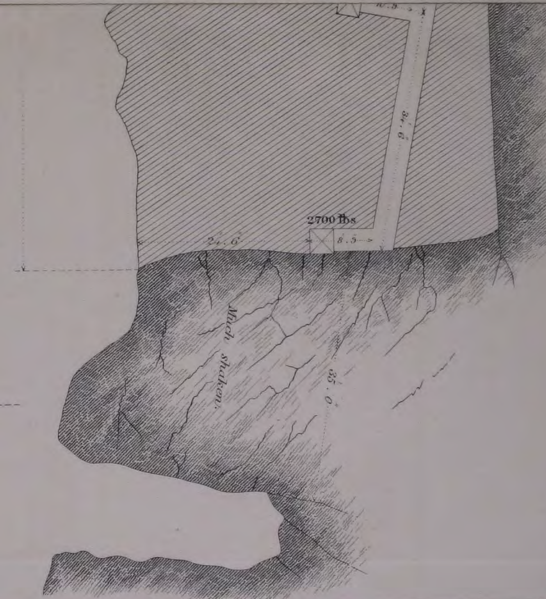
It would be presuming to venture to criticise a proceeding conducted with so much intelligence and success, and after years of constant practice in work of the same character; but it might be worthy of consideration whether an important saving in time, expense, and trouble, might not have been effected, in the driving of the passages, loading the mines, &c., by suppressing the shaft in the interior, 14 feet in depth, altogether.

Had the galleries been so wet as to require baling or pumping out, the inconvenience of the shaft in the interior would have been greatly increased.

I should myself have started from an excavation about 3 feet under the surface at the foot of the cliff, instead of commencing at 12 feet above the ground; and have worked from that level, with a slight rising incline, on the lines laid down on the plan, and have placed the chambers at the same sites and levels as shown on plan and section.

With the entrance thus sunk and well tamped down to the solid ground, with such large charges, and long and tortuous galleries, I should confidently have expected as good results, notwithstanding the *appearance* of the tamping being liable to be blown out, which I do not think it could have been independently of the general effect. But all this is reasonable matter of opinion.





N.B._The Section of the Cliff at the Entrance of the Gallery is shewn by Thick Dotted Lines, and the Outline of the Debris is shewn by Thin Dotted Lines. The part removed by the Explosion is shewn by Light Shading.

C. Moody, Litho. 257 High Holborn.

PAPER VI.

JOURNAL AND REPORTS ON THE OPERATIONS OF THE ROYAL ENGINEERS AT THE SIEGE OF JHANSI.

BY THE LATE LIEUT. COL. T. FENWICK, AND MAJOR EDWARDS, ROYAL ENGINEERS.

JOURNAL OF OPERATIONS OF CENTRAL INDIA FIELD-FORCE IN FRONT OF JHANSI.

25th March, 1858.—The 1st Brigade arrived at Jhansi at 7 A.M., 25th March, after a march of 22 miles, and found the 2nd Brigade investing the town. About 4 P.M. I accompanied Major Boileau, Commanding Engineer, to the front. A mortar battery was established on the eastern side of the town about 1,800 yards from the citadel. (See Plan.)

26th March.—Sent up a working party of Royal Engineers at 5 A.M., under Lieutenant Gossett (1 non-commissioned officer and 12 men), to lay platforms for two 10-in. mortars. Sufficient material was not furnished by the Ordnance. At 7 P.M. commenced laying platforms for two 8-in. mortars. They are of Bombay pattern and answer admirably. They consist of 3 sleepers, with a pivot in front, and a frame of 8″ × 8″ timber, with guide-pieces of iron, between which the mortar recoils. Also commenced forming a parapet with an embrasure for an 18-pr. gun to breach an advanced or salient work at the south-east angle of the fort, forming part of the town wall. (See Plan.)

27th March.—The two 8-in. mortars were removed to the right front. A battery was ordered to be erected for them and the 8-in. howitzer. I consider that the howitzer would have been more effective in the first position proposed. It is now on a lower level by 30 feet, thus losing the advantage of command. Also a sand-bag battery for two 18-prs. was commenced on the knoll to the left, to counter-batter the enemy's guns.

28th March.—The 18-pr. opened fire at about 8 A.M. The first two or three rounds missed the white tower about 600 yards distant. A small hill in advance was occupied as a rifle trench during the night.

29th March.—The mortar and howitzer batteries were completed during the night. After a few hours' firing the position of the howitzer was changed by the Artillery officer.

30th March.—The 18-pr. began to have an effect on the wall of the mound. Batteries still firing. Scaling ladders were ordered to the front. The enemy stockaded the breach with trees during the night.

31st March.—An alarm of enemy advancing in force from the eastward. The 2nd Brigade and part of the 1st went out towards the Betwah River. 1st Brigade shifted camp close to 2nd Brigade, and returned about 9 A.M. to nearly its original position.

1st April.—Enemy advanced during the night and attacked at daylight; they were repulsed after two hours' fighting, with a loss of 17 guns and 4 elephants, and were driven across the Betwah.

2nd April.—The assault of the town in four columns, about daylight, was determined on.

3rd April.—Assaults of the breach at the Mound and of the Rocket Tower by escalade took place at daylight with success. At the right attack 2 officers of Engineers of the Bombay service were killed, and 1 wounded. This attack failed in the first instance.

4th April.—Mortar shelling the fort. Infantry taking gradual possession of the town.

5th April.—The citadel was evacuated before day-break, and the British flag was hoisted on a tower.

(Signed) T. FENWICK, Captain,
Com. Royal Engineer and Field Engineer.

Thermometer 103° at 10 A.M.

MEMORANDA RELATIVE TO JHANSI.

Jhansi, a town in Bundlecund (Lat. 25° 28′, Long. 78° 38′), is situated amidst tanks and groves, and is surrounded by a loop-holed bastioned wall from 22 to 26 feet high. The gateways are all flanked, and were all built up inside by the enemy. Several guns were mounted on the ramparts.

On a rock overlooking the town is the fortress. There are 6 gates, one within another. On the east side it is perfectly impracticable. On the south side are 3 towers 50 feet high, of good masonry, connected by curtains; there is also a second or lower line of works along this face. The tank is close to the south-west tower.

On the west side of the fort there are 4 towers, and an advanced work on a lower level, containing a well of good water.

On the north side there is a double line of works with circular towers.

In the interior there is a large square tower and a palace of four stories, with other buildings. There are some casemates in the north face and a gunpowder manufactory. 27 guns were found in the fort and town.

About 600 yards from the fortress, on the south side, are three ridges of hills nearly as high as the rock on which the fortress stands.

These formed the position of the left attack, and of the following batteries:—

No. 1 Battery of two 18-prs. to counter-batter.

No. 2 Battery of two 10-in. mortars to shell fort and town.

No. 3 Battery of one 18-pr. to breach town-wall at Mound.

No. 4 Battery of two 8-in. mortars and one 8-in. howitzer to shell fort and defences.

(Signed) T. FENWICK, Captain,
Com. Royal Engineer and Field Engineer.

REPORT.

SIR,

I have the honour to forward a copy of my report to the Commanding Engineer, Central India Field-Force, of the assault of Jhansi from the left attack, in which the 21st Company Royal Engineers formed the ladder party, and working party for making a lodgment at the breach. I beg to report that the Company behaved very well and steadily on this occasion, and I have the honour to request that you will bring their conduct to the favourable notice of the Inspector General of Fortifications.

I have the honour to be,
SIR,
Your obedient servant,
(Signed) T. FENWICK, Captain,
Com. Royal Engineer and Field Engineer,
Left Attack.

The Com. Royal Engineer, India.

REPORT ON THE ASSAULT OF THE DEFENCES OF THE TOWN OF JHANSI FROM THE LEFT ATTACK, AT DAY-BREAK, 3rd APRIL, 1858.

To carry out the Division orders of the 2nd April, 1858, the 21st Company of Royal Engineers paraded at 2.30 A.M., and were marched up to the valley in rear of the batteries of the left attack, where they were told off to their respective ladders by Lieutenant Edwards, Royal Engineers; they then moved silently up the valley in rear of the howitzer battery, and the ladders were deposited on the reverse slope of the small hill on which the advanced rifle pit was formed. The party was handed over to Lieutenant Webber, Royal Engineers. The head of the column intended for the escalade was formed in rear. The column, under Colonel Lowth, 86th Regiment, intended to assault the breach, formed as nearly opposite the salient of the mound as possible without attracting the notice of the enemy. On the signal being given (viz., 3 shot from the 18-pr. breaching battery), the columns moved off, and when about 150 yards from the rocket tower, the enemy commenced a brisk fire on the escalading party, of musketry, rockets, &c., wounding two men of the Royal Engineers; and on the party getting close to the wall threw down stones and bags of charcoal, &c. The ladders were at once raised, and placed against the wall of the rocket tower, and the enemy driven from it. Lieutenant Webber conducted and placed the ladders in a most satisfactory manner, and the conduct of the men was admirable.

The column for assaulting the breach moved swiftly up the glacis, and crossed the ditch at a point where it had not been entirely excavated, and ascending the breach with a cheer, obtained possession of the Mound. As soon as the troops had moved down into the town, the Royal Engineers, under Lieutenant Edwards, commenced and formed a breastwork (embracing the guns captured there) under a fire of guns and gingals from the fort. In executing this service two men were wounded.

My thanks are due to Lieutenant Edwards for the energy and coolness with which this service was carried out. I beg also to bring to your notice the services of Lieutenant Gossett, Royal Engineers, who accompanied me with a small party down to one of the town gates, which the enemy had built up with stones and earth, which were cleared away and the communication opened.

T. FENWICK, Captain,
Commanding Royal Engineer, Bombay Presidency,
Field Engineer, Left Attack.

Nominal List of Men wounded.

2nd Corporal Johns	Slightly.
Sapper T. D. Smith	Severely.
„ G. Moore	Severely.
„ R. Mc.Lay	Severely.
„ H. Ramsey	Severely.

NOTES ON THE ASSAULT, BY MAJOR EDWARDS, ROYAL ENGINEERS.

Two assaulting columns were formed at the right attack, and two at the left, all being under the direction of Major Boileau, Madras Engineers.

The columns at the right attack were directed by Captain (now Major) Browne, an officer of the Madras Infantry, who was in command of the native company of Madras Sappers and Miners.

The assaulting columns from the left attack were under the direction of Captain Fenwick, Royal Engineers.

The two escalading columns from the right attack were directed on either side of the Orcha Gate: the ladder party of that on the right was commanded by Lieutenant Meiklejohn, Bombay Engineers, and the other ladder party on the left by Lieutenant Dick, Bombay Engineers. Each party was provided with six or seven ladders, carried by Madras and Bombay Native Sappers. There were two different kinds of ladders, some being similar to those used by us, only perhaps larger, and others being the bamboo ladder used in India. (The bamboo ladders are made of two long bamboos, 30 feet in length, with thin bamboos lashed at proper intervals to form the rungs).

The column on the right found the wall about 25 feet high, and that on the left nearly 30. In each case only three ladders were got to the front. Lieut. Meiklejohn was the first up the ladders with his party, and was dragged over the wall and *cut to pieces.* Lieutenant Dick mounted his ladder first, and on arriving at the top was shot through the head, falling dead at the foot of the ladder: the ladders were then immediately upset, and every effort to place them again was unavailing. The native Sappers by all accounts behaved most nobly, and their severe loss testifies to this.


SIEGE OF JHANSI.
Capt. Robinson's Picquet
Tank
Palace
1 24 Pr.
2 Mort.
Batteries
1 24 Pr.
1 How.
Col. Liddell's Post
RIGHT
ATTACK
Lutchmee Gate
Sauger Gate
Storming Parties
a
4 Mortars
Orcha Gate
TOWN OF JHANSI
a
a. a. a. are the Points Escaladed.
Palace
No. 5 Batty.
Gate
Temple
Cemetery
Jokum Bagh
Arsenal
Mound
Breach
FORT
Gate
Rocket Tower
a
Assaulting Column
LEFT ATTACK
Batteries
No. 4
No. 3
No. 2
No. 1
Ladder Party
100 50 0 100 200 300 400 500 600 Yds.
C. Moody, Litho. 257 High Holborn.

The dispositions of the Engineers for the two columns of the left attack were as follows:—

That on the right, under Colonel Lowth, 86th Regiment, was directed to storm the breach in the town wall on the Mound; it was accompanied by 25 Sappers of the 21st Company, Royal Engineers, under Lieut. Gossett, R.E., to assist in removing any obstacles, and, after it was taken possession of, to throw up an entrenchment on the Mound, so that in the event of our not being able to keep possession of the town, we might be enabled to retain the Mound, which commanded all the surrounding part of the town. The party attacking the breach did not meet with much resistance, as a heavy fire had been kept up throughout the night upon it; but the enemy had stockaded it so strongly that great difficulty would have been experienced in entering if a determined resistance had been made. The greater part of this column proceeded along the town-wall to their right, driving the defenders away from it, until they came to where the columns of the right attack had failed to escalade, thus enabling those columns to replace their ladders and enter the town.

The left assaulting column of the left attack, commanded by Major Stuart, 86th Regiment, was directed to escalade the wall in the valley between the Mound and the Fort.

To effect this object it was provided with seven ladders made somewhat of the same pattern as those now used at Chatham, but I think they were rather broader and heavier. These ladders were carried by 50 Sappers of the 21st Company, Royal Engineers, under the command of Lieut. Webber, R.E. This column was brought up to within 350 yards of the wall previous to the attack, in the dark, and moved off in capital order when the signal was given. When within 150 yards of the wall the party was rather disordered by having to pass over some rough ground, and Lieutenant Webber halted and formed them up in good order, under a smart musketry fire; they consequently arrived at the foot of the wall in perfect order, and the whole of the seven ladders were placed at the same moment, chiefly around a small circular tower. The wall was here 27 feet high, and loopholed. The enemy had prepared large masses of stone along this part of the wall, which they had placed so that they could push them off the wall on to the assailants at the foot: this they did, and broke some of the rungs of the ladders: they also fired rockets through the loop-holes and threw over earthen pots full of powder and some offensive composition. The assaulting party, headed by Lieutenants Dartnell, 86th Regiment, and Webber, soon gained a footing in the Tower. Lieutenant Dartnell was first on the wall, and received a great many sword cuts before Lieutenant Webber (who was prevented from being as soon in consequence of two rungs of his ladder being broken by a large stone) could come to his assistance. After considerable resistance a footing was gained, when the enemy soon vanished.

The four columns then moved on through the town towards the palace, all experiencing more or less resistance, that on the left suffering severe loss from having to pass under the fire of the Fort.

Besides the men employed in making the entrenchment on the Mound, parties of Sappers were employed with the columns in the town, some to open the gateways, some to break open the doors of houses occupied by the enemy, and others in opening up communications between houses, in erecting blinds with old furniture and anything that could be procured, across streets which were looked into by the Fort, which enabled the wounded to be carried off unseen. Corporal Sleavin, Royal Engineers, behaved so well in making a blind across a street, down which there was a very heavy fire, that Sir H. Rose gave him the Victoria Cross.

I am of opinion that to escalade a wall 27 feet high, *except as a surprise*, is an operation that may be considered impracticable in war, with anything like a determined enemy, unless you assault with a front of from 60 to 100 ladders.

In this instance the assaulting column was composed of chosen men of the 86th Regiment, at that time perhaps as fine old soldiers as any in the world, and they had been 18 years in India.

The ladders made in lengths, after Sir C. Pasley's pattern, proved the best on this occasion, but the bamboo ladders, if properly constructed with rungs firmly lashed, are lighter and quite as strong; in general, however, I think the former are the best, as they are put together more quickly, and are less likely to fail, besides being capable of being shortened at pleasure.

JAMES EDWARDS, Major,
Lately Commanding 21st Comp., R.E.

PAPER VII.

Report on two Bridges Constructed over the Gogra and Chowka Rivers, in January and February, 1859.

By LIEUTENANT HARRISON, Royal Engineers.

Bridge over the Gogra River.

The river Gogra between the villages of Mullapoor and Rajhpoor, which is that portion to the west of Buraech, and situated between that town and Khyrabad, may be said to be of an average width of one and a half miles; for the main stream is so split up into numerous channels, with large sandy islands and banks of mud which are perpetually changing their appearance, that the high watermark embraces a very wide extent.

The place selected for a bridge, both on account of its being the shortest road from Seetapore to Buraech, and also because the features of the river presented fewer difficulties to be overcome there than elsewhere, was close to the deserted Fort of Chelari, which afforded some material for the construction of the bridge.

The river is divided at this point into two channels by an island about one and a quarter miles in extent, one being fordable and about 60 yards across, and the other varying from 1 foot to 30 feet in depth, and being 427 yards in breadth at the narrowest part.

The steep bank on the Buraech side of the smaller stream was cut down, and a road made with fascines and small brushwood on both sides of the water, as well as across the island. The Delhi Pioneers, who furnished a daily working party of about 500 men, were employed in making this road over the island, cutting down the high bank on the Seetapore side of the river, and making strong ghats on both sides of the large stream, as well as a roadway of bamboos where the depth of the water permitted.

In the meantime a few carpenters were employed making anchors and piles, and some coolies in making rope; and every effort was made to collect materials, viz., timber, saws, jute for making rope, iron for nails, &c., &c.

It was not till the 17th January, 1859, that, by the help of the Deputy Commissioner of Buraech, who sent up 100 carpenters and sawyers from Bairam Ghat, the bridge can be said to have been commenced: on that date the first plank was sawn, and the first boat fixed in its position, and from that time the work went steadily on till its completion on the 7th February.

The number of boats used was 41, their width varying from 9 to 16 feet, and their length from 20 to 30 feet. The bays were 12 feet wide. The roadway was made of 2-inch planks and was 13 feet wide, the planks being laid transversely on 5 baulks of an average size of 7 in. by 5 in., which overlapped each other about 2 feet, and were bound firmly with rope. The planking was spiked with 7-in. nails made by the natives from arms taken from the rebels. The whole road was covered with straw and horse-litter.

			Feet.
The total number of feet running of Baulks was..	5×1008	=	5040
Add $\frac{1}{10}$ for crossing, &c.		=	504
Total length of baulks........	$(7'' \times 5'')$	=	5544

			Feet.
The total number of feet running of planks was..	13×1008	=	13104
Add $\frac{1}{20}$ for cuttings, &c.		=	655
Total length of planks	$(12'' \times 2'')$	=	13759

A hand railing of bamboo, with uprights of timber 4 feet high, was also fixed, the uprights reaching down to the bottoms of the boats, and being in size 4″ by 3″.

			Feet.
The total number of feet running of uprights....	160×7	=	1120
Add $\frac{1}{10}$ for spare ditto		=	112
Total uprights	$(4'' \times 3'')$	=	1232

Total content of timber about 3,781 cubic feet.

The boats were lashed together fore and aft with bamboo fascines 30 feet long, and were secured by two anchors each, the length of each cable being about nine times the depth of the stream, and the anchors of native construction filled with bricks.

Where the river was very shallow, viz., about 1 foot in depth, a break-water was made, and a roadway constructed of 18 feet fascines of bamboo. The fascines were laid in three tiers, all picketed firmly down, the bottom tier being laid with the stream, and with intervals of 9 inches between the fascines, and the next tier across them. The whole length of this roadway was 91 yards, and its breadth was 18 feet.

The labour employed in making this bridge may be roughly estimated as follows, supposing the materials to be collected on the spot.

From the 17th January to 7th February, viz., 22 days: 1 officer, 1 sergeant, and 14 sappers, 500 Delhi Pioneers, 125 carpenters and sawyers, 40 rope-makers and coolies, 30 smiths, and 47 mullahs or boatmen.

A great number of the Delhi Pioneers were employed in cutting down bamboos and making the fascines, which was a very laborious work, but answered the double purpose of destroying the fort and furthering the construction of the bridge.

The timber was obtained from Khutaee Ghat, about 20 miles up the river, and floated down; from Bounree, about 16 miles down the river, brought partly in hackeries and partly in boats; from mango trees cut down in the jungle at Chelari and Mullapoor; and also from the destruction of Fort Chelari itself.

As soon as the bridge was completed, elephants were sent across to test its strength, and as it sustained their weight satisfactorily it was capable of bearing anything that could be required to cross it. A raft of two large boats was made to shift easily, so as to admit of the passage of any large boats up and down the river.

Bridge over the Chowka River.

The position selected for this bridge was at a place called Cheemy Ghat, about 10 miles from that of Chelari. The river in many places is fordable, but hardly sufficiently so for hackeries.

The bridge was constructed of small boats about 3 feet wide by 25 feet long. The details were as follows, viz.:—Two piers were formed about 16 feet wide and 10 feet long. The number of boats used was 23, consisting of two rafts of 4 boats, and five rafts of 3 boats each, each raft being about 20 feet in extent. The bays were 5 feet wide. The scantling for sleepers for rafts was $22' \times 6'' \times 4''$, and that for bays $12' \times 6'' \times 4''$. The sleepers were laid on transverse baulks lashed to the boats. The planks were $13' \times 2' \times 2''$, and the planked roadway was about 220 feet long. A bamboo hand-railing was fixed on uprights at every 12 feet, of a scantling of $4' \times 6'' \times 4''$. The banks on both sides of the river were well cut down, and a road formed for two or three hundred yards.

The total expense of the two bridges was about 2,500 rupees.

(Signed) R. HARRISON,
Lieutenant Royal Engineers,
Chelari Ghat, Oude.

February, 7th, 1859.

PAPER VIII.

JOURNAL OF OPERATIONS AT THE SIEGE OF AHWAH.

By CAPTAIN CUMBERLAND, Royal Engineers.

Ahwah is a fort of considerable strength, situated generally on a level with the country around, but rising by artificial means in the interior, where the Thakoor's castle or keep is situated, to a height of 20 or 25 feet.

It is defended on the western face, and on the greater part of the northern, by a double line of works, the outer of earth and the inner line a masonry wall with flanking towers at the angles and at intermediate points. The upper part of the wall is loopholed: it is constructed chiefly of stones and mud, and is pointed with mortar; it is 6 feet thick at the foundation and 3 feet 6 inches thick at top, having a batter on the exterior face of about 2½ feet. The height of the towers is about 25 feet, and of the wall between them about 16 or 18 feet. There is no ditch. The exterior or earthen wall is about 16 feet high, and about 30 feet thick at base and 4 at top, with a slope of 50° or 60° outside. It is also protected on the western face by a ditch about 4 feet deep and 20 feet wide, but there is no ditch on the northern face. There are fraizes of thorny brushwood in several parts, and the same materials are used to form an abattis outside.

The eastern portion of the northern line is not so strong, having only one wall of earth 12 to 14 feet high, with masonry towers flanking it; but the tank forms a defence at this part: it is covered by a grove of trees and some temples, which are encircled by an earthen line of works from 16 to 20 feet high, with a slight ditch and abattis; in front of this, on the opposite side of the nullah, is an earthen work, open in rear, covering a temple. The tank extends as far as the eastern gate, which is flanked by two incomplete masonry towers. From this point to the south-east bastion runs an earthen line of works of considerable strength, having a command over the country of about 18 feet, and an imperfect ditch averaging 3 feet in depth and 10 in width, strengthened by an abattis of thorny brushwood. The exterior face is nearly vertical at the upper part, but has an average batter of about 10 feet.

The defences of the southern face consist of a masonry wall 6 feet thick at bottom and 3 feet at top, and from 15 to 18 feet high. Within the wall the ground is high and forms a terreplein, from which men can see over the parapet or fire through the loopholes with which the wall is furnished throughout its whole length. It is flanked by masonry towers; and a cavalier of mud and brickwork rises behind and detached from its centre, having a command over it of about 10 feet. This cavalier, in common with all the towers which have been mentioned, is furnished with embrasures for guns. A line of abattis, raised on a mound from 3 to 4 feet high, covers the south face, hiding the foot of the wall, which is not protected by a ditch. The dry sandy bed of a river runs along this face, and also along a part of the northern face.

There are five gateways in the line of works, which are flanked by masonry towers of more substantial construction than the others.

On an artificial rising ground in the town, rather towards the eastern face, is the Thakoor's Castle, forming a keep to the place. It is of a square form, each side being about 80 yards long. It consists of a number of buildings, surrounded by a masonry wall flanked by towers, in the same manner as the walls of the town, and higher than the buildings about it; but it is not wholly isolated from them.

The fort of Ahwah is much hidden by trees, which surround it on all sides except the south. They stand in thick clusters, lining the defences both inside and out, covering the exterior, and rendering all examination at any distance outside a matter of great difficulty. The contour of the place is thus almost completely concealed.

The preceding information was only obtained after the evacuation of the fort by the enemy. There was no plan, except two native ones, on which but small reliance could be placed, and no information of any sort could be obtained concerning the works of any one face. The garrison was understood to consist of about 1,500 men, and they had about 25 guns of small calibre, throwing shot weighing from 6 to 2 pounds.

SIEGE OPERATIONS.—The field force, under the command of Lieutenant Colonel Holmes, effected a junction before the place on the morning of the 19th January, 1858. It was composed as follows :—

Her Majesty's 95th Regiment..	300	11th Company Royal Engineers	110
Ditto 83rd „ ..	140	Bombay Artillery	110
12th Native Infantry..........	140	Native Regular Cavalry	200
10th Ditto	320	Scinde Horse	500
Total	900	Grand Total	1820

Immediately on arrival before the place a reconnaisance was made. The investment had been made by the cavalry two or three days previously, and it was now rendered more complete.

On account of the trees, the walls could only be seen here and there at isolated points, except on the south, where they were fully open to view. It was necessary therefore to reconnoitre in places to within 400 yards, by which enough was seen to recommend the south as the front to be attacked. It should also be mentioned that the ground in front of the south face was very favourable for the construction of batteries and approaches; at the same time it was not forgotten that with regard to the other faces, the trees would afford good cover to an attacking force. Accordingly camp was pitched to the south, at a distance of 2,000 yards from the town.

First Night, January 19th, 1858. A half sunken battery for 3 howitzers and 1 mortar, 1 magazine, 1 traverse, and 1 epaulment, (No. 1 in Plan*), was

* It has not been considered necessary to lithograph this sketch.—ED.

traced and executed this night. A portion of a hillock was cut away to form No. II Battery for two mortars and one magazine.

Their special object was to maintain a fire of shells on the town next day, which, being directed from several points at the same time, would force the enemy to abandon the fort and fall into the hands of the investing force. No. 1 Battery was also intended to enfilade the south face, with a view to further operations, but as it had become dark when its site was fixed upon, the correctness of its position could not be ascertained; yet as it was thought best to execute it that night (the 19th inst.), and thus avoid delay, a position favourable for execution was chosen, though for purposes of enfilade it should have been more to the right.

Batteries Nos. I and II were completed and armed before noon on the 20th inst.; they commenced firing at noon, in conjunction with Captain Aitkin's field battery of four 9-pdrs. and two 12-pdr. howitzers, which had taken a forward position on the left near the spot marked *A* in the sketch which accompanies this report.

This fire continued for two or three hours, the enemy replying at intervals, but not showing any intention to leave the fort. A closer examination of the south face and of the ground in its front was therefore made; the point *b* in the wall near the South-east Bastion was selected for the position of a breach, and a favourable rise in the ground was observed on which to construct a breaching battery.

In the afternoon of the 20th, a house *c*, in front of the eastern gate, which was occupied by the enemy, and to which they had run out a gun (afterwards withdrawn), was taken and blown up with gunpowder.

Estimate of Men, Tools, and Materials.—1st Relief.

	No. 1 Battery.	No. 2 Battery.	
Guard of the Trenches	50 men	50	
Working party	106 "	10	
Sappers	18 "	7	
	174	67	Total.. 241 men

	No. 1 Battery.	No. 2 Battery.	Total.
Picks	47	7	54 Picks.
Shovels	59	11	70 Shovels.
Rammers	4	"	4 Rammers.
Mallets	2	"	2 Mallets.
Measuring Rods	6	2	8 Measuring Rods.
Do. Tapes (80 yds. each)	4	"	4 ditto Tapes.
Levels	1	"	1 Level.
Lanterns	1	"	1 Lantern.
Tracing Pickets	25	10	35 Tracing Pickets.
Sand-bags	1,390	"	1,390 Sand-bags.
Mining Frames	3	2	5 Mining Frames.
Sheeting Planks	3	3	6 Sheeting Planks.

Second Relief—Men, tools, and materials as before for the first half of this relief.

Third Relief:—

Repairing Embrasures	8 Sappers.	Total—16 Sappers.
Demolishing House	8 ,,	

Tools and Materials for ditto.

4 Picks.	12 ft. hose.
4 Shovels.	9 in. port-fire.
1 Measuring rod.	$1\frac{1}{2}$ ft. slow match.
80 lbs. powder.	

2nd night, January 20th.—Battery No. II was traced and executed: it was made half sunken for 6 guns with a magazine and a traverse. 300 yards of trench communication in rear were also traced and executed so as to afford sufficient cover; this was rendered necessary as the ground in rear was open and the road on the right was enfiladed from a mound (*f*) jutting out from the south-east bastion.

Riflemen were placed in advanced positions on the right and left.

Battery No. II was abandoned, and its mortars moved further forward, obtaining cover under a bank, which thus formed Battery No. IV.

Battery No. III could have opened fire with the siege ordnance, either during the 21st inst. or at daylight on the 22nd, after which it was considered probable that a few hours would have sufficed for the taking of the fort; but at this time information was received that a double line of works existed all around the fort, excepting for about 200 or 300 yards on the eastern face where there was only a single line.

This information came from a native; it was given first in camp, and afterwards in view of the place, at both times in the hearing of two or three officers well acquainted with the language of the country. The native also pointed out the eastern gate and described its approaches and the ground within.*

The evidence of this native, though appearing correct, as guns had been fired several times from the south front from points not immediately on its face, would not have been considered sufficient to change the plan of the attack had it not coincided with two native plans which had come into our hands from different sources.

On account of this information, an examination of the east face (occupying from two to three hours) was made on the afternoon of the 21st inst., after which it was decided to erect a battery on a convenient rising ground, which might serve either to breach the works at a point (*e*) near the centre of the eastern front, or open a passage through the eastern gate.

The ground more to the right of this position was not so favourable for the construction of a battery, nor was the view of the wall so clear.

It was necessary first to burn the brushwood, which concealed the foot of the wall of this front: this was intended to be done by means of carcasses or fire-balls.

Batteries I, III, and IV were firing at intervals to silence the guns of the fort and enfilade the south and east faces.

* This afterwards proved to be correct.

Estimate of Men, Tools, and Materials.

Guard of the trenches	100	Total—308 men.
Working party	198	
Sappers	10	

Tools in proportion.

Materials..	Sand-bags	3,000.
	Mining frames	3.
	Sheeting planks	3.

There was no working party in the trenches after 9 A.M., on the 21st, on account of the heat.

On the 3rd night (21st January), Battery No. V, for breaching, was traced for 4 guns. A magazine was provided for it, but no traverse.

This battery was made half sunken, and was partially executed on this night. 140 yards of trench communication in rear were also traced and commenced, and positions for riflemen were taken up on the mound, some low ruins on its right, and behind some trees.

Battery No. V could not be armed this night as it was found necessary to approximate its form to that of an elevated battery to give it a better command. Independently of this it was also considered advisable to withdraw the working parties of the European regiments (who alone were good for trench work) during the heat of the sun, as the troops had been very hard-worked.

Batteries I, III, and IV fired occasionally.

Estimate of Men, Tools, and Materials.

	No. III Battery.	No. V Battery.	
Guard of the trenches	30	40	
Working party	30	100	
Sappers	8	20	
	68	160	—Total, 228 men.

Tools in proportion.

Materials.			Total.
Sand-bags	350	1,750	2,100 Sand-bags.
Mining Frames	,,	3	3 Mining Frames.
Sheeting Planks	,,	26	26 Sheeting Planks.

4th night, 22nd January.—The Breaching Battery No. V was completed and armed this night, and the communication in rear was completed so as to afford a sufficient cover. Carcasses and light balls were thrown into the brushwood in front of the gate, but without success. As it was considered a point of some importance that this brushwood should be cleared away, it was decided to roll a sap-roller, or gabion filled with combustibles, up to it on the following night, and to provide other means besides for burning it by hand. All arrangements could in the mean time be made for the assault, which would take place on the following day after the guns (which would open fire at daybreak), had made a practicable breach.

Battery No. III fired occasionally to enfilade the east face. Battery No. II shelled the Thakoor's house and vicinity, and No. I enfiladed the south face. The whole were also to silence any gun that might fire from the fort. The European infantry were removed from the batteries from 9 A.M. to 5 P.M. on the 23rd January.

Estimate of Men, Tools, and Materials.

	On the Right.	On the Left.
Guard of the trenches	40	30
Working party	77	33
Sappers	14	9
	131	72—Total, 203 men.

There was no second or third relief, the first relief remaining in position till 9 A.M. on the 23rd inst.

5th night, 23rd January.—The guns were removed from No. III Battery.

Preparations were made this night, in rear of Battery No. V, to burn the brushwood above-mentioned. The night was stormy and dark in the extreme, with thunder and a deluge of rain. Under the superintendence of an officer of Engineers two non-commissioned officers of that corps (Sergeant Doherty and Corporal Kerr), went forward and inspected the position of the brushwood to select the best point for burning it. It was reported as useless to attempt it on that night, much of it being too supple to burn easily even had there been no rain. The attempt was considered not worth the risk of the lives of the men engaged: the party sent forward to examine were fired upon, and it was decided that the breaching battery should open on the gateway at daylight with shot and shell to clear a passage. Before daylight riflemen filled the ground in front, and every arrangement was made for the assault, parties being detailed with materials for blasting, gabions for lodgments and fascines for ditches, and also some with scaling ladders and others with sledge hammers, axes, &c.

It was found however in the morning that the intense darkness of the night had enabled the enemy to escape from the fort, which was therefore occupied by the besieging force at about 6 A.M. on the 24th inst.

Estimate of Men, Tools, and Materials.

	On the Right.	On the Left.
Guard of the trenches	100	„
Working party	6	„

Tools.

1 Hand-saw.	1 Felling axe.
2 Bill-hooks.	1 Dark lantern.

Return of Men, Tools, and Materials used at the Siege.

Tools.

Picks	80	Lanterns	5
Shovels	104	Measuring rods	8
Rammers	4	Clasp knives	29
Mallets	4	Fascine chokers	1
Tapes	7	Tracing pickets	500
Levels	2	Hand-saws	2
Bill-hooks	25	Felling axes	1

Materials.

Sand-bags	6,490
Mining frames	11
Sheeting pieces	26

Men.

Guard of the trenches (generally at two reliefs)			100
Working parties ditto			350
Camp duties, guards, picquets, sick, &c			450
	Total Infantry		900
	Engineers		110
	Artillery		110
Cavalry	Native Regular	200	700
	Ditto Scinde Horse	500	
	Grand Total		1,820

Return of Ordnance employed at the Siege, and Ammunition expended.

No. of Pieces.	No. of rounds expended.
2 18-pdr. guns	27
2 8-in. howitzers	168
2 24-pdr. howitzers	118
2 12-pdr. howitzers	32
4 9-pdr. guns	313
2 8-in. mortars	301
2 $5\frac{1}{2}$-in. ditto	308
For demolition of houses, &c	80 lbs. of gunpowder.
Total Ordnance employed	16 pieces.

Batteries Nos. I, III, and V were constructed of sand-bags, the greater part of which were afterwards recovered.

The following Officers of Engineers were employed at this siege:—

Lieutenant A. Davidson, Bombay Engineers.
" D. C. Walker, Royal Engineers.
" J. B. Paterson, Royal Engineers.

The Commanding Engineer of the Rajpootana Field Force, (Major Tremenheere, Bombay Engineers), joined the force before Ahwah on the 23rd January, but permitted me to remain in command of the Engineers until the place fell.

I have, &c.,

(Signed) C. E. CUMBERLAND, Royal Engineers,
Com. Engineer at the Siege.

PAPER IX.

REPORTS ON THE ENGINEERING OPERATIONS DURING THE DEFENCE OF LUCKNOW, IN 1857.

EXTRACT FROM THE REPORT OF MAJ. GEN. SIR JOHN INGLIS, K.C.B., ON THE DEFENCE OF THE RESIDENCY AT LUCKNOW, DATED SEPT. 26, 1857.

"The description of our position and the state of our defences when the siege began* are so fully set forth in the accompanying memorandum furnished by the Garrison Engineer that I shall content myself with bringing to the notice of his Lordship in Council the fact that when the blockade was commenced only two of our batteries were completed, part of the defences were yet in an unfinished condition, and the buildings in the immediate vicinity, which gave cover to the enemy, were only very partially cleared away. Indeed, our heaviest losses have been caused by the fire from the enemy's sharpshooters, stationed in the adjoining mosques and houses of the native nobility, the necessity of destroying which had been repeatedly drawn to the attention of Sir H. Lawrence by the staff of Engineers; but his invariable reply was, "Spare the holy places, and private property too, as far as possible;" and we have consequently suffered severely from our very tenderness to the religious prejudices, and respect to the rights of our rebellious citizens and soldiery. As soon as the enemy had thoroughly completed the investment of the Residency they occupied these houses, some of which were within easy pistol shot of our barricades, in immense force, and rapidly made loopholes on those sides which bore on our post, from which they kept up a terrific and incessant fire day and night, which caused many daily casualties, as there could not have been less than 8,000 men firing at one time into our position. Moreover, there was no place in the whole of our works that could be considered safe, for several of the sick and wounded who were lying in the banqueting-hall, which had been turned into a hospital, were killed in the very centre of the building, and the widow of Lieutenant Dorin, and other women and children, were shot dead in rooms into which it had not been previously deemed possible that a bullet could penetrate. Neither were the enemy idle in erecting batteries. They soon had from 20 to 25 guns in position, some of them of very large calibre. These were planted all round our post at small distances, some being actually within 50 yards of our defences, but

* The garrison was concentrated at the Residency, on the 1st July, 1857, after blowing up the Muchee Bowun.

in places where our own heavy guns could not reply to them; while the perseverance and ingenuity of the enemy in erecting barricades in front of and around their guns in a very short time rendered all attemps to silence them by musketry entirely unavailing. Neither could they be effectually silenced by shells, by reason of their extreme proximity to our position, and because, moreover, the enemy had recourse to digging very narrow trenches about eight feet in depth in rear of each gun, in which the men lay while our shells were flying, and which so effectually concealed them, even while working the gun, that our baffled sharpshooters could only see their hands while in the act of loading.

The enemy contented themselves with keeping up this incessant fire of cannon and musketry until the 20th of July, on which day, at 10 a.m., they assembled* in very great force all around our position, and exploded a heavy mine inside our outer line of defence at the Water Gate. The mine, however, which was close to the Redan, and apparently sprung with the intention of destroying that battery, did no harm. But as soon as the smoke had cleared away the enemy boldly advanced under cover of a tremendous fire of cannon and musketry, with the object of storming the Redan. But they were received with such a heavy fire that after a short struggle they fell back with much loss. A strong column advanced at the same time to attack Innes's post, and came on to within 10 yards of the palisades, affording to Lieutenant Loughnan, 13th Native Infantry, who commanded the position, and his brave garrison, composed of gentlemen of the uncovenanted service, a few of Her Majesty's 32nd Foot, and of the 13th Native Infantry, an opportunity of distinguishing themselves, which they were not slow to avail themselves of, and the enemy were driven back with great slaughter. The insurgents made minor attacks at almost every outpost, but were invariably defeated, and at 2 p.m. they ceased their attempts to storm the place, although their musketry fire and cannonading continued to harass us unceasingly as usual. Matters proceeded in this manner until the 10th August, when the enemy made another assault, having previously sprung a mine close to the Brigade mess, which entirely destroyed our defences for the space of 20 feet, and blew in a great portion of the outside wall of the house occupied by Mr. Schilling's garrison. On the dust clearing away a breach appeared, through which a regiment could have advanced in perfect order, and a few of the enemy came on with the utmost determiation, but were met with such a withering flank fire of musketry from the officers and men holding the top of the Brigade mess that they beat a speedy retreat, leaving the more adventurous of their number lying on the crest of the breach. While the operation was going on another large body advanced on the Cawnpore Battery, and succeeded in locating themselves for a few minutes in the ditch. They were, however, dislodged by hand grenades. At Captain Anderson's post they also came boldly forward with scaling ladders, which they planted against the wall; but here, as elsewhere, they were met with the most indomitable resolution, and the leaders being slain, the rest fled, leaving the ladders, and retreated to their batteries and loopholed defences, whence they kept up for the rest of the day an unusually heavy cannonade and musketry fire. On the 18th of August, the enemy sprang another mine in front of the Sikh lines with very fatal effect.

* See the Plan at the end of the next Paper.

Captain Orr (unattached), Lieutenants Meecham and Soppitt, who commanded the small body of drummers composing the garrison, were blown into the air; but providentially returned to earth with no further injury than a severe shaking. The garrison, however, were not so fortunate. No less than 11 men were buried alive under the ruins, whence it was impossible to extricate them owing to the tremendous fire kept up by the enemy from houses situated not ten yards in front of the breach. The explosion was followed by a general assault of a less determined nature than the two former efforts, and the enemy were consequently repulsed without much difficulty. But they succeeded, under cover of the breach, in establishing themselves in one of the houses in our position, from which they were driven in the evening by the bayonets of Her Majesty's 32nd and 84th Foot. On the 5th of September the enemy made their last serious assault. Having exploded a large mine a few feet short of the bastion of the 18-pdr. gun in Major Apthorp's post, they advanced with large heavy scaling ladders, which they planted against the wall, and mounted, thereby gaining for an instant the embrasure of a gun. They were, however, speedily driven back with loss by hand grenades and musketry. A few minutes subsequently they sprang another mine close to the Brigade mess and advanced boldly; but soon the corpses strewn in the garden in front of the post bore testimony to the fatal accuracy of the rifle and musketry fire of the gallant members of that garrison, and the enemy fled ignominiously, leaving their leader—a fine-looking old native officer—among the slain. At other posts they made similar attacks, but with less resolution, and everywhere with the same want of success. Their loss upon this day must have been very heavy, as they came on with much determination, and at night they were seen bearing large numbers of their killed and wounded over the bridges in the direction of the cantonments. The above is a faint attempt at a description of the four great struggles which have occurred during this protracted season of exertion, exposure, and suffering. His Lordship in Council will perceive that the enemy invariably commenced his attacks by the explosion of a mine, a species of offensive warfare for the exercise of which our position was unfortunately peculiarly situated, and had it not been for the most untiring vigilance on our part in watching and blowing up their mines before they were completed, the assaults would probably have been much more numerous, and might, perhaps, have ended in the capture of the place. But by countermining in all directions we succeeded in detecting and destroying no less than four of the enemy's subterraneous advances towards important positions, two of which operations were eminently successful, as on one occasion not less than 80 of them were blown into the air, and 20 suffered a similar fate on the second explosion. The labour, however, which devolved upon us in making these countermines in the absence of a body of skilled miners was very heavy.

The Right Hon. the Governor General in Council will feel that it would be impossible to crowd within the limits of a despatch even the principal events, much more the individual acts of gallantry which have marked this protracted struggle. But I can conscientiously declare my conviction that few troops have ever undergone greater hardships, exposed as they have been to a never-ceasing musketry fire and cannonade. They have also experienced the alternate vicissitudes of extreme wet and of intense heat, and that too with very insufficient shelter from either, and in many places without any shelter at all. In addition to having had to repel real attacks, they have been exposed night and day to the hardly less harassing false alarms which the enemy have been constantly raising. The insurgents have frequently fired very heavily, sounded the advance, and shouted for several hours together, though not a man could be seen, with the view, of course, of harassing our small and exhausted force, in which object they succeeded, for no part has been strong enough to allow of a portion only of the garrison being prepared in the event of a false attack being turned into a real one; all, therefore, had to stand to their arms, and to remain at their posts until the demonstration had ceased; and such attacks were of almost nightly occurrence. The whole of the officers and men have been on duty night and day during the 87 days which the siege had lasted up to the arrival of Sir James Outram, G.C.B. In addition to this incessant military duty the force has been nightly employed in repairing defences, in moving guns, in burying dead animals, in conveying ammunition and commissariat stores from one place to another, and in other fatigue duties too numerous and too trivial to enumerate here. I feel, however, that any words of mine will fail to convey any adequate idea of what our fatigue and labours have been—labours in which all ranks and classes, civilians, officers, and soldiers, have all borne an equally noble part.—All have together descended into the mine, and have together handled the shovel for the interment of the putrid bullocks, and all, accoutred with musket and bayonet, have relieved each other on sentry without regard to the distinctions of rank, civil or military. Notwithstanding all these hardships, the garrison has made no less than five sorties, in which they spiked two of the enemy's heaviest guns, and blew up several of the houses from which they had kept up their most harassing fire. Owing to the extreme paucity of our numbers, each man was taught to feel that on his own individual efforts alone depended in no small measure the safety of the entire position. This consciousness incited every officer, soldier, and man to defend the post assigned to him with such desperate tenacity, and to fight for the lives which Providence had entrusted to his care with such dauntless determination, that the enemy, despite their constant attacks, their heavy mines, their overwhelming numbers, and their incessant fire, could never succeed in gaining one single inch of ground within the bounds of this straggling position, which was so feebly fortified that had they once obtained a footing in any of the outposts the whole place must inevitably have fallen.

If further proof be wanting of the desperate nature of the struggle which we have, under God's blessing, so long and so successfully waged, I would point to the roofless and ruined houses, to the crumbled walls, to the exploded mines, to the open breaches, to the shattered and disabled guns and defences, and, lastly, to the long and melancholy list of the brave and devoted officers and men who have fallen. These silent witnesses bear sad and solemn testimony to the way in which this feeble position has been defended. During the early part of these vicissitudes we were left without any information whatever regarding the posture of affairs outside. An occasional spy did indeed come in with the object of inducing our Sepoys and servants to desert; but the intelligence derived from such sources was, of course, entirely untrustworthy. We sent our messengers, daily calling for aid and asking for information, none of whom ever returned until the 26th day of the siege, when a pensioner named Ungud came back with a letter from General Havelock's camp, informing us that they were advancing with a force sufficient to bear down all opposition, and would be with us in five or six days. A messenger was immediately despatched, requesting that on the evening of their arrival on the outskirts of the city two rockets might be sent up, in order that we might take the necessary measures for assisting them while forcing their way in. The sixth day, however, expired, and they came not; but for many evenings after officers and men watched for the ascension of the expected rockets, with hopes such as make the heart sick. We knew not then, nor did we learn until the 29th of August (or 35 days later), that the relieving force, after having fought most nobly to effect our deliverance, had been obliged to fall back for reinforcements; and this was the last communication we received until two days before the arrival of Sir James Outram, on the 25th of September."

Report on the Defences of the Residency at Lucknow, By Lieut. J. C. Anderson, M.E.

Lucknow, October 5, 1857.

The outbreak at Meerut and Delhi, and reports of general disaffection among the Sepoys, caused Sir Henry Lawrence to take immediate measures for the defence of this place. Some time previously he had selected the Muchee Bowun as a site for our magazine and stores, and on account of its very commanding position and the moral effect that the occupation of it would exercise over the city, he in the first instance proceeded to strengthen it. The works were commenced on the 17th May, and carried forward with unremitting energy by Lieut. Innes, under the general direction of Major Anderson, Chief Engineer, until the commencement of the siege.

The defence of the Residency was also commenced, though at first it received a secondary share of attention. It was not till after the mutiny in cantonments (30th May), and the subsequent mutinies of corps in the district, that it became apparent that we should have probably to defend ourselves against a combined attack of mutineers and rebels from the country and city. The more clear this became, the more clearly the inadequacy of the Muchee Bowun as a fortified position became apparent. It was also seen that, if the mutineers came on in great force, we had not sufficient hands to man both it and the Residency; and having ascertained, after full consideration, the defects of the Muchee Bowun, both as regards defensive measures and shelter of troops, and the large European community, Sir Henry Lawrence made up his mind to abandon it on the investment of the city by the enemy.

On this being decided (11th June), the defences of the Residency were proceeded with with vigour. Prior to this, the Chief Engineer was doubtful as to the extent of the force he had to shelter within the line of defences, or to man the works; but now he could form a definite plan, and he lost no time in forming a connected line of defensive works round the buildings he thought it necessary to occupy.

The Residency Compound was first protected by a line of parapet and ditch across it; a strong battery, since named "the Redan," was constructed in a corner of the garden, which furnished a command over the iron bridge.

A battery (called "the Cawnpore") was constructed at the opposite point of our position enfilading the Cawnpore Road, and was then designed chiefly as a barrier to the approach of mutineers from Cawnpore.

Two other batteries were partially constructed, one between Gubbins's and Ommanney's Compounds, the other between the slaughter-house and sheep-pen; but neither were ready at the commencement of the siege, and want of labour prevented their being completed afterwards.

Heavy and light guns and mortars, more or less protected by parapets, were placed in various positions intermediate to the above-mentioned principal batteries. Those positions are marked in the annexed sketch, though of course various changes occurred during the siege; a gun or mortar having been frequently required to silence an enemy's battery and withdrawn when the object was accomplished.

Mr. Gubbins, by means of labourers procured by his subordinates, carried on the defences of his own compound; and the general line round our position was continued from battery to battery, and house to house, by abattis (in lanes), and by parapets and ditches, or stockades.

Outside our line of works also a great amount of labour was required. Masses of buildings extended to within a few feet of us in nearly every direction, and though some of them would act as traverses to us from the enemy's batteries, the majority were a most undoubted source of annoyance to us, and it was necessary to proceed with their removal as vigorously as our means permitted. Several mosques, which occupied positions commanding us, were left alone, much to our future injury; but I believe the reason that prevented their removal was a good one, namely, the danger of precipitating an outbreak before we were prepared for it. But, apart from this, the demolition of private buildings was far from complete. The affair of Chinhut brought the enemy upon us earlier, I believe, than was anticipated by any individual of our force, and our command of labour having been limited, we had to close our gates with nothing in many places separating us from the besiegers but the width of the streets. The houses that remained became nests of rebels, and besides forming secure starting points for their mines, enabled them from under shelter to keep up a deadly fire of musketry upon us day and night, and it is to it, and not to round shot, that we have to attribute the greater part of our casualties. The latter was mainly injurious in destroying the buildings occupied by our troops and camp followers; and, though the loss of life, considering the amount of battering they sustained, was much less than was to be expected, it was a constant source of danger and annoyance to the garrison, and the repair of damage entailed heavy labour on men who were weakened by exposure and want of rest.

The enemy proceeded to invest the place immediately on the return of our force from Chinhut on the 30th June. The Muchee Bowun was still garrisoned by our troops, though the treasure and greater portion of the munitions and stores had been previously removed to the Residency, and it now became an object of primary importance to withdraw the garrison without loss. A telegraphic message was communicated to Lieutenant Innes, the Engineer Officer, to the effect that the powder in the magazine, about 200 barrels, was to be used in blowing up the fort, and that the garrison was to leave at midnight on the 1st July. This order was carried out with perfect success, and the garrison marched into our gates without the loss of a man.

The Garden Battery was one of the first established by the enemy. It played on the Guard House at the Cawnpore Battery, the Battery itself, Brigade Mess, Anderson's, and Judicial Commissioner's. The combined fire of heavy guns and musketry on the Cawnpore Battery became so deadly that our guns could not be served, and eventually it was thought necessary to withdraw them and to leave the position to be defended by musketry, and to repair the parapets as fast as they were damaged by the enemy's round shot.

At the beginning of the siege, the 8 inch howitzer which fell into the enemy's hands at Chinhut, was placed out of sight of our guns on the opposite bank of the river near the bridge of boats, and kept up a destructive fire on the Residency. It was by one of the shells from it that Sir Henry Lawrence was killed.

Batteries were also established by the enemy on the road leading from the iron bridge, in front of Gubbins's House, the Brigade Mess, and Post Office, and at the Clock Tower, and all the buildings were more or less damaged by them. A portion of the Residency was battered down, and six men were buried in the ruins. Many of the buildings were reduced to such a state as to appear to be quite untenable, but the garrison continued to occupy nearly all; and though the defences of the posts have been very much weakened by the continued and heavy fire, not a single one has been abandoned; on the contrary, several buildings (Financial Commissioner's, Sago's, and Innes's) have been occupied and strengthened *since* the commencement of the siege.

When the enemy found that neither by repeated attacks, nor the destruction of our buildings, he could force us from our posts, he had recourse to mining. This had been anticipated, but the chief engineer, acting under the suggestion of the late Captain Fulton, would not take the initiative, as he apprehended that our enemies would at once follow our example, and that the unlimited command of labour they possessed would give us a poor chance of competing with them.

The first mine exploded by the enemy was at the Redan (20th July). It preceded a general attack, and both as regards direction and distance was a complete failure. This was followed by one at the angle of the Seikh Square, and is the only one from which any loss of life on our side has been sustained. The sound of the mining had not been heard owing to the proximity of the cavalry horses, and the guard were completely surprised (27th July). Seven drummers were killed on this occasion.

Two other mines, at the building occupied by the Martinière boys and at Sago's, were also exploded (10th August), but beyond breaking the outer line of walls, did no damage. The enemy in no case showed any great alacrity in assaulting the breaches, and we soon formed retrenchments in rear of them.

We had, meanwhile, commenced countermining, and on the 5th August foiled a mine of the enemy's against the Guard House at the Cawnpore Battery, and since then, up to the arrival of the relieving force, we have been incessantly employed in mining and countermining. We have generally worked into their galleries, and after having frightened the miners away, have destroyed them, or, in some cases, we have blown in their galleries by charging and firing our own. I need hardly add that this was a service of danger.

Two of our mines, for directly offensive objects, require separate notice: the one at Sago's, to the enemy's guard-room, which we blew down with a loss to them of, it is supposed, between twenty and thirty men: the second, to Johannes' house, in which we destroyed above eighty of the enemy. This explosion was followed by a sortie to cover the demolition of the remainder of the house and one adjoining, which object was effectually accomplished, and relieved us from the destructive fire of many of the enemy's best marksmen. I may mention that several sorties were made on other occasions, and with equal success.

We had, on the arrival of the relieving force, fifteen galleries ready for countermining further operations of the enemy. Several of the enemy's galleries have since been discovered and destroyed.

I believe I have now noted every measure of importance with reference to the defence and attack of the place in an engineering point of view, and it remains for me to state the means at our disposal for carrying on work.

During the early part of the siege we had working parties of Her Majesty's 32nd Regiment. On one work, during the night, I have had forty-two men. The soldiers, however, had their other duties to perform, they were exposed to rain, and were very often under arms, which prevented their having a proper amount of rest. They could therefore have little physical strength left to work in the trenches, and as the siege progressed their numerical strength became so much reduced that it was necessary to give up European working parties almost entirely, and to depend on the Sepoys. The latter came forward most willingly, and I cannot speak too highly of the way in which they worked. They have also been of material assistance in our mining operations, and a party of the 13th Native Infantry—thanks to the good management of Lieutenant Aitken—have constructed a battery for an 18-pounder, worked the gun, and dug a shaft and gallery at their own post.

There has been but one squad of European miners (eight men under Sergeant Day), all of whom have worked with the most unremitting zeal throughout.

As regards general superintendence, the late Major Anderson, Chief Engineer, designed the defences of the Muchee Bowun and Residency, and until shortly before his death, directed the construction of the various works and repairs.

Captain Fulton became the Senior Engineer Officer on the demise of Major Anderson on the 11th August. He had constructed the greater portion of the defences, powder magazines, &c., and up to the day of his death displayed the most unremitting energy, in spite of bad health, in advancing our work. In particular he took a most active part in foiling the enemy's attempt to destroy our advanced post by mines, and the manner in which he conducted the blasting operations during our sorties, invariably excited the admiration of all who were present, officers and men.

In the performance of the above-mentioned, and engineering operations generally, he received the most able and untiring support from Lieutenants Hutchinson, Innes, and Tulloh, and the late Lieutenant Birch, and latterly, since Captain Fulton's death, I have received much assistance from Lieutenant Hay, Assistant Field Engineer. The active part I myself have taken in the superintendence of works, has been small, owing to my having suffered from continued ill health.

Finally, I beg to bring to the notice of the Brigadier the excellent service performed by the late Mr. Casey, head accountant to the Chief Engineer, who had been Sergeant Major of Sappers, and who was recommended by Major Anderson for the rank of Assistant Field Engineer; of the late Mr. Supervisor Barrett; Mr. Beale, Overseer; and Sergeant Ryder, Assistant Overseer—all of whom have left families behind them.

J. C. ANDERSON, Lieutenant,
Garrison Engineer.

EXTRACT FROM A REPORT BY MAJOR GENERAL SIR JAMES OUTRAM, G.C.B., ON THE DEFENCE OF LUCKNOW AFTER THE RELIEF OF THE RESIDENCY.

Camp, Alum Bagh, November 25, 1857.

SIR,

I have the honour to acquaint His Excellency the Commander-in-Chief with the proceedings of this force since the 28th of September, the date of my last despatch, and beg to refer to the documents enumerated in the margin. General Havelock has commanded the field force occupying the palaces and outposts, and Brigadier Inglis has continued in command of the Lucknow garrison—an arrangement that has proved most convenient.

The first work required was to open a roadway through the palaces for the heavy train, which had been brought into one of the gardens on the 27th September, and by the 1st October was safely parked within the entrenchment.

Contrary to the expectations expressed in my last despatch, the enemy, relying on the strong position of their remaining battery (the one known as "Phillips' Battery), continued to annoy the garrison by its fire, and to maintain there a strong force. Its capture, therefore, became necessary, and this was effected on the 2nd October, with the comparatively trifling loss of two killed and eleven wounded—a result which was due to the careful and scientific dispositions of Colonel Napier, under whose personal guidance the operation was conducted. Three guns were taken and burst; their carriages destroyed, and a large house in the garden, which had been the enemy's stronghold, was blown up.

With a view to the possibility of adopting the Cawnpore Road as my line of communication with Alum Bagh, Major Haliburton, 78th Highlanders, commenced on the 3rd to work from house to house with the crow-bar and pick-axe.

On the 4th, this gallant officer was mortally wounded, and his successor, Major Stephenson, of the Madras Fusiliers, disabled. During the whole of the 5th these proceedings were continued; but on the 6th they were relinquished, it being found that a large mosque, strongly occupied by the enemy, required more extensive operations for its capture than were expedient; therefore, after blowing up all the principal houses on the Cawnpore Road, from which the garrison had been annoyed by musketry, the reconnoitring party gradually withdrew to the post in front of Phillips' Garden, which has since been retained as a permanent outpost, affording comfortable accommodation to Her Majesty's 78th Highlanders, and protecting a considerable portion of the entrenchment from molestation, besides connecting it with the palaces occupied by General Havelock. During the foregoing operations, the enemy, recovering from their first surprise, commenced to threaten our positions in the palaces and outposts by mining and assaults. As there were only a few miners in the garrison, and none with the field force, the enemy could not be prevented from exploding three mines, causing us a loss of several men; and on the 6th they actually penetrated into the palace in considerable numbers. But they paid dearly for their temerity, being intercepted and slain at all points. Their loss on that day was reported in the city to have been 450 men.

A company of miners, formed of volunteers from the several corps, was placed at the disposal of the Chief Engineer, which soon gave him the ascendancy over the enemy, who were foiled at all points, with the loss of their galleries and mines, and the destruction of their miners in repeated instances.

The Seikhs of the Ferozepore Regiment have zealously laboured at their own mines, and though separated only by a narrow passage (16 feet wide) from the enemy, have, under the guidance and direction of the Engineer Department, defended and protected their position.

The outpost of Her Majesty's 78th Highlanders, under Captain Lockhart, has also been vigorously assailed by the enemy's miners. Its proximity to the entrenchment made it convenient to place it under the charge of the Officiating Garrison Engineer, Lieutenant Hutchinson, under whose skilful directions the enemy have been completely outmined by the soldiers of Her Majesty's 78th Regiment.

I am aware of no parallel to our series of mines in modern war; 21 shafts, aggregating 200 feet in depth, and 3,291 feet of gallery, have been executed. The enemy advanced 20 mines against the palaces and outposts; of these they exploded three, which caused us loss of life, and two which did no injury; seven have been blown in; and out of seven others the enemy have been driven, and their galleries taken possession of by our miners;—results of which the Engineer Department may well be proud. The reports and plans forwarded by Sir Henry Havelock, K.C.B., and now submitted to His Excellency, will explain how a line of gardens, courts, and dwelling houses, without fortified enceinte, without flanking defences, and closely connected with the buildings of a city, has been maintained for eight weeks in a certain degree of security; but notwithstanding the close and constant musketry-fire from loopholed walls and windows, often within 30 yards, and from every lofty building within rifle-range, and notwithstanding a frequent though desultory fire of round shot and grape from guns posted at various distances, from 70 to 500 yards! This result has been obtained by the skill and courage of the Engineer and Quartermaster General's Departments, zealously aided by the brave officers and soldiers who have displayed the same cool determination and cheerful alacrity in the toils of the trench and amidst the concealed dangers of the mine that they had previously exhibited, when forcing their way into Lucknow at the point of the bayonet and amidst a most murderous fire.

But skilful and courageous as have been the engineering operations, and glorious the behaviour of the troops, their success has been in no small degree promoted by the incessant and self-denying devotion of Colonel Napier*—who has never been many hours absent by day or night from any one of the points of operation—whose valuable advice has ever been readily tendered and gratefully accepted by the executive officers—whose earnestness and kindly cordiality have stimulated and encouraged all ranks and grades, amidst their harassing difficulties and dangerous labours.

I now lay before His Excellency Brigadier Inglis's report of the proceedings in the garrison, since its relief by the force under my command, since the capture of the enemy's batteries, and the occupation of the palaces and posts.

The position occupied by the Oude Field Force relieved the garrison of the entrenchment from all molestation on one-half of the enceinte—that is from the Cawnpore Road to the commencement of the river front; and the garrison, reinforced by detachments of the 78th and Madras Fusiliers, was enabled to hold as outposts three strong positions commanding the road leading to the Iron

* Now Major General Sir R. Napier, K.C.B.

Bridge, which have proved of great advantage, causing much annoyance to the enemy, and keeping their musketry fire at a distance from the body of the place.

The defences, which have been barely tenable, were thoroughly repaired, and new batteries were constructed to mount 13 additional guns.

The enemy, after the capture of the batteries, adopted a new system of tactics. Their guns were withdrawn to a greater distance, and disposed so as to act not against the defences, but against the interior of the entrenchment.

The moment they were searched out and silenced by our guns their position was changed, so that their shot ranged through the entrenchment; and but for the desultory nature of their fire might have been very destructive."

Report on the Engineering Operations, by Major Crommelin, C.B., Bengal Engineers.

Lucknow, November 12th, 1857.

Sir,

I have the honour to submit for the information of Brigadier General Havelock, C.B., Commanding the Oude Field Force, a brief narrative of the engineering operations that have been carried on at the palace and gardens of the Chutter Munzil since our occupation of the same up to the present date.

2. Instead of presenting this sketch in the shape of a journal (for which indeed my data are very incomplete), I have determined upon adopting the more simple and intelligible plan of describing the operations under the four following heads, viz.:—"General Defensive Operations;" "Operations at advanced Garden;" "Mining Operations," and "Final Offensive Operations."

The two accompanying Plans, marked A and B, will illustrate the Report.*

General Defensive Operations.

3. It would serve no useful purpose to swell this report, by detailing all the numerous petty operations that fall under this head, such as "Preparing roads for passage of guns;" "Piercing loop-holes in walls of houses and courts;" "Barricading passages and isolated doors or windows;" "Opening out communications between posts and picquets;" "Providing screens at various places against musketry fire," &c., &c., &c.; but the following more important works are deserving of separate notice:—

1st.—On the 8th October, the rebels attacked one of our advanced picquets at A; they were repulsed immediately with loss to themselves; but it was considered advisable to disconnect the close communication that existed between their position and ours. To effect this end a charge of 200 lbs. of powder was laid, under the superintendence of Colonel Napier (Chief of the Staff), at much risk and with considerable difficulty, in a vaulted chamber, under some apartments

* It has not been considered necessary to reprint these plates, but the letters of reference have been inserted in the Plan at the end of the next Paper.—Ed.

adjoining our position and occupied by the enemy. The result of the explosion was most satisfactory; the positions were entirely separated, and a clear view opened down the Khas Bazaar Street.

2nd.—The roof of the picquet above alluded to, serving as a post and road of communication to other points, being exposed to the fire of a 9-pounder gun, posted in the Khas Bazaar Street at a distance of 300 yards, a sand-bag parapet, about 8 feet thick at the base and 4 feet at the crest, was erected in one night along the end of the roof, and has since remained proof against the repeated rounds that have been fired at it from the gun.

3rd.—A battery B for two 9-pounder guns has been constructed at the end of the lane to the south of the Lall Bagh, to sweep down the lane, in the event of the enemy forcing the advanced barricade at C.

4th.—A barricade D, 72 feet in length, composed of boxes, doors, and tent poles, with an embrasure for a single gun, has been constructed at the north-west corner of the Pyne Bagh, connecting the Lall Baradurree with the Jail. This barricade serves the double purpose of a defence against any attack of the enemy by the Pyne Bagh; and as a covered way from the palace to the road that runs direct by the Clock Tower to the Baillie Guard entrenchment.

5th.—A barricade E, similar to the above, 60 feet in length, but without a gun embrasure, has also been constructed close to the most advanced picquet on the water face of the Lall Bagh, to prevent the passage of the enemy down the broad terrace between our palace position and the river. There is a corresponding barricade further up stream, near the Baillie Guard entrenchment.

6th.—The whole of the exposed doors and windows of the Lall Baradurree, Furrad Buksh, and Chutter Munzil Palaces have been provided with shot-proof barricades, composed of boxes and sand-bags. 34-pounder shot, fired from a distance of about 400 yards, have twice struck the top or weakest part of one of the Lall Baradurree barricades, at a height of 10 feet. The sand-bags were on both occasions thrown inwards, but the shot fell harmless on the ground close to the foot of the barricade. At a height of 8 feet those barricades might be considered quite shot-proof.

7th.—On the terrace of the Mosque F, three strong lines of barricades, composed of doors, sand-bags and tent poles, have been constructed, in order that the utmost extent of the Mosque might be defended, in the event of the enemy destroying any portion of it before our countermines could be completed. The enemy succeeded in blowing down the corner of the Mosque (at A); but the explosion tended rather to strengthen than weaken our defensive position, and did not reach even our most advanced line of barricades. A shot-proof parapet was also constructed along the east front of the Mosque, as a protection against a battery G that the enemy commenced, but have not as yet completed, at a distance of 200 yards down the Cheena Bazaar.

8th.—The gateway and picquet house at the end of the lane to the south of the Lall Bagh have been strongly barricaded.

9th.—A Cavalier battery for one heavy gun has been commenced immediately behind the above-mentioned gateway, and is in course of construction.

Operations at Advanced Garden.

4. On the 5th of October, the enemy breached the south face of the advanced garden at *H*, and made an unsuccessful attack at that point. A retrenchment (*a*) was immediately constructed, and has since been rendered shot-proof. A trench (*b*) facing the breach, and extending from the house in the centre of the garden to the east wall, was also constructed for the shelter of a strong guard. A third trench (*c*) for a strong guard, with a communicating trench (*d*), from the gate of the garden, were at the same time constructed, and also a battery (*e*) for two 9-pounder guns to sweep the breach *H*.

Shortly after having formed the breach *H*, the enemy burnt down the gate *K*, in the centre of the east face of the garden, and enlarged the opening by a few round shot. This new breach was at once barricaded, and a retrenchment (*f*) thrown round it, debouching from trench (*b*).

Subsequent to the above operations, the following works were taken in hand and gradually carried to completion :—1st. A trench of communication (*g*) from the gate *L* to the Vinery, near the right advanced picquet *M*. 2nd. A trench of communication (*h*) from the Vinery, to the south-west corner of the garden house. 3rd. A trench (*i*), with double parapet and traverses, running parallel to the north wall from trench (*c*) to the east wall. 4th. A trench (*k*) with traverses, running parallel to east wall, and connecting trench (*i*) with retrenchment (*f*). 5th. A battery (*l*) at the north-west corner of the garden house, for three guns to bear upon the breach *H*, and to oppose two batteries that the enemy had erected outside and opposite to the southern end of the east wall. 6th. A battery (*m*) for two howitzers to assist the foregoing one. 7th. A battery (*n*) for two guns to sweep any breach that the enemy might make in the walls, near the north-east corner of the garden. 8th. The doors and windows of both centre garden house and picquet house *M* have been strongly barricaded with sand-bags and boxes. And lastly, a Cavalier Battery, with six embrasures for heavy guns, to sweep the opposite bank of the river, and the several posts of the enemy, in front of the garden, has been commenced and is drawing to completion.

The whole of the trenches are unrevetted, and were constructed by simple sapping. The batteries are revetted with boxes and doors.

The working parties employed were small, and were composed of men totally untrained to such duties, viz., European and Native soldiers drawn from the different Regiments, and Doolie Bearers.

Mining Operations.

The enemy very shortly after our occupation of the Palaces, showed a disposition to annoy us, as much as possible, by their mines. On the 5th October (as before mentioned), they effected a breach in the south wall of the advanced garden. On the 11th idem, they breached a portion of the boundary wall on the east face of the Sikh position, and on the 17th idem, they succeeded in destroying an upper story room, in front of the Mosque *F*. Our limited supply of gunpowder prevented our retaliating by offensive mines; so we determined upon encircling the whole of that portion of our position, open to attack by mines, with a system of defensive or listening galleries, from which we could discover the approach of the enemy's miners, and break into their mines or destroy them by small charges of powder before they could reach our boundary. Volunteer miners were accordingly called for from the several regiments, and on the 18th of October we started work at five mines, with a force of 51 European soldiers and 48 Sikh sepoys. Subsequently this force was strengthened by three other gangs, consisting of 54 doolie bearers and gun bullock drivers. The number of shafts and galleries that have been completed are as follows:—

Nine in the Sikh position (marked 1 to 9 on Plan), giving an aggregate of 73½ feet of shaft, and 540½ feet of gallery.

Four for the protection of the Mosque picquet A, and adjacent buildings (marked 10 to 13), giving 32½ feet of shaft and 585½ feet of gallery.

Two for the protection of the buildings along the lane to the south of the Lall Bagh (marked 14 and 15), containing 16 feet of shaft and 514 feet of gallery.

Two, marked 16 and 17 for the lane barricade, and south wall of advanced garden, with branches for offensive mines, giving 15 feet of shaft and 765 feet of gallery.

Two, marked 18 and 19, for the east face of garden, giving 16 feet of shaft, and 387 feet of gallery.

Total of shaft 152 feet; ditto of gallery 2,791½.

The shafts average 8 feet in depth, and the general section of the galleries may be set down as 3 feet in height by 2 feet in breadth, with an arched roof. We found the soil to be generally light and sandy; still the greater portion of the galleries were run without casing, although occasionally it was found absolutely necessary to resort to rough open casing. I may here mention, as an extraordinary fact that two galleries were run respectively to lengths of 298, and 192 feet, without the aid of air tubes; in the latter the lights burned well, but in the former the men were obliged to work in the dark, and were somewhat (though not greatly) affected by the foulness of the air. In working these, we occasionally withdrew the miners for an hour or two, in order to purify the galleries. The daily progress in each gallery varied from 13 to 20 feet.

The utility of the above-mentioned galleries has proved most marked. On eight different occasions the enemy were heard mining towards our position. We waited patiently and quietly until their miners broke into our gallery. We then fired on them through the opening, wounding several, and in every instance we captured their galleries and tools, and then destroyed the former without using any powder. On two other occasions, when the enemy were heard approaching, we commenced running out short branches from our own galleries, in order to lodge charges for blowing in those of the enemy. Their miners in both enclosures abandoned their galleries. Our success has so alarmed the enemy that they have latterly been afraid to approach near our position, and have twice exploded charges at ridiculously long distances from the works that they intended to destroy, indeed nearer to their own buildings than to ours. I may say that since we commenced our listening galleries, the enemy have failed to do us any injury with their mines, and that our exposed front has remained perfectly secure.

Our offensive operations that are now in progress, and which I trust will prove conclusive, will form the subject of a future communication, in which I will take the opportunity of bringing to the notice of the Brigadier General Commanding the names of those officers and men of the department who have rendered good service.

I have, &c.,
W. A. CROMMELIN, Captain,
Chief Engineer, Oude Field Force.

REPORT ON THE ENGINEERING OPERATIONS, BY MAJOR CROMMELIN, C.B.

Camp Alum Bagh, November 25th, 1857.

SIR,

In continuation of my letter dated 12th instant, I have the honour to report, for the information of the Major General Commanding the Oude Field Force, upon the "Final Engineering Offensive Operations" at the palace and gardens of the Chuttur Munzil.

The Cavalier Battery, alluded to at the conclusion of my previous report, was completed during the night of the 13th instant, and was armed with the heavy guns on the morning of the 14th, viz., the day originally appointed for the storming of the Hern Khana, Engine-house, and King's Stables.

During the night of the 13th, 29 charges of powder (each 25 lbs. in weight) were laid in chambers that had been previously prepared for them, under the foundation of the east face of the advanced garden wall, and immediately in front of the Cavalier Battery. These charges were intended for the demolition of that part of the wall that screened the Engine-house, Stables, and the other adjacent buildings, that were to be breached from the guns of the battery. I would here remind you that our attack was postponed from the morning of the 14th to that of the 16th. The charges of powder were thus exposed, in common canvas bags, for more than forty-eight hours, to the damaging influence of a very damp sandy soil; so that when they were exploded, their effect, owing to the deterioration of the powder, was only sufficient to shake and split the wall in several places, and to form a small breach. The wall, however, was so much injured, that the artillery had an easy task in battering down as much as was necessary. The charges, I may mention, were half as large again as those recommended by Sir W. Pasley (our best practical authority on this as well as most other points of engineering detail), and were such as had been successfully used by myself, at Peshawur, in a precisely similar case.

During the night of the 12th and 13th, the trench (*d d*) was widened for the passage of guns; screens were also constructed in the advanced garden; and other precautionary measures taken, to protect our force against any musketry fire that might be poured in through the breaches in our own wall.

During the 15th the three mines that had been prepared for the formation of breaches in the Hern Khana, were loaded and tamped. These mines were sprung on the afternoon of the 16th. That at the north-west corner of the building effected the breach by which the right and centre columns of attack entered. Lieutenant Hall, in his report, erroneously states that this breach was made by the 18-pounder gun at the barricade.

The centre mine failed to explode, owing, I imagine, to some wet sand having been dislodged from the roof of the mine, by the concussion of our artillery, and having fallen upon the powder hose.

The left charge, which was the largest, exploded; but it proved to be 10 feet short of the building, and consequently effected no breach or injury. This error in the position of the charge is not to be wondered at, when it is considered—1st, that we could not, by the most careful survey, satisfy ourselves as to the exact position of the Hern Khana; and, 2ndly, that we could not survey the mine itself with the prismatic compass, as no lights would burn, owing to the foulness of the air near the end of a gallery that had been carried to the (I believe) unprecedented length of 289 feet, without the aid of air-pipes.

On the morning of the 16th everything was ready for the attack upon the Hern Khana, Engine-house, and Stables. Copies of instruction, the details of which had been prepared by myself, from memoranda drawn out by Colonel Napier (Chief of the Staff), were handed over to each of the five officers commanding the storming parties, and to the engineer officers accompanying them; and these instructions were further explained, by the aid of plans, to several of the commanding officers.

For an account of the operations of the storming parties, I must refer to the enclosed reports (in original) of Lieutenants Hutchinson, Russell, Limond, and Hall, with the remark that the duties of the officers under my command appear to me to have been rapidly and efficiently carried out.

I must also refer to a separate report by Lieutenant Hutchinson, directing engineer, upon the engineering operations, from the 16th November to the hour of our evacuation of the Bailey Guard Entrenchment and the Chutter Munzil Palace—confinement to my quarters owing to an injury of the leg, having prevented my superintending them personally.

It now remains for me to bring to the favourable notice of the Major General Commanding, those officers and men of the Engineer Department who have rendered good service; and, in the first place, I trust it may not be considered out of order that I hereby thankfully record my acknowledgment of the assistance that has always been afforded me by my experienced brother officer, Colonel Napier, Military Secretary and Chief of the Staff to Major General Sir James Outram, G.C.B., who, notwithstanding the pressure of his other important duties, was ever ready to aid me with his valuable counsel and advice, to meet my constant demands for workmen and materials, and to superintend and direct the works during the last month of our operations, when I was disabled from personally superintending them myself.

Lieutenant G. Hutchinson, of the Engineers, deserves very great credit for the very able manner in which he discharged the duties of Directing Engineer of the works, during the last ten days of our operations. His services, as one of the engineers of the original garrison, will be duly reported by the proper authority.

Lieutenant Russell, of the Engineers, has rendered me very efficient aid as Brigade Major of Engineers; his constant and unwearying exertions, both by night and by day, merit my best thanks and the highest praise.

Lieutenant Limond, the only other Engineer officer under my command, has also proved himself a very able and energetic officer, and has rendered very excellent service. To him, and to Lieutenant Russell, was entrusted the general supervision of all the works from the time that I was disabled until the appointment of Lieutenant Hutchinson as Directing Engineer—a period of about three weeks.

The officers and volunteers that have acted in the capacity of Assistant Field Engineers have, without exception, given me their best and readiest assistance; but I may with justice more conspicuously notice the names of Captain Oakes, 8th Native Infantry; Lieutenant Hall, 1st Bengal Fusiliers; Mr. Coldsworthy, Volunteer Cavalry; and of Mr. Cavanagh, Superintendent of the Chief Commissioner's Office.

Sergeants Duffy and Connell, Assistant Overseers in the Department of Public Works, have proved most useful, and their duties in supervising workmen and collecting materials, &c., &c., have been most cheerfully and efficiently performed.

I cannot close this report without noticing, in the most favourable manner, the important services performed by the under-mentioned soldiers, as superintendents of miners:—

Acting Sergeant Cullimore, " " Banetta, " " Farrer, Corporal Dowling,	Her Majesty's 32nd Regiment.

" Hosey, Madras Fusiliers.
Private Baylan, Her Majesty's 5th Fusiliers.

Their duties have been of a very dangerous and arduous character, and have invariably been performed to my complete satisfaction."

I have, &c.,
W. A. CROMMELIN, Captain,
Chief Engineer, Oude Field Force.

EXTRACT FROM A MEMORANDUM OF WORK EXECUTED AT CAPT. LOCKHART'S POST, FROM THE FIRST POSSESSION OF IT UNTIL THE 21ST OF NOV., 1857,

BY LIEUT. G. HUTCHINSON, BENGAL ENGINEERS.

Barricades were at once and primarily erected at all outlets, and loop-holes cut along all the walls.

Doorways of communication were opened between the three main houses, which originally were distinct buildings, and such arrangements made as enabled us to command to the utmost the ruins on the right and left of our position.

A cannon-proof barricade was erected across the Khas Bazaar, communicating with the post of the 84th, and an embrasure opened through it for a gun: a second barricade was afterwards placed across the Cawnpore Road.

The enemy commenced mining against us at *H* on the left of our position, about six days after our occupying the post. We sunk a shaft, preparatory to driving a gallery, to meet them; but before we could complete the shaft, the enemy exploded a very large charge of powder, some 10 feet short of our outer enclosure wall, which had the effect of shaking down the wall and filling up our shaft, by the masses of earth thrown into the air and descending into our shaft. I regret to say we lost one man in this shaft. By some fatality, though the men on duty and at the mine saw the enemy's train burning, and volumes of smoke issuing out of the houses, from which they knew the enemy were mining, they did not move from the spot, but merely sent to report to their officer. We were prepared for the explosion, and had the enclosure already barricaded off, so that the enemy gained nothing by the mine.

From this time up to within the last six days, we have been almost constantly at work day and night, countermining against them.

Our general success has been very good, having held our ground with an expenditure of but 200 lbs. of powder, and resisted numerous attacks of the enemy's miners.

On two particular occasions our success was more than usual. A gallery, driven from our shaft *C*, intercepted a gallery of the enemy's, and our explosion completely cut off some 12 feet of it; so that the next morning, on breaking into the portion so cut off, we dug out, or rather dragged out, four dead bodies, the enemy's miners having been completely cut off in a tomb, as it were, for the gallery they were in was not broken down, but stopped up by our explosion.

In the other case our operations commenced from shaft *D*.

We broke into their gallery some 12 feet from our wall about 12 o'clock at night, and Sergeant Day, our Superintending Miner, remained below, assisted by others, holding the entrance to their gallery until I arrived.

On entering the enemy's gallery, I took Corporal Thompson, of the 78th Highlanders, with me, and observing the apparently great length of the enemy's mine, proceeded cautiously to extinguish the lights, so as to keep ourselves in darkness as we advanced. At this time the enemy were in the mine at or near their shaft, which, contrary to their usual practice, they evidently wished to hold uninjured. They usually fill them in at once when we take their galleries.

I proceeded, extinguishing the lights, until I distinctly saw the enemy at the far end: and to advance further would be to advance in a blaze of light. I therefore lay down and waited, as our preparations above, carried on under Lieutenant Tulloch, were not yet ready. Whilst lying there, I saw a sepoy with musket at trail advance down the mine, and when within 40 feet of him, fired at him. My pistol missed fire, and before Corporal Thompson could hand me his pistol the sepoy had retreated. After remaining some time longer, I placed another man with Corporal Thompson, and went up to get an officer down, as I felt it required a very steady man down there to support us. While we were laying the charge, and making various arrangements, which utterly precluded our watching against an enemy's advance at the same time, Lieut. Hay, of the 78th Highlanders, then commanding the picquet, kindly volunteered and took up my old post. Lieutenant Tulloch and Sergeant Day quickly got the powder down, and all arrangements having been made, we withdrew Lieut. Hay behind the partial barricade we had formed; and whilst here, still watching with Corporal Thompson, he got two shots at another man who attempted to come down the mine, and apparently wounded him. The enemy made no more attempts to come down the mine, but went outside their building, and came over our heads, apparently with the intention of breaking through. After a quarter of an hour's walking over head, they, I conclude, could not find the direction of the mine, and retreated into the house.

Our charge of 50 lbs. which I laid outside our barricade at a point 82′ along the enemy's gallery, was soon tamped, and the charge fired by Lieut. Tulloch. The charge being laid with nine feet of sand-bag tamping behind it, and none in front, the main force of the powder acted towards the enemy's shaft, but it destroyed the gallery for 40′ towards us, leaving us a length of 40′ to use as a listening gallery. I deduce the enemy's mine to be 200 feet long and upwards, from the reconnoitring of Lieutenant Hay and myself before we commenced laying our charge, and from the position of the houses it came from. The gallery had numerous air-holes and was thoroughly ventilated.

I was much indebted to Lieutenant Hay and Corporal Thompson in this business, and also to Lieutenant Tulloch, who himself also fired the mine—a somewhat difficult task, as our hose being short, he had to retreat some sixty feet through the enemy's gallery and ours, and then out of the shaft. Such is a brief account of our mining operations."

PAPER X.

REPORTS ON THE ENGINEERING OPERATIONS AT THE SIEGE OF LUCKNOW, IN MARCH, 1858,

BY MAJOR GEN. SIR R. NAPIER, K.C.B., COL. HARNESS, C.B., AND LIEUT. COL. LENNOX, ROYAL ENGINEERS.

REPORT FROM THE CHIEF ENGINEER, NOW MAJOR GENERAL SIR R. NAPIER, K.C.B., TO THE CHIEF OF THE STAFF.

La Martinière, 31st March, 1858.

SIR,

I have the honour to submit a Report of the Engineer operations at the Siege of Lucknow, accompanied by a map, and also a Report by Colonel Harness, commanding the Royal Engineers, of the operations in detail which were conducted under his immediate directions by officers of the corps under his command.

The City of Lucknow stretches in an irregular form on the right bank of the Goomtee, for a length from east to west of nearly five miles, and an extreme width at the west side of one and-a-half miles; the east side diminishes in width to less than one mile.

2. Two bridges, one of iron, and the other of masonry, span the Goomtee, leading the traffic of the country from the north of the Goomtee into the heart of the city.

A canal of deep and rugged section, enclosing the city on the east and south sides, bears away to the south-west, leaving the approach to the west side of the city open, but intersected with ravines; towards the north-east, where the canal joins the Goomtee, its banks are naturally shelving and passable.

The city is too extensive to be commanded by any single point, and has no such predominant feature as would imperatively direct the attack.

The important positions are:—

1. The Kaiser Bagh (*A*) or Royal Palace, about 400 yards square, containing several tombs and ranges of buildings; not originally fortified, but strengthened since the last occupation of the Residency by British troops.

2. The Ferhad Bux (*B*), and adjoining palaces, occupied by the British troops under Outram and Havelock.

3. The Residency (*C*).

4. The ruins of the ancient Fort, called the Muchee Bowun (*E*), commanding the Masonry Bridge, and situated on the south side of it.

5. A series of strong buildings; the Juminia Bagh (*F*), the Shesh Mahal* (*G*), and Ali Nukki Khan's House (*H*), extending to the west along the right bank of the river, and more or less surrounded by streets and houses.

6. The Imambarah and a range of palaces (*I*), stretching from the Kaiser Bagh eastwards towards the canal.

7. A mile and a half west of Ali Nukki Khan's House, lies the Moosah Bagh (*K*), a walled enclosure and country house.

8. On the east side of the city beyond the canal, stands the Martinière (*L*), a fine range of buildings.

9. On the brow of a table land overlooking the Martinière and the eastern suburbs, is the Dilkoosha House.

In recommending the east side for attack, I was guided by the following reasons:—

The west side presents a great breadth of dense, and almost impenetrable city, resting on the strong buildings on the river bank. After overcoming these obstacles, there would have remained the Kaiser Bagh, with the enemy's principal defences still to be reduced.

The east side offered—1st, the smallest front, and was therefore the more easily enveloped by our attack; 2ndly, ground for planting our Artillery, which was wanting on the west side; and 3rdly, it gave also the shortest approach to the Kaiser Bagh (the Royal Garden), a place to which the rebels attached the greatest importance; more than all, we knew the east side and were little acquainted with the west.

The enemy, profiting by experience, had strengthened their defences by works exhibiting prodigious labour. Sir Colin Campbell's former route across the canal, where its banks shelved, was intercepted by a new line of canal of very formidable section, flanked by strong bastions. This line of defence was continued up the canal beyond the Char Bagh Bridge† (*M*), more or less complete, and the banks of the canal, as before noted, were scarped and impassable.

A strong battery for three guns, resting against a mass of buildings (*N*), called the Huzrut Gunj, supported the outer line, at the junction of three main roads.

A second line of bastioned rampart and parapet rested with its right on the Imambarah (*O*), a strong and lofty building; thence embracing the Mess House (*P*), it joined the river bank near the Motee Mahal (*R*).

A third line covered the front of the Kaiser Bagh (*S*).

The enemy were represented to have about 100 guns, a report which was doubted, but has proved quite true.

The bastions on the outer line of defence were not fully armed; the enemy seemed waiting to ascertain our real point of attack, before bringing forward their guns.

All the main streets were also commanded by bastions and barricades, and every building of importance, besides being loophold, had an outer work protecting its entrance.

* These buildings are to the west of the Muchee Bowun and are shewn in the plan opposite to page 38, Vol. IX, of this Series.—Ed.

† The Char Bagh Bridge is about 3,000 yds. to the west of the Dilkoosha Bridge.—Ed.

It was ascertained, as one part of the city after another fell into our hands, that it had been the intention of the enemy to offer a very determined resistance, even after their outer lines should be taken. Houses far in the depths of the commercial parts of the city were found carefully defended with mud walls and parapets, several mounting guns; and in addition to vast quantities of gunpowder found lying in large buildings, almost every house had its own small supply.

MEANS FOR THE ATTACK.—Ordnance.

Naval Brigade.		
Guns	8-in.	6
Ditto	24-pdrs.	8
Howitzers	8-in.	2
Artillery.		
Guns	24-pdrs.	8
Ditto	18 „	8
Howitzers	10-in.	4
Ditto	8 „	6
Mortars		43

A complete Engineer Park, with materials for two cask bridges, calculated to bear the heaviest ordnance.

Having in my possession a very accurate survey of part of the city and its environs, by the late Lieutenant Moorsom, of Her Majesty's 52nd Regiment, and being aided by the excellent information received from the Intelligence Department, attached to Major General Sir James Outram, G.C.B., I was enabled at a very early period of the operations to determine which side of the city offered the greatest facility to our attack.

Formidable as the defences thrown up by the enemy on the eastern side of the city were described to be, it still appeared most evident that they were in reality obstacles less difficult to be overcome than the heavy and dense portions of the city to the west; and I would add here that though I hardly gave full credit to the native statements as regards the sections and extent of the enemy's works, yet it has proved on inspection that the intelligence given me was remarkably good and clear.

The side of attack being fixed, the two next steps of primary importance were, after taking up a position in the Dilkoosha Park, to bring a direct fire on those points in the enemy's fortifications in rear of the canal the fire from which would affect the line by which we should cross them, and to enfilade those fortifications from the left bank of the Goomtee.

These two operations being completed, and the first line of fortifications in our possession, the next step was to establish ourselves at Banks's House and the *D* Bungalows (*DD*) and from that position to reduce the Begum's Palace (*T*).

A glance at the map will show that this palace is the extreme point of a line of strong buildings, which extend to the walls of the Kaiser Bagh, and secured us a covered way for our safe but irresistible progress into the heart of the enemy's position, turning successfully their second and third lines of fortifications, and avoiding entirely the fire of their artillery.

The elevated gateways and roofs of these buildings, commanding the ground on either flank, would give us the choice of positions for establishing our batteries to bombard the Kaiser Bagh and other parts of the town.

Should the fall of the Kaiser Bagh not entail the abandonment of the city by the enemy, the successive reduction of their strong positions on the banks of the river would be necessary.

Much importance was attached to vertical fire, for which the ample provision of 43 mortars was made in the Siege Train.

The interval which elapsed between the arrival of the Engineer Establishment at Alum Bagh and the commencement of the attack was most valuable, and was profitably employed in preparing a large supply of gabions and fascines, and proving and perfecting the cask bridges; also in practising the Department in the rapid construction of batteries, field powder magazines, &c., &c.

Six guns, forming Battery No. 1 *L*, had been placed in front of the Dilkoosha, to protect the camp, to keep down the fire of the enemy's batteries in their first line of fortification, and check two or three guns that the enemy had advanced to the northern angle of the Martinière.

The first operation of the siege was the construction of two bridges of casks over the Goomtee, below the Dilkoosha House, on the night of the 4th and morning of the 5th March. The officers of Engineers employed were:—Major Nicholson, and Lieutenants Wynne, Pritchard, and Swetenham, Royal Engineers, and Lieutenant Smyth, Bengal Engineers.

On the 6th, General Outram's Division crossed to the left bank of the Goomtee, and encamped on the Fyzabad Road.

On the 7th, it was supplied with the following ordnance for the siege operations on the left bank: four 24-pdrs., four 18-pdrs., four 8-in. howitzers, ten 8-in. mortars; to which were added five 10-in. mortars by order of His Excellency the Commander-in-Chief.

On the 8th, the enemy's fortifications were reconnoitred from the left bank of the Goomtee by His Excellency the Commander-in-Chief, accompanied by the Chief Engineer, Captain Taylor, and Major Nicholson, R.E. During the night a battery for ten guns, *en barbette*, No. 1, *R*, was constructed at the Kokral Bridge, to command the enemy's position near the Race Stand, and opened fire at day-break on the 9th. On the same day General Outram, after defeating the enemy, occupied the whole of the left bank as far as the Badshah Bagh, and established Battery No. 2, *R*, of twelve guns, to enfilade the enemy's first line of fortifications. No cover was required. The enemy made no reply, and abandoned their defences.

Major Nicholson, R.E.
Lieut. Watson, B.E.
" Swetenham, R.E.
" Nuthall, Pun. Prs.

During the night of the 8th, batteries 2, *L*, and 3, *L*, the former of four guns, to batter the Martinière, and the latter of four guns, to silence the enemy's right batteries, were prepared and opened fire early on the 9th.

Two guns of the Naval Brigade were placed under natural cover, to fire on the Martinière, in flank and reverse. After a severe cannonade the Martinière was taken on the afternoon of the 9th with little resistance from the enemy, and a trifling loss.

Capt. Lennox, R.E.
Lieut. Pritchard, R.E.
" Malcolm, R.E.
" Lang, B.E.
" Forbes, B.E.
" Thackeray, B.E.

Lieut. Beaumont, R.E.
Hon. A. Fraser, B.N.I., attached to Engineer Brigade.
Lieut. Lang, B.E.
" Forbes, B.E.

Late in the afternoon the first line of fortifications, having been abandoned by the enemy, was seized by the 42nd Highlanders and Wyld's Sikhs, forming the advance of General Lugard's Division. Our troops penetrated as far as the bridge on the Martinière Road, and secured themselves in a strong position for the night.

Capt. Taylor, B.E.
Lieut. Greathed, B.E.
" Brownlow, B.E.

Early on the morning of the 10th, Battery No. 4, *L*, for four guns, one howitzer, and three 8-in. mortars, was established, with little labour, under natural cover, to breach and shell Banks's House, which was taken the same morning.

In the right attack, Battery No. 3, *R*, for four 24-pdrs., two 8-in. howitzers, and five 8-in. mortars was constructed near the Badshah Bagh, to fire upon the Kaiser Bagh.

Thus, on the morning of the 10th, the enemy's first and most formidable line of fortifications had been completely taken possession of. In the left attack, Battery No. 5, *L*, for four guns and eight mortars, was constructed near Banks's House to breach and bombard the Begum's Palace. In addition to this, two guns (one 8-in. gun and one 8-in. howitzer) of the Naval Brigade, and six $5\frac{1}{2}$-in. mortars, were placed in position in the *D* Bungalows, their fire being also directed against the Begum's Palace and the bastion in front of Huzrut Gunj.

Lieut. Greathed, B.E.
" Brownlow, B.E.

These batteries were erected and the guns brought up with such energy that they opened fire very soon after Banks's House was in our possession.

Lieut. Gulliver, B.E.

Communications were made between the *D* Bungalows and Banks's House.

Major Nicholson, R.E.
Lieut. Wynne, R.E.

On the right attack, roadways for guns were made through the Badshah Bagh; and the Dilaram House (*U*), was seized, and fortified under a heavy fire from the Chutter Munzil.

During the night, a Battery, No. 4, *R*, of four 24-pounders and two 8-in. howitzers, and five mortars, was erected in front of the garden of the Badshah Bagh, and opened fire at day-break on Kaiser Bagh.

Capt. Taylor, B.E.
Lieut. Maunsell, B.E.
" Scratchley, R.E.
" Scott, M.E.
" Smyth, B.E.

The fire from our batteries, which had been continued all night, having made two practicable breaches in the compound wall of the Begum's Palace, and severely shelled the interior, it was taken by assault at 3.30 P.M.

The European Barracks and Kuddum Russool were also occupied on the morning of this day.

A breast-work was thrown up during the night for two guns to fire at the enemy's bastion in their 2nd line of fortifications, which commanded the road leading past the Begum's Palace from Banks's House.

A Serai on the right of this road had been taken at the same time as the Begum's Palace.

A Battery, No. 5, *R*, for two 24-pdrs., was thrown up on the north side of the Iron Bridge, to subdue the enemy's fire from the opposite side of the bridge, and command the Stone Bridge.

On the morning of the 12th, the attacking force on the left then held a strong position in the Begum's Palace, the European Barracks, the Kuddum Russool, the Secundur Bagh, and the Shah Nujjef, whilst the right attack was in position from the Iron Bridge to the Badshah Bagh.

Lieut. Medley, B.E.
„ Lang, B.E.
„ Carnegie, B.E.

Openings were made during the night into Jaffir Ali's compound, *V*, and a serai on the right of the road was occupied in advance of the one taken the preceding evening, together with a mosque overlooking it.

Col. Harness, R E.
Capt. Lennox, R.E.
Lieut. Greathed, B.E.

Four 8-in. mortars were moved into this serai, *W*, and two 8-in. mortars placed in position in its rear, also five 10-in. mortars placed in the serai taken on the 11th inst., the fire from all being directed on the Imambarah and buildings between us and the Kaiser Bagh.

In the right attack a Battery, No. 6, *R*, for four 8-in. guns, was erected in front of the Badshah Bagh to fire on the Residency, and on the buildings extending to the Kaiser Bagh.

Another Battery, No. 7, *R*, for two 24-pdrs., was erected on the left of the Iron Bridge to subdue the fire from the opposite side of the river.

At day-break of the 13th, the house and compound called Jerar-o-Dowlah's, in advance of Jaffir Ali's, was taken possession of, an entrance having been cut through solid masonry during the night.

Colonel Harness, R.E.

A Battery, No. 13, *L*, was formed within 70 yards of the Imambarah, and in Jerar-o-Dowlah's compound, for two guns (one 8-in., one 24-pdr.) to breach the outer wall of the Imambarah. The guns were placed in position in the afternoon, and by evening had effectually breached the outer wall and partly breached the inner.

In the right attack, four 8-in. mortars were added to the armament on the right front of the Badshah Bagh this day, of

10—8-inch mortars.
4—10 do. do.
4—24-pounders.
2—10-inch howitzers.
And on the city from the Iron Bridge Batteries
3—24-pounders.
1—8-inch howitzer.
On the Left we had
5—10-inch mortars.
9—8 do. do.
4—5½ do. do.

directed on the Imambarah and the Kaiser Bagh with the intermediate buildings.

On the 14th March, a heavy fire having been kept up all night on the breaches until 9 A.M. of this day, the breaches into the Imambarah were deemed practicable, and accordingly the building was assaulted and taken at 10 A.M. without much opposition from the enemy.

Col. Harness, R.E.
Capt. Lennox, R.E.
Lieut. Greathed, B.E.
" Beaumont, R.E.
" Lang, B.E.
" Brownlow, B.E.
" Medley, B.E.
Ensign Ogilvy, M.N.I., attached to M. Sappers.

The troops following up this assault by an advance along the road towards the Kaiser Bagh, obtained possession of an outer court-yard of the palace itself, and the Engineer Officers and men were busily employed for the remainder of this day in securing this portion of the Kaiser Bagh, and the Mess House, Motee Mahal, and Tara Kotee, all of which buildings were found deserted by the enemy.

On the right attack we held the same position as yesterday, our batteries principally directing their fire on the Residency and other buildings in advance of the Chutter Munzil.

The 15th found us in possession of all the principal buildings up to the Chutter Munzil between the city and the Goomtee, and of a secure lodgment in the Kaiser Bagh.

Engineering operations were immediately directed to assist the troops through the remainder of the various court-yards of the palace, to complete our communications with the rear, and to clear away such parts of the enemy's works as impeded free and practicable communications between the different posts.

Lieut. Hutchinson, B.E.
" Scratchley, R.E.
" Brownlow, B.E.
" Champain, B.E.
" Smyth, B.E.
" Nuthall, P.P.
" Knowles, P.P.
Mr. May, C.E.

On the morning of the 16th, General Sir James Outram, G.C.B., crossed the Goomtee by the bridge of casks and drove the enemy from the Residency and Iron Bridge, and later in the day seized the Muchee Bowun, Stone Bridge, and Imambarah.

Six 8-inch mortars were immediately placed in position in the Imambarah, and maintained a steady bombardment on the enemy's position in the city throughout the night; two naval guns and five 10-inch mortars were also posted at the Residency, and kept up a steady fire upon the city during the night of the 16th and morning of the 17th.

From this time all siege operations ceased, though parties of the enemy still clung to the streets of the city and suburbs, and were not dislodged till several days afterwards.

I have no precise information concerning the proceedings of the force of His Highness Jung Bahadoor, which acted on the opposite border of the city at too great a distance for its effects to be visible from our line of attack.

On the 17th of March, by desire of His Excellency the Commander-in-Chief, the Goorka picquets were extended from the Char Bagh Bridge down the Cawnpore Road, to connect with those of the British Regiments in the Kaiser Bagh which had advanced half-way between the two points.

The Char Bagh Bridge was repaired by order of General McGregor, material being furnished for the purpose by the Engineer Park, and communication along the Cawnpore Road was completely opened.

It is now my gratifying duty to recommend to the notice of His Excellency the Commander-in-Chief the gallantry and exertions of my brother officers and soldiers of the Royal and the Hon. East India Company's Engineers.

To Colonel Harness, Commanding the Royal Engineers, I am very greatly indebted for his arrangements for reducing the Imambarah, for his energetic exertions and gallantry in securing the Kaiser Bagh, after it had been carried by a small advanced party of our troops, and for his very cordial co-operation and assistance on all occasions.

Major Nicholson, Royal Engineers, conducted most satisfactorily, and with great energy and judgment, all siege operations on the left bank of the Goomtee with the Division under Sir James Outram.

To Major A. Taylor, Commanding Bengal Engineers, I am deeply obliged for his invaluable services and energy in the preparation of the Engineer Park, in which nothing we required was wanting, for his great energy in the arrangements for attacking Banks's House and the Begum's Palace, in which latter operation he was unfortunately wounded, and for his most valuable assistance in all the duties of the siege.

Captain W. O. Lennox, Royal Engineers, conducted the columns in the attack on the Martinière, and was actively employed in securing the Begum's Palace, and in all the subsequent operations, which led to the capture of the Kaiser Bagh, and is especially and honourably mentioned by Colonel Harness, Royal Engineers.

Lieutenant Greathed, Bengal Engineers, was Directing Engineer in the attack on Banks's House, and subsequent operations, including the Kaiser Bagh: and was Field Engineer with General Outram's column at the attack of the Moosah Bagh, and is also especially and most honourably mentioned by Colonel Harness, Royal Engineers.

The following officers particularly distinguished themselves in the several attacks on the enemy, and have materially aided by their gallantry and intelligence in the reduction of the defences:—Lieutenant Beaumont, Royal Engineers, who is also most honourably mentioned by Colonel Harness, Royal Engineers; Ensign Ogilvy, Madras Native Infantry, attached to the Madras Sappers, who was severely wounded at the capture of the Kaiser Bagh; Lieutenants Medley, Hovenden, Lang, Champain, Carnegie, of the Bengal Engineers; Lieutenant Wynne, of the Royal Engineers; also Lieutenant Maunsell, Bengal Engineers, commanding Bengal Sappers and Miners; Lieutenant Gulliver, Bengal Engineers, commanding Punjab Pioneers; Lieutenant Scott, commanding Madras Engineers; and Lieutenant Horsford, commanding Delhi Pioneers, who have taken their share in all active duties in addition to the command of their respective corps.

To Captain Cox, Royal Engineers, Adjutant to the Royal Engineers; to Lieutenant Humphrey, Bengal Engineers, Adjutant to the Bengal Engineers; and to Lieutenant Pemberton, Bengal Engineers, Director of the Engineer Park, my cordial acknowledgments are due for the very efficient manner in which they performed their important duties.

Lieutenant Hutchinson, Bengal Engineers, my Major of Brigade, has been most indefatigable and zealous in the discharge of his duties, and distinguished himself particularly in the capture of the Iron and Stone Bridges, the Muchee Bowun, and the great Imambarah.

My thanks are also due to Lieutenant Scratchley, Royal Engineers, Lieut. Hon. A. Fraser, and Lieutenant Tulloch, Bengal Native Infantry, Assistant Field Engineer, my Orderly Officers, who have attended me in every operation, for their constant valuable services.

I beg to bring to the notice of the Commander-in-Chief Lieutenants Vaughan and Young, of the Royal Navy, for the courtesy and promptitude with which all my requisitions were attended to. Their guns were always to be found in the front the moment they were required. Their fire was directed with an accuracy which nothing could withstand.

To Brigadier Barker, Royal Artillery, Commanding Siege Artillery; and to Colonel Maberly, Royal Artillery; and to Major Carlton, Bengal Artillery, I am deeply indebted for their cordial assistance.

I have deeply to lament the loss of Captain Clerke, a valuable officer, and of fourteen men of the Royal Engineers, who were destroyed by an accidental explosion of gunpowder, which they were removing; also of Lieut. Brownlow, Bengal Engineers, whose gallantry and indefatigable exertions from the commencement of the siege have been most conspicuous, and gave every promise of a distinguished career.

As it is impossible, within the limits of a despatch, to mention individually every officer deserving of notice, I must commend to His Excellency's favourable consideration the valuable services of the officers whose names are not particularly mentioned, and men of the Royal and Honourable East India Company's Engineers.

It would be a great injustice were I to omit my obligation to Captain Orr and Captain Weston, in charge of the Intelligence Department of General Outram's Force, for their very accurate information about the enemy's works, and also to Canoge Lal and Pooran, through whom the information was procured.

During the operations in the city, Pooran has attended me constantly as a guide, and from his intimate acquaintance with it has been extremely useful.

I subjoin a list of the officers and men of the Engineer Brigade present at the siege, together with a return of casualties.

I cannot conclude this report without remarking that in nine days' operations the enemy have been completely driven from a series of strongly defended positions extending over seven miles of city and suburbs; and though they had prepared for the most desperate resistance, their opposition was crushed by the irresistible power of artillery directed against them from all quarters, for which they were not prepared.

R. NAPIER, Brigadier,
Commanding Engineer Brigade.

LETTER FROM LIEUT. COLONEL H. D. HARNESS, COM. ROYAL ENGINEERS, TO BRIGADIER R. NAPIER, BENGAL ENGINEERS, COM. ENG. BRIGADE.

Kaiser Bagh, Lucknow, 19th March, 1858.

SIR,

In compliance with your request I have to report that the siege operations in which the Royal Engineers under my command have been engaged may be considered to have commenced on the night of the 4th-5th inst., when the 4th Company and a detachment of twenty men from the 23rd Company of Royal Engineers were employed under the direction of Major Nicholson, Royal

Engineers, in making two cask bridges, close together, across the Goomtee. Each was intended to be 102 feet in length, and the remainder of the width of the river was to be traversed by an embankment formed from the left bank by native labourers attached to the Force. One of these bridges was completed by the morning of the 5th, but the number of casks and extent of superstructure being insufficient to span the space between the right bank and as much of the embankment as could be completed during the night, only one communication could be effected, which was done by making the barrel portion about 135 feet in length. During the day of the 5th, embankments of sufficient length were formed, and two bridges completed in accordance with the original design, by the native Sappers and Miners under their proper Officers. Cover for men and guns to protect the bridge was formed on the left bank, by a working party of the line under the direction of Captain Lennox, Royal Engineers.

On the 6th inst., the 4th Company Royal Engineers was detached from the Engineer Brigade to join Sir James Outram, who crossed the Goomtee the same day with the 1st Division. Major Nicholson's report of the works performed by his Company, while so detached, is forwarded herewith, and I must request your particular attention to the praise he bestows on Lieutenant Wynne, Royal Engineers, for his conduct on the 14th inst.

On the evening of the 6th instant, in consequence of an order given to me by His Excellency, and reported to you by me, I ordered Lieutenant Harrison, Royal Engineers, to inspect and report upon the road between the camp of the Commander-in-Chief, near the Dilkoosha, and that formed by Sir James Outram. His report was forwarded to you by me on the morning of the 7th instant.

On the 7th, Captain Lennox, with the men of the Royal Engineers available for work, was employed in moving the lower of the two bridges established on the 6th inst., about a mile lower down the river, which work he completed during the afternoon, and the portion of siege train attached to Sir James Outram passed over it.

On the 8th inst., the upper bridge of casks was removed by Captain Lennox from its first position to within a short distance of the new position of the lower bridge.

On the afternoon of the 9th inst., Captain Lennox, R.E., with Lieutenants Malcolm and Pritchard, all three having been present with the former advance of the Commander-in Chief on Lucknow, and therefore acquainted with the Martinière, were ordered to accompany the column appointed to assault that building; and in the evening, after that building had been carried, and it was observed from it that the enemy had abandoned a large portion of the entrenchment in its rear, Lieutenant Beaumont was directed to attend the officer ordered to occupy the abandoned portion during the night; and Captain Lennox remained in the Martinière with General Lugard, by whose Division that building, and the entrenchment referred to, had been carried.

During the night of the 9th and 10th, Captain Clerke and Lieut. Harrison, Royal Engineers, were employed with the 23rd Company and a large party of natives, in moving the upper bridge of casks from the place down the stream to which it had been moved on the 8th instant, to that part of the river on which the enemy had closed the left of the entrenchment taken by us the preceding evening.

On the 11th inst., Major Nicholson having reported that Lieut. Swetenham had been wounded, and that he much needed another officer, Lieut. Malcolm was detached to his assistance.

The same day, being ordered to repair the bridge across the canal near Banks's House, Captain Clerke, Royal Engineers, was directed to execute that service, assisted by Lieutenant Pritchard, Royal Engineers. The space to be spanned was 36 feet in width, and twenty-one hours were occupied in repairing it by about fifty men of the 23rd Company. In the afternoon of this day the garden wall of the Begum's Palace, the entrenchment in front of it, and the serai on the opposite side of the road, having been breached by guns in battery near Banks's House, and the intention to assault by three columns having been communicated to me, I requested you to permit me to detail an officer for one of the columns of assault, which being assented to, I named Captain Cox, Royal Engineers, and it was arranged, in order that he might not supersede the subaltern officers already appointed to the columns, that he should accompany the column to which Major Taylor, who was to be the Directing Engineer of the assault, intended to attach himself.

This was done, but Major Taylor being unfortunately wounded during the operation, Captain Cox became the senior officer with the party within the captured premises, and was, as such, placed by me in communication with the Brigadier commanding the troops by which the assault was effected.

During the evening I received an order from you to remain in the captured buildings, and since that period I retained, by your desire, the principal direction of the operations which terminated in the capture of the Kaiser Bagh on the 15th inst. During the night of the 11th-12th, the obstacles to a free communication within the premises of the Begum's Palace and with the public roads were removed, and an epaulment thrown up to protect a communication across the road, between the palace and the serai, and to serve also as a parapet to two guns to oppose the enemy's works which enfiladed the road. And during the day of the 12th, two openings were effected through the wall separating the Begum's property from Jaffir Ali's, whose house was then occupied without resistance; and a small serai, in advance of that captured on the preceding evening, was also occupied without resistance, together with a mosque contiguous to and overlooking it. Some 8-inch mortars were moved into the small advanced serai, and some placed in rear of it, also some 10-inch mortars in the larger but more retired serai, with directions to shell that part of the city immediately in our front, extending to and including the Kaiser Bagh.

In the night of the 12th-13th, an opening was made through the wall between Jaffir Ali's and Jerar-o-Dowlah's premises; and in the morning the latter were occupied without resistance. But as it was found at daylight that the musquetry of the Imambarah could bear on the opening that had been made in the front wall of Jaffir Ali's property, a new opening was made through it into a row of sheds at right angles to it, by the destruction of the cross walls of which a perfectly covered route for the guns was obtained: they were placed in battery that afternoon within about 70 yards of the wall of the outer court of the Imambarah, and had completely breached the outer walls and partially breached the inner wall before dark, one 8-inch gun and one 24-pounder being employed for the purpose.

During the night of the 13th-14th, the outer breach was examined and found to be very easy of ascent; it was also intended to have examined a trench which it was observed the enemy had formed across the road on our left, to flank the outer wall of the Imambarah, but the enemy discovered the attempt and wounded the Sikh soldier, who, together with one of the Sikh officers, was accompanying the Engineer Officer. Fire was maintained upon the breach during the night, every two discharges of round shot being followed by a shell and a round of grape; and at daylight the breaches were considered so far advanced that arrangements were made for the assault.

A party of 100 Sikhs were to form the storming party, and to be followed by the native Sappers with powder bags under Lieutenant Brownlow, of the Bengal Engineers, and 32 men of the 23rd Company under Captain Clerke, Royal Engineers, with scaling ladders and crow bars, axes, &c., these to be followed by 200 Infantry, after whom were to advance 50 native Sappers with ladders and tools, under Lieutenants Medley and Lang, and a native working party under Lieutenants Scott, Fraser, and Burton, with tools and materials for any cover or entrenchment that might be found necessary; and the whole of Brigadier Russell's Brigade was to be retained in readiness to support the assault.

It had been observed that between the trench, which the enemy had made across the road, and the breach, there was a door in the outer wall of the Imambarah, and it was reported that there was a corresponding door opposite to it which would lead into the principal building. Arrangements were therefore made for a party of 25 men to advance against the trench, followed by the officer, with powder bags to blow in this outer door, at the same time that the storming party moved forward; and Lieutenant Brownlow was directed, on passing the first breach, to turn to his left, and blow in the opposite door, if he found one.

Lieutenant Beaumont, Royal Engineers, was ordered by me to be prepared to blow in the outer door, and his attention being thus directed to that part of the enemy's works, he found reason to believe that the trench on our left was in connection with a house on our side of the road between our front and the Imambarah, and that if manned when we proceeded to the assault, it would be from that house. He therefore asked permission to be allowed to work his way through the few earthen walls between us and the house referred to, and with the aid of Major Brasyer and a few of his men, to blow in the wall of the house and expel the enemy. This permission was given to him by me with the approval of Brigadier Russell, on the understanding that he would return and report the result, or if his proceedings were not complete before the breach was, that I should recall him to carry out the original plan of blowing in the door. He succeeded in driving the enemy from the house, and then proceeded to blow in the outer wall of the Imambarah, which being successfully executed, the Sikhs with him rushed in at the moment that the storming party had been ordered to their arms.

The unexpected entry of the Sikhs through the opening made by Lieutenant Beaumont checked resistance, and the assaulting columns passed the breaches without difficulty, and were able to seize, as rapidly as openings could be made for them, the enclosure of the King's Coachman's, and King's Brother's houses. The roofs of the latter, looking down on the Kaiser Bagh, offered a good position for our new front, and having succeeded in collecting about 100 men in each of the two buildings which compose the King's Brother's residence, I recommended Brigadier Russell to stop the further advance, and obtain firm possession of the ground we had passed over. The Sikh Regiment, however, persisted in pressing forward, and made their way into the courts of the Kaiser Bagh, followed by many of the troops who had taken part in the advance. As soon as practicable, therefore, an opening was formed from the Chena Bazar into the court where the two large tombs are situated (the place recommended by Mr. Kavanagh, whose local knowledge at this moment was valuable), and small detachments of men who had not lost their order were placed in commanding buildings, viz., in the larger tomb, one of the detached buildings in the principal court, and the gateway in the centre of the north-west side of that court. Soon after a party of about sixty men of the 10th Regiment was marched round the great square in order, halting occasionally as they passed the south-east and south-west sides, from which some fire was maintained by the enemy, and sending a section in to search the buildings. At two or more points large numbers were seen by the parties thus sent in, endeavouring to escape; and in these instances more were sent in and ordered to fire from the roofs. No doubt many of the enemy were thus killed.

During the afternoon and evening, as troops came up, they were quartered in the buildings, and the return of the enemy in force was prevented by their presence, though casualties continued to occur until late.

Much gunpowder was found by the men who searched the buildings, and Lieutenant Beaumont, who accompanied the party, was employed in destroying such portions as appeared most in danger from the fires then burning in three parts of the square.

On the 15th inst., the whole day, and all the available working men were employed in merely checking fires, and in destroying gunpowder.

I have thus related, to the best of my recollection, the events which took place under my notice from the 4th to the 15th inst., and have only to report to you that every officer under my command, whose name I have mentioned in this report, conducted himself with zeal and intelligence, and that all deserve your approbation.

But I must particularly record the very high opinion which these operations have enabled me to form of Captain Lennox, Royal Engineers, and Lieutenant Greathed, Bengal Engineers.

I must also praise most highly the intelligence and zeal of Lieutenant Beaumont, Royal Engineers, though I do not approve of his having blown in the outer wall of the Imambarah before he had reported progress and obtained instructions.

I annex the report addressed to me by Lieutenant Greathed of the proceedings adopted for the occupation of the Tara Kotee on the 14th instant.

Memoranda relating to the Siege of Lucknow in March, 1858, more especially with reference to the distribution of the Royal Engineers during the Operations. Compiled in 1860, from Notes of different Officers, by Lieut. Colonel Lennox, R.E.

2nd March.—The Siege of Lucknow may be considered to have commenced on the 2nd March, 1858, when the Commander-in-Chief advanced from Buntara and marching through the camp at the Alumbagh, gained possession, with trifling loss, of the buildings of the Dilkoosha, and encamped on the east side of the city in the Dilkoosha Park, which touches the right bank of the River Goomtee.

3rd March.—On the morning of the 3rd March the Engineer Brigade and some more of the Force joined the Commander in-Chief from the Alumbagh, where, however, some troops were still left. The Engineer Brigade and Park were established in the gardens at Bibiapore, where the Commander-in-Chief subsequently fixed his head-quarters.

During the day some Native Sappers threw up a breast-work for two guns in front of the Dilkoosha House: Lieutenant Pritchard, R.E., and 30 men of the 23rd Company, Royal Engineers, during the night extended this work into a Battery (No. 1, *L*), for four guns to keep down the fire of the enemy's batteries in their first line of works, and to check that of two or three guns which they had advanced to the northern angle of the Martinière. Strong picquets were posted in the garden of the Dilkoosha and in the Mahomed Bagh*.

A ford across the Goomtee was staked out; and some Delhi Pioneers were employed in preparing the banks of the river for the formation of bridges of casks: these parties were protected by a covering party of the 4th Company, Royal Engineers.

4th March.—On the 4th March a force under Major General Franks joined: this force, which consisted of Her Majesty's 10th, 20th, and 97th Regiments, five battalions of Goorkas, and some artillery, had marched towards Lucknow from the south-east.

At sunset two barrel-pier bridges were commenced under the direction of Major Nicholson, Royal Engineers; the party employed consisted of Lieutenants Wynne and Swetenham, four sergeants and 106 men, Royal Engineers; and Lieutenants Tennant and Smyth, Bengal Engineers, with 120 Native Sappers. Each bridge was intended to be 102 feet in length, and the remainder of the width of the river was to be traversed by embankments extending from the left bank. One communication was effected during the night, by using 135 feet of barrel-piers for its bridge. Captain Lennox, R.E., was Directing Engineer at the Dilkoosha House; Lieutenant Pritchard, 1 sergeant, and 33 men of the 23rd Company, Royal Engineers, were employed in improving the battery (No. 1, *L*), in front of the Dilkoosha House during the first portion of the night, and subsequently they were sent to reinforce the party making the bridges.

5th March.—Early in the morning of the 5th March the enemy brought out a horse battery to annoy the working party at the bridges, but it was soon driven off by the two guns with the covering party.

* An enclosure 1,400 yards to the south of Banks's House.

During the day the causeways were continued from the left bank, and both the bridges were completed in accordance with the original design: a party of 1 sergeant and 10 men, Royal Engineers, remained on duty at them to keep them in order.

A tête-de-pont, a battery for four guns on some mounds to the north-west of the bridge, and an infantry trench, to connect the battery with the tête-de-pont, were thrown up on the left bank of the Goomtee, under the direction of Captain Lennox, Royal Engineers, by a working party of 200 men of Her Majesty's 53rd Regiment; Lieutenant Keith and 11 men of the 4th Company Royal Engineers (relieved at 10 P.M. by a similar party of the 23rd Company under Lieutenant Malcolm, R.E.), were employed on these works, which were finished during the night.

Lieutenant Harrison, R.E., 1 corporal and 8 Sappers of the 23rd Company, Royal Engineers, constructed a shot-proof parapet on the advanced tower of the Mahomed Bagh this evening.

6th March.—At 2 A.M., on the 6th March, a force of about 7,000 of all arms, under Major General Sir James Outram, G.C.B., commenced crossing the Goomtee by the two barrel bridges: it consisted of the 3rd Infantry Division, 14 Squadrons, 3 Troops of Horse Artillery, 2 Field Batteries, the 4th Company of Royal Engineers, with Lieutenants Wynne, Swetenham, and Keith, Royal Engineers, Lieutenant Watson, Bengal Engineers, and 200 of the 15th Punjaub Native Infantry (Pioneers) under Lieutenant Hovenden, Bengal Engineers, and Ensign Nuthall: the Engineer force was under the command of Major Nicholson, Royal Engineers, who conducted all the siege operations on the left bank of the Goomtee.

Sir James Outram, after crossing the river, inclined slightly to the eastward, and clearing the country and villages as he proceeded, he established his camp on the great road from Fyzabad to Lucknow: strong picquets were posted to keep up the communication between the two camps. Lieutenant Harrison, Royal Engineers, was sent to inspect and report on the road with a view to the movement of the heavy artillery.

Captain Lennox, Royal Engineers, with 2 sergeants and 53 men of the 23rd Company, Royal Engineers, dismantled the lower bridge during the night, preparatory to removing it lower down the river to a spot where it could not be seen by the enemy occupying the Martinière.

7th March.—The enemy made an attack upon Sir James Outram's position this morning, but was repulsed.

The lower bridge was moved down stream to a point near Bibiapore, where the bridge was again formed by a party under Captain Lennox, Royal Engineers.

Lieutenant Swetenham, Royal Engineers, with 20 men of 4th Company Royal Engineers, and 60 Muzbee Sappers, prepared the road for the heavy artillery between the two camps, as pointed out by Lieutenant Harrison, Royal Engineers. The siege train for the operations on the left bank crossed the river this evening by the lower bridge and joined Major General Outram's camp.

8th March.—On the 8th a party of 1 sergeant and 32 men, Royal Engineers, under Captain Lennox, R.E., moved the upper barrel bridge lower down the river.

A party of Native Sappers under Lieutenant D. Ward, Bengal Engineers, made a battery (No. 2, *L*) near the Dilkoosha Park for six guns, to bear on the Martinière.

A battery (No. 3, *L*), for four guns, was also thrown up on the right front of the Mohamed Bagh, to fire on the Martinière, by Lieutenant Fulford, Bengal Engineers, and a party of Muzbee Sappers.

On the right attack during the night a battery for 10 guns en barbette (No. 1, *R*) was constructed at the Kokral Bridge to command the enemy's position near the Race Stand.

9th March.—A heavy fire was kept up from all the batteries including those made last night.

Sir James Outram stormed the Race Stand, and carrying all before him, occupied the whole of the left bank of the river as far as the Badshah Bagh and the Hazari Bagh. He immediately established a battery (No. 2, *R*) of 12 guns, no artificial cover being required, to enfilade the enemy's first line of works.

A battery for 4 guns, was thrown up to the east of the Race Stand at *y*, to fire on the Shah Nujjif and the Motee Mahal.

Lieutenant Beaumont, Royal Engineers, was Directing Engineer at the Dilkoosha Park this morning. Two guns of the Naval Brigade were placed under natural cover in advance of the Dilkoosha at *z*, to fire on the Martinière in flank and reverse.

About 2 P.M., after a heavy cannonade, the Martinière was taken with little resistance by Hope's Brigade. Captain Lennox, Royal Engineers, was the Directing Engineer in this attack, and remained on duty with Major General Lugard's Division that night; the following parties were with the columns: Lieutenants Malcolm and Pritchard, Royal Engineers, 2 corporals, and 6 men of the 23rd Company, Royal Engineers; Lieutenants Lang, Forbes, and Thackeray, Bengal Engineers, with 200 Muzbee Sappers. Communications were immediately made across the numerous trenches that had been dug by the rebels around the Martinière: the outer wall of the Martinière Garden was loopholed; the village to the north-west of the Martinière was occupied and prepared for defence, as also was the village of Jea Mhow, on the other side of the canal, the banks of which at that spot are sloping. Late in the evening the 42nd Highlanders and Wyld's Seiks advanced and occupied a part of the enemy's first line, which had been evacuated on account of the enfilade fire from the guns on the right attack. Lieutenant Beaumont, Royal Engineers, was directed to remain with the force occupying the left, and Lieutenant Thackeray, Bengal Engineers, with that occupying the right of the abandoned line: these officers loopholed buildings where necessary, and otherwise secured the advanced position, which extended from the river nearly up to the bridge on the Martinière Road. Lieutenant Lang, Bengal Engineers, with 200 Muzbee Sappers, was employed in making a road through the first line of works: he was relieved at 11 P.M., by Lieutenant Judge, Bengal Engineers, and Ensign Nuthall with 100 Muzbee Sappers and 200 Delhi Pioneers.

The upper bridge of casks was moved up entire to a point above the enemy's first line of works by Captain A. J. Clerke, R.E , Lieutenant R. Harrison, R.E., Lieutenant Champain, B.E., and Ensign E. C. Garstin, 29th Native Infantry, and a strong body of Royal Engineers, Native Sappers, and Pioneers. This operation occupied 17 hours, and was completed by 7 A.M. on the 10th March.

10th March.—At daylight two horse artillery guns joined the left advanced party, moving in by the road made during the night.

Early this day a battery (No. 4, *L*) for four guns, one howitzer, three 8-inch mortars, and some rockets, was established at the end of the Martinière Park: advantage was taken of some natural cover, and the guns were soon playing upon Banks's House, the garden wall of which was breached early, when it was taken by the 42nd and Wyld's Seiks, who also gained possession of the houses on the other side of the road as far as No. 3, *D* Bungalow. Lieutenant Greathed, B.E., was the Directing Engineer in this attack; Lieutenants Beaumont, R.E., and Brownlow, B.E., accompanied the storming parties. The Karabola was also occupied about the same time. Thus on the morning of the 10th March the enemy's first and most formidable line of works had been completely taken.

Natural cover on the right of Banks's House was converted into a battery (No. 5, *L*) for four guns and eight mortars to shell and breach the Begum's Palace. Places were also prepared among the *D* Bungalows for two 8-inch naval guns (Battery No. 7, *L*) to batter the bastion in front of the Huzrut Gunj and for six $5\frac{1}{2}$-inch mortars (Battery No. 8, *L*).

Communications were at the same time made between Banks's House and the *D* Bungalows, and also to the rear.

These batteries (under Lieutenants Greathed and E. Brownlow, B.E.,) and communications (under Lieutenant Gulliver, B.E.,) were very expeditiously made under the superintendence of Captain A. Taylor, B.E., and the guns were brought across the ditch and opened fire soon after Banks's House was in our possession.

On the right attack the following works were made under the superintendence of Major Nicholson, Royal Engineers.

A battery (No. 3, *R*), for four 24-pdrs., two 8-inch howitzers, and five 8-inch mortars, was formed on the left of the Badshah Bagh to counterbatter the batteries between it and the Kaiser Bagh, and to fire on the palace itself: this battery opened fire during the day.

Roadways were made through the Badshah Bagh.

The Dilaram House was seized, and fortified, under a heavy fire from the Chutter Munzil, by a party under Lieutenant Wynne, Royal Engineers.

During the night a battery (No. 4, *R*), for four 24-pdrs., two 8-inch howitzers, and five mortars, was thrown up in front of the Badshah Bagh to fire on the Kaiser Bagh: this battery opened fire on the morning of the 11th.

11th March.—Captain Clerke, Royal Engineers, with Lieutenant Pritchard, 3 sergeants, and 48 men of the 23rd Company, Royal Engineers, was employed in repairing the bridge across the canal near Banks's House.

The European Barracks, the Secundra Bagh, the Kuddum Russool, and the Shah Nujjif were taken possession of this morning by parties conducted by Lieutenants Medley, Lang, and Carnegie, Bengal Engineers. The enemy were just about to occupy the Secundra Bagh when our troops moved up.

Two 8-inch naval guns were put in position (at No. 9, *L*), in rear of the garden wall of No. 3, *D* bungalow: these guns were intended to breach the wall of the loopholed serai on the opposite side of the road to the Begum's Kotee, which they succeeded in doing through two kutcha garden walls which intervened.

The fire from the batteries had been kept up all night, and had made two practicable breaches in the compound wall of the Begum's Palace, and in the entrenchment and palisade defences in front of it. The assault was given at

$3\frac{1}{2}$ P.M. by three columns, two against the Begum's Palace, and one against the loopholed serai opposite to it. Captain Taylor, Bengal Engineers, who had the general arrangement of the attack, accompanied the left column, to which Captain Cox, R.E., Lieutenant Scratchley, R.E., and Lieutenant Smyth, B.E., were attached, and Lieutenants Maunsell, B.E., and Scott, M.E., led the two other columns. Parties of Royal Engineers and Native Sappers with powder bags and ladders, &c., were attached to them: the assaulting columns were furnished by Hope's brigade of Lugard's division, and Brigadier Napier, attended by Colonel Harness, Commanding Royal Engineer, and Captain Lennox, R.E., accompanied the column: the assault was successful; in it 4 officers, and 60 or 70 men were killed and wounded, many of them by men who barricaded themselves in the dark rooms around the courts, where they could not be got at except by making holes in the roofs or blowing in the doors. Captain Taylor, Bengal Engineers, having been unfortunately wounded, the securing of the position devolved on Captain Cox, R.E. Later in the evening Colonel Harness, Commanding Royal Engineer, received orders to remain in the captured premises, and to take the principal direction of further operations. The works carried on during that night were—removing the obstacles to a free communication within the premises of the Begum's Palace and with the public road; and throwing up an epaulment to protect the communication across the road, and also to serve as a parapet for two guns (No. 10, *L*), to fire at the enemy's bastion in the second line, which enfiladed the road.

This afternoon, Maharajah Jung Bahadoor arrived with a large force of Goorkas, and was sent round to the south side of the city: Lieutenant Sankey, Madras Engineers, was the engineer officer with His Highness's force.

Lieutenant Malcolm, R.E., was transferred to the right attack to replace Lieutenant Swetenham, R.E., who had been wounded.

Lieutenant Harrison, Royal Engineers, was sent this day to visit the right attack, and to ascertain the movements going on there. General Outram, having shifted his camp to a position close to the Race Bungalow, advanced with two columns against the northern suburbs: the first column made a great detour, surprised and cut up a large body of the enemy's cavalry, took two guns and reached the stone bridge; but the General, finding the extent of ground too great for his force, fired that part of the suburbs, and contented himself with holding the position round the iron bridge, which had been taken by the second column. His loss was about 8 officers and 40 men killed and wounded.

A battery (No. 5, *R*), for two 24-pdrs. was immediately commenced on the north side of the iron bridge: it was completed during the night by a party under Lieutenant Malcolm, Royal Engineers; its object was to subdue the enemy's fire from the opposite side of the bridge and to command the stone bridge.

12th March.—On the right attack during daylight on the 12th March two batteries were thrown up under Major Nicholson's orders.

Battery No. 6, *R*, for four 8-inch guns, to fire on the Residency and also on the buildings extending from thence to the Kaiser Bagh, was constructed on the right front of the Badshah Bagh.

Battery No. 7, *R*, for two 24-pdr. guns, was on the left of the iron bridge, and intended to subdue the fire from the opposite bank of the river.

On the left attack Captain Clerke, Royal Engineers, completed the repair of the bridge across the canal, which was commenced yesterday, with the assistance of Lieutenants Pritchard and Harrison, 3 sergeants, and 48 men Royal Engineers: this service occupied 21 hours, the space to be spanned being 36 feet.

Under the direction of Colonel Harness, Commanding Royal Engineer, the advance was carried steadily on: two openings were effected through the wall separating the Begum's property from an adjacent mosque and Jaffer Ali's house, which were both occupied without resistance. A small serai on the other side of the Huzrut Gunj Road, in advance of the loopholed one captured on the previous evening, was also occupied without resistance, together with a mosque contiguous to and overlooking it. Four 8-inch mortars were moved into the advanced serai, and two 8-inch mortars, were placed in position in its rear; also five 10-inch mortars were moved into the loopholed serai taken on the 11th. The fire from all was directed on the Imambarah and the buildings between it and the Kaiser Bagh. The communications with the rear were also improved.

When a hole had been made through the wall between Jaffir Ali's and Jerar-o-Dowlah's gardens, the enemy opened a smart musketry fire on it, a gun was therefore brought up, and replied with grape, but the gun was withdrawn after some casualties had occurred, as it prevented the Sappers continuing to enlarge the opening, which was through solid masonry. Lieut. Harrison, R.E., was with the working party of that corps that day.

The usual mode of pushing forward the advance, after the capture by assault of the Begum's Kotee, was as follows:—a heavy fire of shells was kept up on the buildings to be attacked, while the Engineers were employed in forming openings through the walls: holes were at first made by blasts in the walls, or by charges under them; these charges were small for fear of bringing down the upper parts of the walls, the removal of the rubbish from which would have caused additional labour and loss of time. When once holes were made through the walls, they were enlarged into practicable openings by means of crowbars, pickaxes, &c. Small parties were then moved through and secured the newly gained ground. The windows of the prominent adjacent buildings were provided with sand-bags, and the parapets and other walls loopholed; and from these positions our riflemen kept down the fire of the enemy.

13th March.—At day-break on the 13th, possession was taken of Jerar-o-Dowlah's house and compound, and a battery (No. 13, *L*), was formed behind its advanced wall: this battery was intended to breach the little Imambarah, the outer wall of which was within 70 yards of it. Lieutenant Gulliver, B.E., was engaged in the construction of this battery.

As a great portion of Jerar-o-Dowlah's compound, and also the opening made into it last night from Jaffir Ali's compound, could be seen from the little Imambarah, a new opening was made on the right, under cover of Jerar-o-Dowlah's house, and also one on the left into a row of sheds running towards the Imambarah, by the destruction of the cross walls of which a perfectly covered route for the guns was obtained. One 8-inch gun and one 24-pdr. were brought up and placed in the battery by noon, and they had breached the outer wall completely, and the inner wall partially, before dark.

Colonel Harness, Commanding Royal Engineer, examined the outer breach and found it to be easy of ascent: he also proceeded, accompanied by Lieutenant Da Costa and one of his Seikhs, to examine a trench which the enemy had formed across the road on our left, to flank the outer wall of the Imambarah, but was discovered by the enemy, who wounded the Seikh soldier in attendance.

Openings were made through the front wall of Jerar-o-Dowlah's compound to the right and left of the battery (No. 13, *L*), and the buildings were taken possession of as far as the road next to the Imambarah. A battery (No. 14, *L*), was also made this night for two guns to breach a white serai on the right of the Huzrut Gunj Road, and for five mortars to shell the city in our front.

During this night Lieutenant Harrison, 3 sergeants, and 42 men, Royal Engineers, were employed at the upper bridge of casks.

On the right attack four 8-inch mortars were added to the amount on the right front of the Badshah Bagh. These batteries and the mortars on the left attack kept up during the night a heavy fire of shells on the little Imambarah, the Kaiser Bagh, and all the buildings between them. Fire was also maintained on the breach in the Imambarah, every two discharges of round shot being followed by a shell and a round of grape.

14th March.—At daylight on the 14th the breaches were considered so far advanced that the following arrangements were made for the assault: the storming party to consist of 100 Seikhs, to be followed by native Sappers with powder bags, under Lieutenant Brownlow, B.E., and 32 men under Captain Clerke, R.E., with scaling ladders, crow-bars, axes, &c.: these to be followed by 200 Infantry, after whom 50 native Sappers were to advance with ladders and tools, under Lieutenants Medley and Lang, B.E., and a working party of natives under Lieutenants Scott, Fraser, and Burton, M.E., with tools and materials for any cover or entrenchment that might be found necessary. The whole of Brigadier Russell's Brigade of General Franks's Division was to support the assault.

While these parties were being formed up, Lieutenant Beaumont, R.E., worked from the left of the advanced post through a few earthen walls to a house on our side of the road between our front and the Imambarah: he was accompanied by Major Brazyer and some of his Seikhs, and succeeded in blowing in the wall and driving the enemy out of the house, which proved to be in connection with the trench intended to flank the outer wall of the Imambarah. He next blew in the outer wall of the Imambarah, and the Seikhs who were with him rushed in: this unexpected entry checked resistance, and the assaulting column passed the breaches without difficulty at 9 A.M., and were able to seize, as rapidly as openings could be made for them, the enclosures of the King's Coachman's and the King's Brother's houses, which overlooked the Kaiser Bagh.

Here it was considered advisable to stop and obtain secure possession of the ground that had been passed over, but Brazyer's Seikhs persisted in pressing forward, and made their way into the court of the Kaiser Bagh on the left, followed by many of the troops who had taken part in the advance: as soon as practicable therefore an opening was made from the Chena Bazaar into the court in which Saadut Ali's tomb stands. Small detachments of troops were placed in the commanding buildings, viz., the tomb, the building at the north corner of the Kaiser Bagh, the gateway on the north western side, and a detached building in the centre of the grand court.

Colonel Harness, R.E., shortly afterwards marched a party of 60 men of the 10th Regiment round the grand square, who systematically cleared the buildings: much gunpowder was found, and Lieutenant Beaumont, R.E., who accompanied the colonel, destroyed such portions of it as were most in danger from the fires then burning in three parts of the square.

The Engineer Officers employed in these operations were Colonel Harness, Commanding Royal Engineer, Captains Cox, Clerke, and Lennox, R.E., Lieut. Greathed, B.E., Lieutenant Beaumont, R.E., Lieutenant Lang, B.E., Lieutenant Brownlow, B.E., Lieutenant Medley, B.E., Ensign Ogilvy, attached to Madras Sappers (severely wounded); 3 men of the 23rd Company, Royal Engineers, were also wounded.

In the mean time the Mess House and the Motee Mahal were occupied by troops moved up from the European Barracks and the Secundra Bagh, and more troops coming up prevented the return of the enemy to the Kaiser Bagh in force, though casualties continued to occur.

Lieutenant Pritchard, R.E., was employed at the Secundra Bagh, and Lieut. Harrison, R.E. in breaking up the upper bridge of casks and moving it up stream.

On the right attack a breast-work was thrown up by Lieutenant Wynne and a party of the 4th Company, R.E., on the Iron Bridge. Previously to the assault on the Imambarah the batteries directed their fire on the buildings between it and the Kaiser Bagh, but afterwards this fire was turned on the Residency and other buildings in advance of the Chutter Munzil.

15th March.—On the 15th, the whole of the Kaiser Bagh was secured, and also all the principal buildings up to the Chutter Munzil.

Battery No. 15, *L*, for six $5\frac{1}{2}$-inch mortars, was established in the north-west court of the Kaiser Bagh to play on the city.

Large parties were employed in improving the communications between the different posts and with the rear, in checking fires, and in destroying the enormous quantities of gunpowder which were found in all directions. The 23rd Company, Royal Engineers, took up its quarters in the Zenana at the Kaiser Bagh.

Lieutenants Beaumont, Pritchard, and Keith, with 100 Royal Engineers, constructed a barrel-pier-bridge near the Secundra Bagh.

Lieut. Wynne, 1 sergeant, and 9 men of the 4th Company, Royal Engineers, removed the breast-work from the Iron Bridge: this was a service of much danger, and the conduct of the party was highly praised by Major Nicholson, R.E.

16th March.—Douglas's Brigade was moved across from the left bank by the bridge of casks at the Secundra Bagh, and attacked and drove the enemy from the Painted House, the Residency, and the Iron Bridge: and later in the day seized the Muchee Bawun, the Stone Bridge, and the Great Imambarah. These operations were directed by Brigadier Napier B.E., the Engineer Officers employed being Lieutenant Hutchinson, B.E., Lieutenant Scratchley, R.E., Lieut. Brownlow, B.E., Lieutenant Champain, B.E., Lieutenant Smyth, B.E., Ensigns Nuthall and Knowles and Mr. May, C.E. Major General Hope Grant, with the Cavalry division on the north, and Brigadier Campbell, with the Cavalry from the Alum Bagh, pressed out to intercept the fugitives, and the Goorkas attacked the native city on the south.

Five 8-inch mortars were immediately placed in position in the Great Imambarah: two naval guns and five 10-inch mortars were also posted in the Residency, and the whole kept up a steady fire upon the city during the night.

Colonel Harness, Commanding Royal Engineer, advanced from the Kaiser Bagh with a portion of the 97th Regiment and took possession of Philips's House and Mumtaj-o-Dowlah's. Large parties were employed on the communications, destroying powder, and putting out fires.

17th March.—On the morning of the 17th, Colonel Harness, Commanding Royal Engineer, accompanied by Captains Cox and Lennox, proceeded with the 97th Regiment, 30 men of the 23rd Company, Royal Engineers, under Lieut. Harrison, R.E., and 50 Pioneers, under Lieutenant Scott, M.E., to open up the Cawnpore Road, from the Kaiser Bagh, while three Regiments of Goorkas, accompanied by Lieutenant Sankey, M.E., and Lieutenant Murray, B.E., advanced from Alum Bagh by the same road: these columns did not meet with any resistance. The principal houses were occupied, the Char Bagh Bridge was repaired by Lieutenant Sankey, M.E., and the obstructions on the road were removed by the Engineers.

In the mean time Brigadier Napier, B.E., had conducted a portion of the 3rd Infantry Division, accompanied by Captain Clerke, Lieutenant Pritchard, and 30 men of the 23rd Company, Royal Engineers, and Lieutenants Brownlow and Lang, B.E., from the Great Imambarah to clear the city in that direction. In one of the streets the enemy had left some carts containing about three tons of gunpowder: the Engineers were engaged in removing this powder and throwing it down a well, when from some unexplained cause it exploded. Captain Clerke, R.E., Lieutenant Brownlow, B.E., and 14 men of the 23rd Company, Royal Engineers, died from the effects of this explosion, as also about 50 men belonging to other Corps.

Lieutenant Harrison, R.E., commenced a sketch of the enemy's lines.

The 4th Company, Royal Engineers, under Major Nicholson, came in and encamped at the King's Brother's House, Kaiser Bagh.

18th March.—On the 18th March a mine was discovered under the Stone Bridge: it was untamped: the gallery was 60 feet long and the charge consisted of 1,400 lbs. of powder which was removed and destroyed.

The officers and men of the Engineers who were blown up yesterday were buried at 2 P.M. in the garden x near the small mosque of the Kaiser Bagh.

The communications were improved and more of the city was occupied during the day.

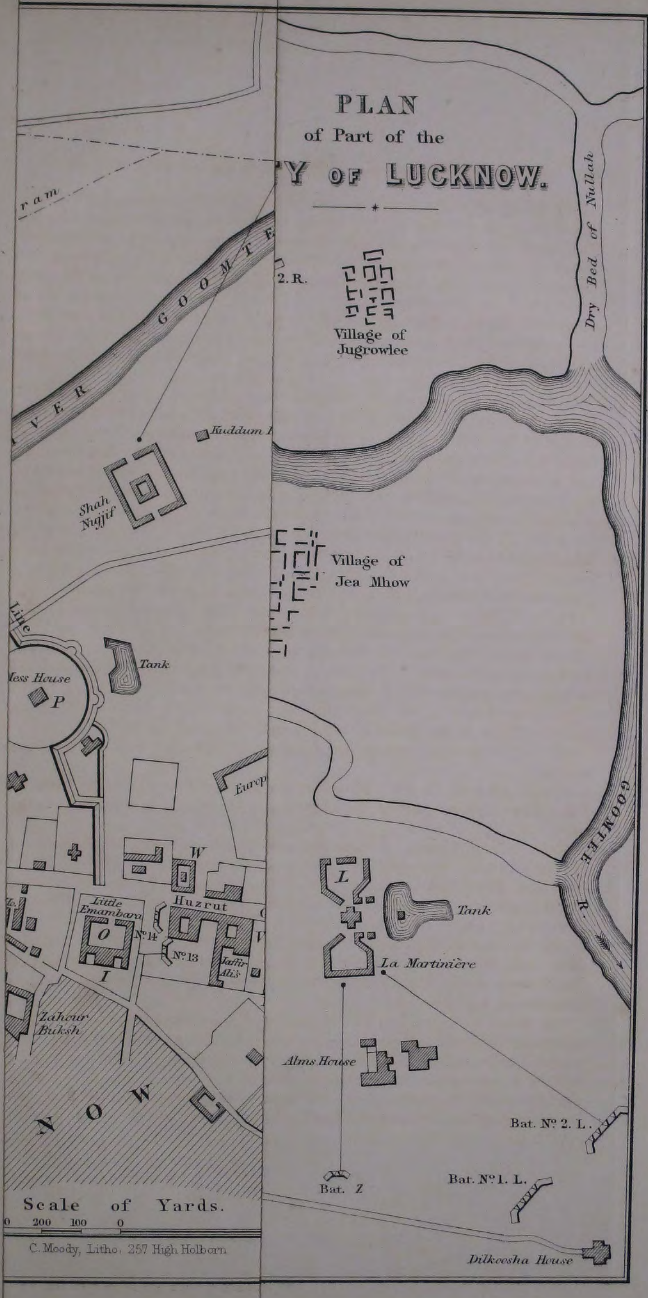
19th March.—On the 19th, Lieutenant Keith and 50 men of the 4th Company, Royal Engineers, dismantled the lower bridge of casks and returned it to the park.

Major General Outram attacked and took the Moosa Bagh; he pursued and cut up between 400 and 500 of the enemy and took 12 guns. Major Nicholson, R.E., Lieutenant Greathed, B.E., and some of the 4th Company, Royal Engineers, accompanied his force. Brigadier Campbell had been ordered to intercept fugitives with the cavalry from the south of the city.

20th March.—On the 20th the Moulvie returned with a body of men and took up a position in the city, from which he was however driven by a party of Highlanders on the 21st, from which day the whole city may be considered to have been in our possession.

21st March.—During this time large parties were employed under the Engineers in fortifying and preparing accommodation in the buildings about to be occupied as barracks, in levelling those portions of the town which interfered with their defence, in making roads through the heart of the city, and in constructing military posts at the two bridges as described in Paper V of the 9th volume of the Professional Papers.

W. O. L.



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Dilkoosha House
Scale of Yards.
200 100 0
C. Moody, Litho. 257 High Holborn

PAPER XI.

Report to the Secretary of State for War on the Result of investigations conducted at Woolwich and Chatham on the application of Electricity from different sources to the Explosion of Gunpowder.

By C. WHEATSTONE, Esq., F.R.S.,

Professor of Experimental Philosophy at King's College, London,

AND

F. A. ABEL, Esq., F.R.S.,

Chemist to the War Department.

Introduction.

The experiments relating to the application of electricity to the explosion of mines, of which the results form the subject of the present report, were entered upon by the late Ordnance Select Committee by direction of the Secretary of State for War, the inquiry having been proposed by Professor Wheatstone, and strongly recommended by General Sir John Burgoyne.

A Sub-committee was appointed by the Select Committee in March, 1856, to determine upon the experiments to be performed, which consisted of—

Colonel Tulloh, R.A.
Lieutenant Colonel Eardley-Wilmot, R.A.
Captain Younghusband, R.A.
Captain Bainbrigge, R.E.
Captain Boxer, R.A.
Professor Wheatstone.
Professor Sylvester.
Mr. Abel.
Mr. Anderson.
Captain Scott, R.E. (Chatham), afterwards added to the list of members.

This Sub-committee met on several occasions, and witnessed experiments made with an electro-magnetic induction coil constructed by Ruhmkorff of Paris; with a hydro-electric machine, constructed by Sir William Armstrong; and with a magnet of very considerable size, constructed by Mr. Henley, which was exhibited by him at the Paris Exhibition of 1855, and was afterwards purchased for the use of the Royal Gun Factories. (The construction of this instrument was precisely the same as that of the magnets devised by Mr.

Wheatstone many years since for ringing electro-magnetic bells. The armature, instead of being rotating, is suddenly detached from the magnet by means of a lever.)

The contrivance of the fuzes, and the preparation for, and general superintendence of the trials at Woolwich, Chatham, and elsewhere, were undertaken by Mr. Abel. The experimental apparatus was constructed under the direction of Professor Wheatstone, partly at the expense of the Committee, while a portion was lent by him for the investigations.

The Sub-committee made three preliminary reports, on the 24th July and 11th September, 1857, and 13th May, 1858, to the Ordnance Select Committee, on some of the results arrived at, and communications were also addressed to the Committee by Mr. Abel on the subject of particular fuze-arrangements and compositions prepared by him, with which he had obtained successful results in the course of the experimental investigations carried on by him for the Sub-committee.

In consequence of the success which ultimately attended the experiments on the application of the magnet to the explosion of charges, after the production of a particular fuze by Mr. Abel, directions were given by the Secretary of State for War for the further prosecution of experiments by that gentleman in connexion with the Ordnance Select Committee, with a view to test, by direct application in the field at Chatham, the results which had been obtained.

Soon after the commencement of these experiments, the late Ordnance Select Committee having been dissolved, and the labours of the members of the Sub-committee having therefore officially terminated, the subject was left for further elaboration in the hands of Messrs. Wheatstone and Abel.

When the results arrived at by the Chatham experiments were considered to have been sufficiently conclusive, those gentlemen were requested by the Secretary of State for War to prepare a report on the whole of the experiments which had been instituted.

The most important subjects inquired into, and on which conclusions were arrived at by experimental investigation, as detailed in the present report, were the applications of the following sources of electricity to the explosion of charges of gunpowder :—

1st. Electro-magnetic induction, discovered by Faraday, and employed in its most available form, as produced from the apparatus known as Ruhmkorff's Induction Machine.

2nd. Discharges from a jar or battery, charged by Sir William Armstrong's hydro-electric machine, a new and powerful source of electricity of high tension.

3rd. Magneto-electric induction, the electricity being developed from permanent magnets, as also discovered by Faraday.

No experiments were made by the Sub-committee on exploding gunpowder by the direct charge of a voltaic battery, when the current is employed, either to produce inflammation by means of the ignition of a very fine wire, as in the method hitherto adopted, or to produce a spark in an explosive mixture, rendered a good conductor, as in Mr. Statham's plan. The numerous accounts of such experiments made by Engineer officers and others, already published, have rendered any repetition of them unnecessary*.

* See p. 113, Vol. IV., and p. 139, Vol. VII., of this Series.—Ed.

PART I.

Application of Electro-magnetic Induction-currents to the Explosion of Charges in the Field.

This form of electricity was first applied with practical success in 1853 by Colonel Verdu, a Spanish officer. His earliest investigations were made with the assistance of M. Ruhmkorff, at Paris. In the account of experiments subsequently made by himself in Spain, it is stated that, with the aid of Statham's fuzes charged with fulminate of mercury, and employing only a single element of a Bunsen's battery, he effected the simultaneous explosion of six mines in the circuit, at a distance of 300 metres from the apparatus. When he wished to produce a greater number of explosions he distributed the mines in groups of five, and interposed each of these groups in a special circuit; then, by bringing each wire, in rapid succession, to one of the poles of the machine, all the mines were exploded with such rapidity that their discharge appeared simultaneous. In one of these experiments the distance was 3,500 metres.

It is well known that the discharge of a Leyden battery will pass through several hundred solutions of continuity, producing a spark at each interruption. It might be expected that the induction-discharge, considering its energetic physiological effects, and its great tension, which enables it to pass through shellac, gutta-percha, and even glass, would do the same; but this is not the case; the discharge becomes so enfeebled by successive solutions of continuity that it has been found impracticable to explode with certainty more than four mines, in a single circuit, on this system.

To obviate this inconvenience, M. Savare, a French Engineer officer, has devised another system, which offers great practical advantages. He interposes the fuzes in derivations or branches of the principal circuit. It is easily understood that the mine which is nearest the apparatus, or, the fuze of which presents the least resistance to the transmission of the current, explodes in preference to the others. In consequence of the abrupt separation of the two ends of the wire between which the spark is transmitted, the current can no longer pass through this branch, the electric action is consequently augmented in the other branches, and, in a similar manner the explosions necessarily take place in them.

The most extensive application yet made of the electro-magnetic induction-machine in producing explosions at a distance, appears to be in the great operations undertaken by Messrs. Dussaud and Rabattu at the port of Cherbourg in 1854, according to a system organized by Vicomte Du Moncel. At the first trial, six monster mines, containing many thousand kilogrammes of powder, were inflamed at the same moment, with a single detonation, and more than 50,000 cubic metres of rock were detached at a single explosion.

The objects of the inquiry which led to the conclusions given below were:—

1. To obtain definite information with regard to the maximum number of charges which could be fired with certainty by means of a voltaic battery of low power, and a powerful induction coil-machine.

2. To discover the description of priming best adapted for application in the fuzes to be used with the volta-induction current.

3. To ascertain the extent to which an electro-magnetic coil, made of the best and most portable construction, would be likely to resist injury by ordinarily careful use, and by transport.

The coil-machine employed in the first experiments was one of considerable size and recent construction, prepared by M. Ruhmkorff, and lent for the purpose by Mr. Wheatstone. Another apparatus of similar power, but constructed for the Ordnance Select Committee by M. Ruhmkorff, with special regard to its service in the field, was also subsequently employed in many of the experiments. A battery of cast-iron cells and zinc plates (the dimensions of the latter being 5 inches by 3 inches) was employed as the most economical for general purposes.

In the greater number of the experiments, the current was made to pass to the charges or fuzes through one mile of copper wire, 16 gauge, insulated with gutta percha, the metallic circuit being in many instances interrupted by an earth-connexion of about 200 yards in length.

The results furnished by a large number of experiments led to the following conclusions:—

1. Fine-grain or mealed gunpowder was found to be ignited readily, by means of the induction coil, with the employment of one cell of the battery. Numerous substances of a more highly explosive character were tried alone, and in admixture with gunpowder, in order to arrive at the description of priming material most suitable to aid in effecting the ignition of the maximum number of charges by means of the coil-machine. The best results were obtained with fulminate of mercury, and with the composition which furnished such successful results with the magnet (see Part III). The efficacy and delicacy of the fuze were also found to depend in very great measure upon a proper adjustment of the wire-terminals which it enclosed.

2. The number of charges placed in succession in single circuit which can be fired at once by means of powerful coil-machines, such as those used, and with the employment of twelve cells of the battery specified above, does not exceed eight (and was generally below that number) even when priming compositions of a sensitive character, containing fulminate of mercury, gun-cotton, sulphide of antimony, and chlorate of potash, &c., were employed. The discharge of this number cannot, however, be relied upon with any certainty, and the employment of twelve cells does not appear to offer any decided advantage over the use of only four. The ignition of two charges can be effected almost with certainty by the employment of only one cell, and the result appears to be rendered certain by the use of four cells.

3. By employing a rheotome for changing the direction of the current, so as to bring wires, connected with one or more charges, successively into the circuit, as in the system employed by MM. du Moncel and Verdu, a considerable number can be fired in very rapid succession. The result is, however, perfectly certain only when a single charge is brought into the circuit at one time.

4. If, instead of arranging the charges in a simple circuit, in the ordinary manner, each one is separately connected with the main wire and the earth (or

with the two wires), as first proposed by M. Savare, the current, when established, will distribute itself along each divided portion of the circuit, and ignite simultaneously or in rapid succession the several fuzes which have been introduced. Five or six charges may thus be at once exploded, and a far more considerable number ignited, with a rapidity almost instantaneous, as the first of the very rapid succession of currents established by the coil-machine passes through and ignites those fuzes which offer the least resistance, while the others are fired in their turn by the succeeding currents.

This method of exploding a number of charges at once or in very rapid succession is far more efficient than that described at paragraph 3 *(supra)*, and renders the operator independent of the uncertainty of firing three or four charges simultaneously when arranged in a simple circuit; for, when the charges are arranged in a single line, if the ignition of the whole number is not perfectly instantaneous, the explosion of the first prevents the discharge of the remainder, while, in the arrangement just referred to, the connection of each fuze with the instrument is independent.

5. In the course of the experiments carried on with the two coil-machines constructed by M. Ruhmkorff (one of which was, as already stated, specially prepared for these experiments), a considerable irregularity was observed in the power of the same machine at different periods, although the battery-power employed was, to all appearance, the same on each occasion; an irregularity which must be ascribed to defective insulation, arising from the deposition of moisture on some portion of the apparatus. It was also found that the arrangement attached to the coil-machines, known as the condensor, and upon which the intensity of the current produced greatly depends, was very liable to become deranged in the transport of the apparatus and by other trifling causes. Such a derangement was found to be fatal to the efficiency of the apparatus.

The perfect insulation of each coil of the secondary wire, and other somewhat delicate portions of the apparatus, were also found liable to injury from a variety of sources, which it would be very difficult to guard against in the employment of coil-machines for field purposes, and by persons not thoroughly acquainted with their somewhat complicated construction and their action.

Although, therefore, the system of exploding charges by means of the induction coil-machine offers very important advantages over the voltaic battery, employed alone (one of the principal being the great reduction effected by its use in the power of battery required), its adoption as a general substitute for the old system of operation with the voltaic battery cannot be recommended with confidence, principally because proper reliance cannot be placed upon the certainty and permanent uniformity of action of the induction coil-machine.

PART II.

Employment of Armstrong's Hydro-electric Machine as a Source of Electricity for the Explosion of Charges of Powder.

The first proposal to employ electricity, generated by an ordinary machine, for the explosion of mines, was made by Dr. Priestley, in 1767, but the first actual experiments were made in 1831 by Mr. Moses Shaw of New York. By employing fuzes containing a mixture of gunpowder and fulminate of silver, he succeeded in exploding simultaneously several mines, and detaching thereby large masses of rocks; but he states that he was unable to operate during the greater part of the year in consequence of bad weather. More favourable results were obtained by Professors Warrentrap of Brunswick and Gätzmann of Freiburg in 1842 and 1843. Employing fuzes which contained a mixture of sulphide of antimony and chlorate of potassa, and special contrivances for ensuring more perfect insulation, they succeeded in exploding from eight to ten mines simultaneously through 78.5 metres. Notwithstanding their precautions, the evil effects of humidity compelled them to discontinue the experiments. Still more successful results were obtained in 1845 by Mr. Charles Winter. By means of a fuze containing a preparation of phosphorus, he inflamed powder through the telegraphic line between Vienna and Hetzendorf, a distance of 4,906 metres.

In 1853 the Imperial Academy of Military Engineers at Vienna was charged with the investigation of this subject. Experiments on a large scale were continued for three years, results of great importance being arrived at, which were examined and verified by a Commission, and ultimately the process adopted was introduced into the Austrian army, and employed also in many industrial operations. A most interesting report of these experiments was published in 1855 by Baron von Ebner, in the proceedings of the Academy of Vienna, from which publication the following brief particulars are extracted :—

"A portable electrical machine, in which the electricity was excited by the friction of two glass plates, one foot in diameter and four lines in thickness, was employed, in conjunction with a Leyden jar having an external coating of 276 square inches. These were enclosed in a case, the interior of which was kept dry and heated by means of a small stove, which was fixed to it, and so arranged that the products of combustion should not enter the case. The conductors were of copper wire covered with gutta percha. The chemical mixture in the fuzes consisted of equal parts of chlorate of potassa and sulphide of antimony, a composition of sufficient inflammability, but less dangerous in its use than fulminate of mercury, which was at first used. An extensive series of experiments was instituted, in which equal attention was paid to the effects obtained at great distances with considerable quantities of powder; by mines in holes perforated in rocks; through great spaces under water; and by apparatus exploded under water. The greatest distance at which the explosion was attempted was four German miles. On several occasions 50 mines were simultaneously discharged in the same circuit; the fuzes were two klafters (toises) from each other, and the electric machine was 140 klafters from the nearest fuze. In like manner, 36 charges were simultaneously exploded in one of the branches of the Danube; these charges were placed six feet under the water, and had remained submerged during 20 hours previous to the operation. Other operations on a large scale, in marble quarries, in the beds of rivers, &c., in which considerable masses of matter were displaced, are given in detail; they place the efficiency of the process beyond doubt. Its drawbacks are, that some scientific skill is required in the manipulations, that great care is needed in the preservation of the apparatus, and that the inductive action is sometimes so energetic that explosions are occasionally determined in other mines not intended to be included in the series, and not connected with the machine."

The experiments to be described in this portion of the report were undertaken at the suggestion of Mr. Wheatstone, for the purpose of ascertaining whether the hydro-electric machine of Sir William Armstrong might not be advantageously substituted for the ordinary electric machine for charging a Leyden jar or battery in the field.

A small portable hydro-electric machine was constructed specially for the inquiry, and placed at the disposal of the Ordnance Select Committee by Sir William Armstrong.

It consisted of a small vertical boiler (supported on a sheet iron stand in which a grate was fixed) of two gallons capacity, provided with a safety valve by which the pressure of steam could be regulated up to 90 lbs. on the inch. The head of the boiler was provided with a cock, so as to admit of the escape of steam, to which was fixed a horizontal iron pipe, nine inches in length, and of half an inch internal diameter, and fitted with the jet and wooden cylinder which serve for the issue of the steam and the development of the electricity. The iron pipe was surrounded by a small metal box, which, when the apparatus was in use, was partly filled with water, so as to effect a partial condensation of the vapour as it passed through the pipe. A brass fork, raised to a level with the jet, and capable of adjustment at different distances from it, served the purpose of conducting the electricity from the jet of steam to the Leyden jar or jars, which were placed in a sheet iron casing immediately under the steam jet. The boiler was very well adapted to the rapid generation of steam of considerable pressure. About twenty minutes after a wood fire was kindled a pressure of 60-70 lbs. was obtained, the boiler being one-third full of water.

To avoid the possibility of the water in the boiler priming during an operation, in which case the charging of a jar with electricity could not be accomplished, it was indispensable:—

1. That the boiler should not contain too large a quantity of water (it was found safest to employ it not more than one-half full).

2. That the water should be free from solid matter in suspension. It was therefore necessary, not only to employ perfectly clear water, but to clean out the boiler after each experiment (if spring or river-water were employed), so as to remove all solid matter deposited by the boiling water. With the employment of rain or distilled-water this precaution was of course rendered unnecessary.

The time required to charge with electricity a Leyden jar of about $1\frac{1}{3}$ square feet surface, when the machine was in good working order, was found to be from five to seven seconds. The rapidity with which the jar was charged proved, under favourable conditions, to be proportionate to the pressure of steam employed, the most suitable being from 60 to 70 lbs. per square inch.

The first experiments on the ignition of charges were conducted with only short lengths (from 12 to 50 feet) of wire, to serve as connexions between the jar and the charges. The machine was worked in a locality sheltered from wind or draught. The priming composition employed in the charges was the same as that ultimately adopted in the experiments with the magnet (see Part III).

Two different plans were available for firing the charges:—

1. By completing the circuit before the jar was charged, and allowing the fuzes to be fired by the spontaneous discharge of the jar.

2. By allowing a definite time (about 6 or 7 seconds) for the charging of the jar before completing the circuit.

The first method would be preferable for the ignition of a very large number of charges in the same circuit, as the employment of the maximum charge attainable would thus be secured. If, however, the ignition of the charges had to be effected at a given time, it would be necessary to employ the second method.

The results obtained by this apparatus were very variable. On one or two occasions (five seconds being allowed for the charging of the jar), it was found impossible to fire six charges, placed in a simple circuit, simultaneously, with certainty; although, when eight, and afterwards twelve, were connected in a similar manner, seven and eleven were fired, the conditions (as to pressure, &c.) being apparently the same. On another occasion, with a pressure of 70 lbs., and an allowance of seven seconds for the charging of the jar, forty fuzes were placed in circuit, and the whole number discharged. One hundred and twenty were afterwards placed in circuit, and of these one hundred were instantaneously discharged. Attempts were subsequently made, under apparently the same conditions, to obtain a repetition of these results, but without success.

Experiments, made to effect the ignition of several charges in circuit through a considerable length (one mile) of covered wire and an earth-connexion, were only very partially successful. At first the greater portion of the wire was left in a coil, for the sake of convenience, and only a short earth-connexion (about 20 feet) was employed. Very successful, though not uniform, results were obtained, forty and fifty fuzes (the entire number in circuit) having, in some instances, been ignited, while in others a few were left in different parts of the circuit. Upon uncoiling the wire to the extent of about 600 yards, and causing the circuit to be completed by the earth, these results could not be in any way depended upon, and on no occasion were as many as forty charges fired, the number at times not exceeding five or six.

A few experiments made with small Leyden jars charged with electricity from the ordinary cylindrical machine, were confirmatory of the comparative uncertainty in firing a large number of charges through an extended metallic circuit of considerable length. Forty charges were fired by means of a Leyden jar containing 60 square inches of surface, the electricity passing through about 20 feet of wire-circuit, but on employing one mile of wire, with an earth-connexion, the ignition of twenty-five charges, though once or twice successful, could not be depended upon.

Attempts were made on two occasions to employ the hydro-electric machine in the field. The spot selected for the experiment was the open and sloping ground near Brompton Barracks, Chatham, known as St. Mary's (and as the locality of the field works near the Royal Engineer Depot).

The machine was placed in the open air, on rising ground, and 880 yards of covered wire were employed, of which about 60 yards were extended, an earth-connexion of that length being used in place of a second wire. Two Leyden jars, each containing about $1\frac{1}{3}$ square feet of surface, formed the battery. They were enclosed in a stout wooden box, and every precaution was taken to have them dry at the commencement of the experiments. The time to be allowed for the charging of these jars, as determined by previous experiments, made in a sheltered locality, was about ten seconds, with the employment of steam at 70 lbs. pressure. The atmosphere was dry, and a slight breeze blowing, on the day of experiment. The machine was so placed that the steam-jet should be as little as possible affected by the wind.

Repeated unsuccessful attempts were made to fire fifty charges in circuit; these were then gradually reduced to twenty, when only five were ignited, in different parts of the circuit. It was soon found impossible to charge the jars to more than a very slight extent. This unfavourable result was ascribed partly to an interference of the slight wind with the steadiness of the jet of steam, and partly to the difficulty of maintaining the Leyden jars in a suitably dry condition. The machine was removed to a trench of some depth, for the purpose of sheltering the steam jet from the wind, but with no better result.

On a second occasion the machine was sheltered from the wind, which blew freshly, by being placed behind a shed. Forty fuzes were placed in circuit, with 200 yards of covered wire, coiled up, and an earth-connexion of about 20 feet. The two Leyden jars were employed, and the whole of the charges were simultaneously ignited.

The wire was afterwards uncoiled, and the same number of fuzes were again placed in circuit, but these did not fire. On reducing the number to twenty-five, nineteen were exploded, six being left in different parts of the circuit.

The experiments with this hydro-electric machine were not continued, as it was considered sufficiently proved by those already instituted that the details, or rather the auxiliaries, of this apparatus, must undergo some considerable modifications before anything like definite results could be obtained with it. Arrangements for securing the preservation of the jars in a sufficiently dry condition, and for screening the jet of steam from the prejudicial influences of the wind or draught, might readily be carried into effect, and would unquestionably contribute greatly towards rendering the apparatus more certain in its action.

With reference to the possibility of using the hydro-electric machine with advantage in mining operations, even the results already obtained are of a nature to warrant the adoption of the following conclusions :—

1. That in mining operations of very extensive character (the destruction of docks, bridges, &c.), where it is desirable to ignite a very large number of charges simultaneously, and at which, as is most generally the case, full appliances and conveniences are at command for thoroughly fulfilling every condition of success, there is no doubt that the hydro-electric machine is readily susceptible of very effective application, and possesses great advantages over other arrangements by which static or dynamic electricity may be applied to the same purpose.

2. That for general use in the field, the hydro-electric machine, even if its appliances are arranged in a much more efficient manner than was the case with the apparatus above referred to, is not very likely to prove an instrument upon the certainty of whose action, at any moment, the proper reliance can be placed, and principally on account of the difficulty of ensuring, in the field, the fulfilment of those conditions which appear essential to the proper generation of electricity by means of the steam-jet.

PART III.

Application of permanent Magnets to the Explosion of Mines and Submarine Charges.

The ignition of gunpowder by the direct magneto-electric current, though well known to be practicable, has never yet been applied to military or industrial operations, and, so far as the reporters are aware, no satisfactory experiments showing its practical applicability to these purposes have yet been published.

The experiments forming the subject of this portion of the report were commenced with the employment, in the first instance, of the very powerful magneto-electric machine constructed by Mr. Henley, spoken of in the introduction.

A few trials sufficed to show that, even with this instrument, gunpowder itself could not be ignited with any degree of certainty. Results obtained with Statham's and other fuzes, though superior to those furnished by gunpowder alone, were still far from satisfactory.

The first experiments were, therefore, directed to the discovery of a suitable agent to serve as a perfectly certain medium (or priming material) for effecting the ignition of charges by means of the magneto-electric machine.

For this purpose a variety of compositions of a more or less sensitive character were prepared for trial with the magnet. The principal of them consisted of the following ingredients:—

Meal powder and powdered coke.
Ditto and sulphur.
Ditto sulphur and iron filings.
Ditto ditto and carbon.
Ditto and fulminate of mercury.
Meal powder, fulminate of mercury, and iron filings.
Ditto ditto and coke.
Fulminate of mercury (alone).
Percussion cap composition, alone and with coke.
Detonating composition (sulphide of antimony and chlorate of potassa).
Ditto and iron filings.
Ditto and coke.
Gun cotton alone, and mixed with some of the above.
Amorphous phosphurus, in admixture with oxidising agents.

It will be observed that the composition of the above mixtures was varied so as to test the sensitiveness of readily ignitable substances, both alone and when mixed with bodies which would serve as electrical conductors.

Many of these compositions furnished results to a certain extent favourable; a number of fuzes, primed with them, having been fired in succession with the magnet, and from two to four charges in one circuit having been ignited in a very few instances. But no perfect certainty of discharge was attained with any one of the above materials, the attempt to fire a fuze being frequently unsuccessful, while no difference between it and a successful fuze, containing the same composition, could be detected by careful examination.

These preliminary trials, however, established the fact that the sensitiveness (ready explosiveness) of a priming material was not alone sufficient to determine its success, but that those which possessed a certain, though not too considerable, degree of conducting power, were more readily and certainly ignited than others of a far more sensitive character.

Some successful results obtained accidentally with one of the experimental compositions, which had become damp by exposure to air, led to a trial of the effect of moisture in promoting the ignition of but slightly sensitive compositions, and it was ultimately found that the impregnation of ordinary gunpowder with a small amount of moisture (by an expedient similar in principle to one adopted with considerable success by Captain H. Scott, R.E., in connexion with charges to be fired by the induction coil-machine), rendered its ignition by means of the magnet a matter of certainty.

Some important precautions were, however, indispensable to the attainment of this definite result. If the slightly damp powder were employed in a finely-divided condition, it very frequently became caked between the wire-terminals in the fuze, and the current would then pass through the composition without igniting it. This was found to take place occasionally, even when the powder was employed in its original granular condition. Several attempts were made to overcome this difficulty by modifying the form and position of the terminals, and an arrangement of a completely successful nature was eventually contrived, in which only the sectional surfaces of the extremities of the terminals, which consisted of fine copper wire (23 gauge, or $\frac{1}{40}$th inch diameter) were exposed in the interior of the fuze so as not to project at all. The prepared gunpowder, therefore, simply rested upon the surfaces, and a perfect uniformity in the action of the fuze was attained. The priming composition consisted of fine-grain gunpowder, which had been soaked in an alcoholic solution of chloride of calcium, of a strength sufficient to impregnate the grains with from one to two per cent. of that salt. The prepared powder was exposed to the air for a short time, to permit of a sufficient absorption of moisture by the deliquescent salt.

Upwards of 500 quill-fuzes (of the description employed for firing guns), primed with the prepared gunpowder, and fitted with the arrangement of the terminals above referred to, were fired with the large lever-magnet. The failures did not amount to more than 3 per cent., and were all proved to be due to defective manufacture.

In the experiments with these fuzes, one or two simple arrangements (already referred to in Part II.) were successfully employed for effecting the rapidly successive discharge of a series of fuzes.

This fuze (which was submitted to the Ordnance Select Committee by Mr. Abel, in a letter dated 29th October, 1857,) was found to be easy of manufacture and permanently effective. While, however, it presented a certain means of effecting the ignition, by the aid of a powerful magnet, of single charges, or of a large number to be fired in moderately rapid succession, it was inapplicable to the ignition, with certainty, of more than one charge in circuit.

A new description of priming material for the fuze was, however, prepared soon afterwards (being brought to the notice of the Ordnance Select Committee by Mr. Abel, in a letter dated the 11th May, 1858), which greatly exceeded in sensitiveness any of the other compositions hitherto tried. A very gradual separation of the armature from the large magnet sufficed to effect the ignition of the fuzes primed with this material, and the induced current obtained by means of a very small magnet, with a rotatory armature, such as that employed in Wheatstone's magneto-electric telegraph, was sufficiently powerful to produce the same result.

This priming composition consisted of a very intimate mixture of sub-phosphide of copper, chlorate of potassa, and levigated coke, the latter substance being employed to add to the conducting power of the mixture, which was found otherwise insufficient. (Details of the proportions of the ingredients, their preparation, &c., will be found in the Appendix).

In the experiments subsequently carried on with fuzes which contained this composition, it was found that a slight residue, consisting principally of the coke employed, occasionally remained on the surfaces of the terminals in the fuze, after its discharge, and, by forming a good conducting link between them, interfered with any further effects of the magnetic current in other directions, by the establishment of a complete circuit.

The obstacle to the complete success of the composition was entirely removed by the substitution of another material, more easily acted on by the chlorate of potassa, than the coke, and answering equally well with the latter as a conducting medium, viz., the sub-sulphide of copper.

No instance has occurred in the discharge of several thousand fuzes, primed with the mixture of sub-phosphide and sub-sulphide of copper with chlorate of potassa, in which the terminals have not been found quite free from adherent residue, after the ignition.

The sub-phosphide of copper, which is produced at an elevated temperature, is a compound of very stable character, and the mixture of the three constituents is quite as unalterable as the explosive mixtures which are in general use for the preparation of percussion caps, &c. The stability of the mixture has already been submitted to very satisfactory tests. Fuzes primed with it have been found to have lost none of their delicacy and certainty when tried more than two years after preparation.

Before passing to a statement of the results obtained by the aid of this priming composition, in investigating the extent to which magneto-electricity could be applied with certainty to the simultaneous ignition of a number of fuzes, some little account must be given of the properties of the priming material itself, and of the results which led to the adoption of the particular proportions given (see Appendix) for the preparation of the mixture.

The sub-phosphide of copper, intimately blended with chlorate of potassa, forms a mixture in a high degree sensitive to the effect of heat, and possessed at the same time of some power of conducting electricity. With the employment, however, of magneto-electric machines of comparatively low power, and in cases where the resistance to be overcome by the current is considerable, this conducting property is not sufficient to ensure the ignition of the mixture by assisting the passage of the current across the interruption in the metallic circuit (*i. e.* across the small distance between the terminals of the wires in the fuze). It must be borne in mind that the striking distance, or the space between the terminals, across which the current from even a powerful magneto-electric machine will leap, is very small. With the large lever-magnet, the spark could only be produced when the wires were almost in contact. Since, however, it is indispensable to the proper insulation of the wires in the fuze-arrangement, that the terminals should be at least one-sixteenth of an inch apart, it will be readily understood how essential to success, in operations with these machines, it is that the priming material should possess considerable conducting power. Hence the necessity of increasing the conducting power of the mixture of sub-phosphide of copper and chlorate of potassa; a result which, it has been already stated, was attained in the first instance by the employment of finely levigated coke, and afterwards by the substitution of sub-sulphide of copper for that substance.

Many experiments were of course required to determine the proportions in which it was advisable to employ the conducting constituent, so as to facilitate the passage of the current through the mass as far as possible, without interfering too much with the sensitiveness of the explosive mixture, or producing an almost perfectly continuous connexion between the two poles in the fuze, and thus promoting the passage of the current so greatly as to prevent the ignition of the composition.

Considerable difficulties were encountered in the endeavours properly to balance these conditions, when attempts were made, which will presently be mentioned, to apply the mixture in question to the ignition of several charges in circuit. The increase in the resistance of the current, consequent on the introduction of more than one interruption in the metallic circuit, necessitated an increase in the conducting power of the mixture, which it was difficult to attain, unless at a considerable sacrifice of the sensitiveness of the composition.

It was consequently found that when the proper conditions had been attained for ensuring the passage of the current through several (five or six) fuzes in circuit, the absolute certainty of the fuze, when applied in this manner, had been sacrificed. Thus, out of several fuzes tried together, which had been most carefully prepared, so as to be, as far as possible, perfectly alike, the current would ignite a few, passing through the others without affecting them, and would thus point to minute differences in the conducting powers and sensitiveness of different portions of one and the same quantity of the mixture, which, it is almost needless to observe, was prepared in such a way as to ensure the greatest possible uniformity.

The results of many experiments established the fact beyond any doubt, that the proportions of ingredients already referred to furnished a mixture possessed of the highest conducting power attainable without detriment to the sensitiveness (ready explosiveness) of the material. The perfect certainty of its action, when applied in the fuze, to the explosion of a single charge by means of magneto-electric machines, has been proved by the ignition of at least 5,000 fuzes, without failure. A large number of these have been fired by means of the smaller machine already referred to.

Numerous experiments, made with the aid of this composition, established the fact that the current obtained by means even of a very powerful magneto-electric machine, when applied to the ignition of several charges arranged in succession in one circuit, is very limited in its powers. In illustration of this it may be stated that, on trial being made of twenty-one consecutive sets of four charges, eighteen of the sets were perfectly discharged, but, in the other three sets, only two or three of the charges were ignited. Out of five sets, of five charges each, only two sets were completely discharged, and in several attempts made to ignite six fuzes in one circuit only four were fired in each case. In all these experiments, when charges had escaped ignition, the current had passed through the sensitive composition without firing it. When the discharged fuzes were removed, and the remaining ones properly connected, they were all fired.

It has been already stated that no beneficial effects were attained by modifying the proportions or ingredients in the priming composition, so as to diminish or increase its conducting power.

Three charges were therefore the most that could be ignited *with certainty* by means of a powerful electro-magnetic machine, when they were arranged in succession in simple circuit.

The plan, originally suggested by M. Savare, of arranging the charges in divided circuits, was next tried, and furnished far more successful results. The simultaneous ignition of twenty-five charges was repeatedly effected by means of the large magnet, each charge being connected with a separate branch attached to the main line, which led from one pole of the machine, and their connexion with the earth established by means of uncovered copper wire, the extremity of which was wound round an iron stake driven into the ground.

A still larger number of charges (forty) was similarly exploded on several occasions.

These results were all obtained with the large magnet, the current being established by rapidly separating the armature from the poles by means of a lever. By a simple arrangement for shifting the connexion of the main wire with the exploded charges, from them to a second series, similarly arranged, twenty-five were also simultaneously ignited, on allowing the armature to return to the poles of the magnet. It was found, moreover, that the same number could be fired by means of this magnet, even if two folds of thick brown paper were interposed between the poles and the armature, so that on depression of the lever the armature had no longer to be forcibly detached, but simply to be removed from the magnet.

These successful results (which were described to the Ordnance Select Committee by Mr. Abel in a letter bearing date 23rd June, 1858,) led to trials of magneto-electric machines of comparatively small size, with revolving armatures. In the employment of these machines, it was of course not expected that any single induced current obtained from them should distribute itself among a number of fuzes placed in divided circuit, as was the case with the comparatively much more powerful current obtained with the large magnet, but it was hoped that the very rapid succession of currents furnished by them would produce a very similar result, by distributing themselves over the different branches of the circuit with which the fuzes were connected, and that the ignition of the whole of the fuzes, though it could not be so positively instantaneous as when the one current was discharging the entire number, might yet be effected with such rapidity as practically to amount to a simultaneous discharge.

The results obtained fully confirmed these expectations. With a small horseshoe magnet seven inches in length, one inch in breadth, and one and three-quarter inches in thickness, provided with a revolving armature and multiplying wheels, by which great rapidity of motion could be attained, twenty-five charges were fired; the effect of the discharge on the ear was, however, not like that of one single explosion, as was the case in the former experiments, but like that of an exceedingly rapid volley, in which the explosion of any single charge could not be distinguished.

Still more favourable results were obtained with a very compact arrangement of six magnets, each about half the size of the above, devised by Mr. Wheatstone, for the production of an extremely rapid succession of currents, established in such a manner that the effect would be almost equal to a continuous current (for a description of the instrument, see Appendix).

By means of this apparatus, twenty-five charges were frequently fired in divided circuit, with such rapidity that the effect on the ear was as of one explosion, only of slightly longer duration than when the large magnet was employed.

On some occasions, when a slight difference was made in the velocity with which the apparatus was worked, an interval could be distinctly noted between the first and last discharge, but even in those instances the effect could not be considered as otherwise than a practically simultaneous discharge.

Some sets of fifty charges in divided circuit were also ignited by means of this apparatus, but in those instances the interval between the first and the last discharge was naturally longer, being about the same as that observed when twenty-five charges were fired by means of the small magnet above referred to.

The system of firing charges by means of magneto-electricity, with the aid of the phosphide of copper fuze, having been thus far successfully developed, a series of experiments was instituted on it at Chatham, for the purpose of thoroughly testing its certainty and applicability in the field, and subsequently for ascertaining the extent to which it admitted of application to the explosion of submarine charges. These experiments extended over a period of six months, and were performed under various conditions of weather.

It will readily be understood that the best and most simple methods of connecting the fuzes, enclosed in the charges, with the branch-wires and the earth, of arranging the experimental charges for explosion, and of carrying out the various small but essential details involved in the experiments, were only gradually arrived at, and that, consequently, in many of the first experiments, which were only partially successful, the failures were traced to causes unconnected with the efficiency of the magneto-electric apparatus or the fuze. These imperfect results, though most indispensable to the proper elimination of the conditions essential to success, and most valuable, therefore, at the time of experiment, would, if described in this report, necessitate the introduction of lengthy details with regard to the modes of operation and causes of individual failure, which lose their interest or importance by the side of the methods of proceeding ultimately proved to be the best, and those results which were finally accepted as conclusive.

It is, therefore, considered advisable to confine the description of the various steps in the experimental operations at Chatham to those which were ultimately adopted, and only to employ the results of those which may be termed the preliminary experiments, for the purpose of demonstrating the necessity of certain precautions, or in illustration of points of importance for consideration in connexion with the system of exploding mines.

The locality selected for the operations was the same as that spoken of in Part II. of this report. The magnetic apparatus employed in all the field experiments was Mr. Wheatstone's arrangement of six small magnets just now spoken of (see Appendix for description of the instrument), which had been fitted for the purpose with a compact system of multiplying wheels, and so arranged that the whole apparatus was enclosed in a box, the only exposed portions being the binding screws for the attachment of the wires, a handle for setting the armatures in motion, and a key, by the depression of which, at a given signal, the circuit could be completed.*

To employ the instrument at any moment, the following were the operations necessary:—

The insulated wire and the copper wire passing to the earth were fixed to the apparatus by means of the binding screws; the instrument was raised from the ground by being placed on its packing-case; at that height a man could operate with it when in the kneeling posture.

At a signal "ready," the handle was turned with one hand, so as to cause the armatures to revolve with the greatest possible velocity, whilst the other hand was pressed against one corner of the instrument, close to the key, so as to steady the box and to be ready at the signal "fire," to depress the key with the thumb.

The connexion of the instrument with the earth was effected as follows:—

A moderately clean spade was selected from among those used by the men in digging holes for the charges. One end of a piece of stout copper wire was placed under the edge of the spade, in such a manner that when the latter was firmly forced into the ground it was pressed by the earth on both sides against the iron surface. The protruding wire was wound once or twice round the bottom of the spade-handle, and then attached to the binding screw of the magnet.

The gutta-percha-covered wire used in the experiments having been in occasional service at Chatham for some years, the coating had sustained some injury in two or three places. Such defects were protected from possible contact with the earth by means of waterproof cloth or sheet India-rubber. The total length of wire used was 881 yds., of which 600 were extended, lying along the ground.

The instrument was placed on the glacis of the ravelin in front of Cumberland Bastion, the ground sloping gradually towards the spot where the charges were exploded.

To the extremity of the covered wire a number (from 12 to 25) of pieces of similar insulated wire, varying in length between three and six yards, and serving to connect it with the individual charges, were attached in the following manner:—About six inches of the extremity of the main wire and of each of the branch-wires were laid bare, and cleansed; the end of the former was then surrounded with those of the latter (placed in an opposite direction), and the whole tightly twisted together by means of pliers, so as to be brought thoroughly into contact with each other and with the main wire. The twisted wires were

* The instrument employed in these experiments was subsequently purchased for the Royal Engineer Establishment at Chatham.

then bound round with moderately fine copper wire, which was made to bring every portion of the exterior of the bundle into connexion. The joint was made rigid with pieces of stick tied against it, and the whole securely enveloped in a piece of waterproof cloth or canvas, to protect it from damp and contact with the earth.

These connexions, though of a very rough description, and most readily prepared by any soldier, were thoroughly effectual. No instance occurred, in the whole of the experiments, of the failure of a charge, which could be attributed to an imperfect connexion of its branch-wire with the main wire.

The following was the method adopted for connecting the fuzes with their respective branch-wires and with the earth :—

The fuzes, as they were manufactured, were always fitted (as shown in Fig. 10) with two pieces of covered wire twisted together. They were thus ready for insertion into the bag or other receptacle containing the charge of gunpowder, the ends of the covered wires protruding from the opening of the latter to a convenient distance for effecting the junction with the branch and earth-wires. The extremities of one of the other fuze-wires and of a branch-wire (from both of which the gutta-percha was removed to a distance of about two inches) were connected by hooking them firmly one in the other with pliers (in the manner shown in Fig. 11). A piece of fine copper binding wire, about six or eight inches in length, was then twisted over the whole of the connexion, and the joint was finally enclosed in a small wrapping of oiled canvas, in a manner similar to that adopted at the principal junction with the main wire.

The extremity of the other fuze-wire was attached to an uncovered copper wire of sufficient length to bring the whole of the charges into connexion with each other in this manner. The wire was fixed in a convenient position by being twisted round short stakes or pickets driven into the ground, and its extremities were buried in the earth, being attached either to spades, as already described, or to zinc plates about eight inches square.

The very rapid and comparatively rough manner in which these various connexions were made (the tedious operation of brightening every metallic connexion, so essential with the employment of the voltaic battery, being dispensed with), and their universally efficient character, were particularly commended by the officers and men who witnessed and assisted in the experiments.

With reference to the earth-connexion, the employment of large metallic surfaces was also proved, by repeated experiments at Chatham and Woolwich, to be superfluous. The simple insertion, into the ground, of the uncovered extremities of the fuze-wires was found to afford a perfectly sufficient connexion for ensuring the ignition of the charges. The plan above described of connecting together the whole of the charges was, however, adopted as being undoubtedly the most certain mode of proceeding.

The largest number of charges which it was attempted to fire at once at Chatham was twenty-five. The ignition of twelve charges was repeatedly effected, and with such rapidity as to have the practical effect of a simultaneous discharge of the whole. With twenty-five charges, the interval between the first and last discharge was very decided, being certainly longer than when the same number of charges were fired at Woolwich with the employment of a greater length of wire, of which, however, the larger portion was coiled up, the space between the earth-connexions being only about one-half of that introduced at Chatham; yet it was considered that even the ignition of the twenty-five charges (at a distance of 600 yards from the magnet, and with the employment of 881 yards of covered wire, and, in addition, about 100 yards in the form of branch-wires), was effected with sufficient rapidity to allow of that number being employed in cases where a simultaneous discharge was required.

Another instance of the apparent effect of increased resistance (in the form of an increase in the length of wire laid out) in diminishing the rapidity of discharge, was observed in the employment of one branch-wire of four or five times the length of the others. A distinct interval was noted between the explosion of the other (eleven) charges and that of the one attached to the longer branch-wire.

Experiments were made to ascertain whether the employment of a second insulated wire, in the place of 600 yards of earth-connexion, would modify the rapidity of ignition of a number of charges; but no difference of effect was observed.

It need scarcely be stated that in dealing with electricity of induction, defects in the insulation of the main and branch-wires had to be very carefully guarded against. Several failures in the first experiments were eventually traced to some defect of that kind. An instance even occurred, before the proper method of protecting the connexions of the charges with the insulated wires was adopted, in which the deposition of moisture upon the gutta-percha-covered wire, near the charge, prevented the ignition of the latter, by forming a connecting link between the extremity of this wire, where it was exposed and attached to the fuze, and the uncovered wire leading to the earth in consequence of the two wires being in contact at a distance of several inches from the fuze.

It is therefore always a preliminary precaution of primary importance, that the insulating covering of the wire to be employed be carefully inspected while the latter is being laid out for use, and that any imperfections be protected from possible contact with the earth or from the access of moisture; a result readily attainable by the application of some waterproof envelope to the injured portion.

The experiments instituted at Chatham with the object of applying the magneto-electric current to the ignition of *sub-marine* charges were attended with greater difficulties than those which served to test the system in its application to land operations; nevertheless, the results ultimately attained were also of a character to lead to definite and favourable conclusions.

The method of establishing the connexions of a charge with the wire and the earth differed naturally in some respects from the mode of proceeding already described.

The charges of powder were contained in canisters of block-tin carefully soldered, so as to be water-tight. Any vessels of this material, such as turpentine cans, may be employed, provided they be perfectly coated inside with marine glue, or some other description of varnish.

The fuze, with two wires attached as before, the one a few inches longer than the other, was inserted into the charge, and fixed in its proper position in the canister by means of a loose-fitting bung, pushed a little distance into the neck, and cut out on one side, so as to admit of the passage of the longer insulated wire, while the bare part of the shorter wire was firmly pressed by the cork against the inside of the neck. The latter was then completely filled up with melted gutta-percha, and the extremity of the short uncovered wire was bent back over its side, so as to be in close contact with the metal surface. In this manner the enclosed fuze was brought into good metallic connexion with the wet earth or water by which the canister would be surrounded. (See Fig. 12.)

The insulated wire projecting from the mouth of the canister was connected with one of the branch-wires in the manner already described; but, in order thoroughly to protect the connexion from the water in which it would become immersed, a piece of vulcanized India-rubber tubing of suitable length, and a tin tube rather longer and wider than the latter, were slipped on to the branch-wire, before it was joined to the fuze-wire, and when the junction had been effected, the India-rubber tube was pulled over it, and tied very firmly at both ends on to the gutta-percha covering of the wires. (See Fig 13.)

A small quantity of cement (consisting of bees-wax and turpentine) was rubbed in between the latter and the ends of the India-rubber tube, so as thoroughly to ensure the exclusion of water, and finally, the tin tube was pulled over the joint, and fixed (by compressing the ends), for the purpose of imparting rigidity to the junction, and thus protecting it from injury by a sudden twist or strain. By these arrangements, when carried out with moderate care, the perfect exclusion of water from the charge, and from its connexion with the branch-wire, was effected.*

The first trials of these charges were made in a shallow canal with a mud bottom, and from which at the time of experiment the water was receding so rapidly, that before the whole of the charges had been immersed several of them were left half imbedded in the mud. Twenty-five charges were arranged, of which 13 were exploded, though less rapidly than in the experiments on land. On the next occasion, when twenty-five charges were regularly surrounded by water (simply resting upon the firm bed of a pond of some depth), only four of the charges were exploded. Several other attempts were made to fire a smaller number of (ten and five) charges, similarly immersed, but in every instance only four were ignited. A careful examination into the cause of the invariable explosion of so comparatively limited a number of charges under water led to the following explanation.

* In an equipment prepared a few months ago for effecting sub-marine explosions, by means of the magnet, in China, stout bags of vulcanized India-rubber (as proposed by Captain the Hon. G. Wrottesley, R.E.) were provided for the reception of the charges. These bags were fitted with sockets and screw-plugs of gun metal. The fuzes furnished for use with these bags were attached to two pieces of covered wire, about 18 inches long, which were enclosed side by side in a cylindrical plug of gutta-percha about 4 inches long, and carefully made to form one mass with the coating of the enclosed wires. (See Fig. 14.) This plug was made to fit pretty tightly into a thick washer of India-rubber, contained in the socket of the bag. An inner screw-socket, which was brought to bear with great force upon a metal ring resting on this washer, when the plug had been inserted, compressed its internal surface against the latter in such a way as to ensure a perfectly water-tight joint.

It will be remembered that the explosion of numerous charges in a divided circuit by the magneto-electric apparatus with revolving armatures, is effected by the action of an exceedingly rapid succession of currents. The rapidity with which they follow each other, however great, cannot equal that with which the terminals of a fuze, exploded in a small charge under water, come into contact with the latter after the explosion. The instant this occurs a complete circuit is established through the water, and any further action of the currents is at once arrested.

By the time, therefore, that four charges had been ignited in extremely rapid succession, so as to be apparently exploded at once, a sufficient interval of time had in reality elapsed to allow the water to re-occupy the space filled for a brief period by the gaseous products of the first explosion, and thus to rush in upon and complete the circuit with the terminals of the fuze. It appears probable that, with the employment of larger charges of powder (about eight ounces was the quantity exploded in each charge), when the volume of water displaced by the explosion would be more considerable, a greater number of charges would be exploded before the circuit could be completed by the water. No opportunity occurred, however, during the experiments, of ascertaining this by actual trial.

The instances, however, in which it is indispensably necessary that a number of charges should be exploded together, suspended in water, or simply resting on the ground below, and being in immediate contact on almost all sides with water, appear to be of exceptional occurrence.

It is believed that charges are generally so arranged for submarine operations as to be partially or completely surrounded by the objects upon which the force of the exploding charge is to be exerted, and that they are even at times firmly fixed in their position by being partly or wholly embedded in sand, mud, or some similar material. In such cases, the resistance to be overcome by the explosion is greater than if, under conditions otherwise similar, the charges were simply in direct contact with the water, and hence the interval is increased which must elapse before the water can complete the circuit.

The results of some experiments made at Chatham appear to show that, under such circumstances, the number of charges ignited at one time by the magneto-electric apparatus must be greater than if they were simply immersed in water. One experiment has already been mentioned, in which thirteen charges out of twenty-five were exploded at one time, most of them being imbedded in mud.

On another occasion the charges were placed in small pits filled with water, the canisters being covered in with mud beneath the latter. Nine of the charges were fired; the branch-wire of the tenth was accidentally severed at the moment of the explosion, from its lying across one of the pits.

An attempt was made to fire simultaneously fourteen charges similarly arranged, by the current obtained from the large lever magnet, but only seven were exploded; the other seven were fired on a second trial. It should be mentioned that the length of extended wire and the interval between the earth-connexions were greater in these experiments than in those made at Woolwich with the large magnet, in which twenty-five charges were fired with perfect certainty by the single current obtained from it. Possibly the very great difference in the results obtained might have been partly due to some minute defects in the insulation of the branch-wires employed at Chatham, which escaped notice on the inspection of the wires, but sufficed to diminish the intensity of the current when these were immersed in water.

It is most difficult, even in a long continued series of carefully observed experiments, to separate the pure results furnished by the application of a system, such as that which forms the principal subject of this Report, from results which are brought about, or, at any rate, greatly modified by accidental circumstances. It appears, however, apart from the latter, that in the application of electricity (whether frictional or magnetic) to the explosion of charges the effects to be produced by the current are modified by the resistance offered to it in its passage along wires of very considerable length, and that the effects of the current seem very much less when the insulated wire is extended than when it is employed in the form of a coil.

The retardation in the explosion of several charges in divided circuit by a rapid succession of currents, and the diminution in the number of charges fired by one single powerful current, both of which results were repeatedly noticed in the course of the many experiments with the magneto-electric and hydro-electric machines, could only be ascribed to modifications in the intensity of the electricity by the greater resistance which is encountered.

Conclusions.

The conclusions arrived at by a careful consideration of the results furnished by the series of experiments on the application of magneto-electricity to the explosion of charges are as follows:—

Firstly. The explosion of a single charge of powder by means of the phosphide of copper fuze and a magneto-electric apparatus (even of the smallest size generally manufactured) is absolutely certain.

Secondly. The phosphide of copper fuze is as safe and permanent as any arrangement employed in the service for the ignition of gunpowder by the aid of friction or percussion.

Thirdly. With the employment of a magneto-electric apparatus similar to that used in the Chatham experiments, and termed by Mr. Wheatstone the "magnetic exploder," the ignition, at one time, of fuzes varying in number from two to twenty-five, is certain, provided these fuzes are arranged in the branches of a divided circuit in the manner described. To attain this result it is only necessary to employ a single wire, insulated by a coating of gutta percha or India-rubber, and simple metallic connexions of the apparatus and the charge with the earth.*

Fourthly. The explosion of from twelve to twenty-five charges may be effected in the above manner, at a distance of at least 600 yards from the apparatus, with a rapidity which in its results will in all probability have the practical effect of a simultaneous discharge. This statement refers only to charges on land.

* An uncovered wire, raised from the ground, and supported on poles by insulators, might also be successfully applied.

Fifthly. The number of sub-marine charges which can be exploded with certainty at one time by means of the magnetic exploder, is more limited; but if such charges are entirely or partially imbedded in sand, mud, or other dense materials, from two to ten may be fired with certainty. If the charges are suspended in, or immediately in contact with water, only four can be exploded at one time with certainty. This statement is based upon the employment of small charges (about 8 oz.), and it is possible that with heavier charges a larger number may be exploded.

By the employment of separate wires, leading from the instrument to each charge, or by adopting Vicomte du Moncel's rheotomic arrangement (referred to in Part I.), there is little doubt, however, that the results obtained with the magnetic exploder in submarine operations would be quite equal to those definitely established for the ignition of charges on land.

Sixthly. The only important precautions to which it is necessary to attend rigidly, in order to ensure uniform success in the application of the magnet, are the proper insulation, throughout, of the main wire and branch-wires leading from the instrument to the charges, and the thorough protection of all connexions of wires from the access of moisture.

Seventhly. The system of firing charges by magneto-electricity possesses important advantages over the application of the voltaic battery to the purpose. The following are the principal of these:—

a. The magnetic exploder is at any time ready for immediate employment; it is easily transported by hand, being of small dimensions and weight; it is not liable to injury or derangement, provided the most ordinary care be applied to its preservation and transport; it may be employed for many years without suffering any important diminution of its power; and, as all arrangements in connexion with the instrument are mechanical, any injury which they may sustain can be repaired by ordinary workmen.

b. The magnet-fuze is more certain than any fuze-arrangement applied with the voltaic batteries. It may be preserved for a great length of time in any climate, and will bear very rough treatment without chance of injury.

c. The implements and materials required for carrying on operations with the magnet, in addition to the instrument, the wire, and the fuzes, are very few in number, inexpensive, and readily replaceable; they occupy but little space, and require no more care in their transport than ordinary artisans' tools. (A list of the requisites is given in the Appendix, to which is added some account of the proximate expense of the principal items.)

d. All the operations necessary in the employment of the magnet (the connexion of the fuzes with the instrument, their introduction into the charges, and the explosion of these), are of the simplest possible character, and can therefore be performed by any person of the most ordinary intelligence.

It can be confidently affirmed that the general certainty of the magneto-electric arrangement is decidedly greater than that of voltaic batteries, and that the necessity of ensuring a proper insulation of wires and connexions, though it may be regarded in the light of a difficulty by those accustomed to carry on operations with the voltaic current, is in reality a condition which may be fulfilled readily and with certainty by the use of very simple means and precautions.

There is little question that with battery-power of great magnitude, and with the successful fulfilment of the numerous indispensable conditions and precautions (which long experience has shown to be almost a matter of chance), it is possible to fire at one time a very much larger number of charges than those which have been quoted as the greatest task to be accomplished with certainty by the apparatus proposed for general use.

It has, however, been stated by high military authorities on these subjects, that the instances in which it is required to fire more than from twelve to twenty charges at one time are quite exceptional, and that, indeed, twelve may be considered as the greatest number of charges which it may be necessary to apply in all general operations.

In special cases, such as the destruction of very massive works, where it would be advantageous to apply the force of exploding gunpowder simultaneously to a very large number of different places, the employment of arrangements of a special character is always admissible.

The reporters are strongly of opinion that the instrument which, in such instances, will furnish results far surpassing in magnitude and in certainty those attained by the most powerful voltaic batteries hitherto applied, is the hydro-electric apparatus of Armstrong, which, they feel convinced, may be so arranged in its details as to admit of ready application with confidence in the most extensive mining operations.

A considerable number of experiments would, however, still be required before its adoption in such instances could be confidently recommended.

For all operations of a general character, however, it is considered that the results obtained, up to the present time, have satisfactorily proved that the system of exploding charges, whether in the form of mines, or for proof and experimental practice with guns, by a magneto-electric current, is, in point of certainty and simplicity, superior to any other which has hitherto received application, and that no impediment whatever exists to its being at once adopted in military operations.

C. WHEATSTONE.

F. A. ABEL.

APPENDIX.

I.—Description of Wheatstone's Magnetic Exploder.

The magnetic apparatus employed in all the field experiments was designed especially for the purpose by Mr. Wheatstone.

It consisted of six small magnets, to the poles of which were fixed soft iron bars surrounded by coils of insulated wire. The coils of all the magnets were united together, so as to form, with the external conducting wire and the earth, a single circuit. An axis carried six soft iron armatures in succession before each of the coils. By this arrangement two advantages were gained; all the magnets simultaneously charged the wire, and produced the effect of a single magnet of more than six times the dimensions, and at the same time six shocks or currents were generated during a single revolution of the axis, so that, when aided by a multiplying motion applied to the axis, a very rapid succession of powerful currents was produced. A single large magnet with a rotating armature could not be made to produce the same succession of currents without the application of considerable mechanical power. Another peculiarity of this apparatus was that the coils were stationary, and the soft iron armatures alone were in motion; by this deposition the circuit during the action of the machine was never broken. In the usual magneto-electric machines with rotating armatures the circuit is necessarily broken twice during every revolution, and this frequently gives rise to irregularities in the production of the currents. By the construction adopted, the currents can never fail to traverse the circuit.

The total weight of the instrument, enclosed in a case, as described in the Report, Part III., was 32 lbs. 11 oz. It was enclosed for transport in a small packing case, weighing about 7 lbs.

Some further important improvements have recently been effected by Mr. Wheatstone in the magnetic exploder, whereby its size and weight have been very considerably diminished.

II.—Description of the Construction of the Magnet-Fuzes invented by Mr. Abel, and of the Mode of Preparation of the Priming Material used in the Fuze.

The fuze for mining purposes consists of—

a. A head for receiving the wires which connect the fuze with the magnet and the earth;

b. Of the insulated wires, with the terminals of which the priming material is in close contact;

c. Of a small cartridge or charge of powder, enclosing the terminals, upon which the sensitive composition rests.

The fuze-head, which is of box-wood, contains three perforations (Figs. 4 and 5); the one, passing downwards through the centre, receives about two inches of double insulated wire, *a*, *a*, (Figs. 4 and 5, two copper wires of 24-gauge

0·022-inch diameter, enclosed side by side, at a distance of $\frac{1}{16}$th inch, in a coating of gutta-percha of $\frac{1}{8}$th inch diameter)*; the other two perforations, which are parallel to each other on each side of the central one, and at right angles to it, serve for the reception of the circuit-wires. The arrangement for securing the connexion of these with the insulated wires in the fuzes is as follows:—

The piece of double covered wire above referred to is originally of a sufficient length to allow of the gutta-percha being removed from about one and a half inches of the wires. These bare ends of the fine wires, which are made to protrude from the top of the fuze-head, are then pressed into slight grooves in the wood, provided for their protection, and the extremity of each is passed into one of the horizontal perforations in the head, in which position it is afterwards fixed by the introduction into the hole of a tightly fitting piece of copper tube, so that the wire is firmly wedged between the wood and the exterior of this tube, and is thus at the same time brought into close contact with a comparatively large surface of metal. It will be seen that it is only necessary to fix one of the circuit-wires into each of these tubes, in the opposite sides of the fuze-head, in order to ensure a sufficient and perfectly distinct connexion of each one of them with one of the insulated wires in the fuze.

The extremity of the double covered wire, which protrudes to a distance of about three-quarters of an inch from the bottom of the fuze-head, is provided with a clean sectional surface by being cut with a pair of sharp scissors, care being taken that the extremities of the fine copper wires are not pressed into contact by this operation.

A small cap of about half an inch in length is then constructed of thick tinfoil (Figs. 4 and 6), into which is dropped about one grain of the priming material. The double wire is then inserted, and pressed firmly down into the cap, so that the explosive mixture is slightly compressed, and in close contact with the surfaces of the wire-terminals.

The cap is fixed by winding a piece of twine once or twice round its upper part, tightening the ends of this, and then removing it. The actual fuze is then ready for enclosure in a small charge of gunpowder. (Figs. 7 and 8.) The powder is contained in a paper case tied on to the head, or in a cylinder of sheet tin tightly fitting on the fuze-head at one end, the other, after the introduction of the powder, being closed with a plug of clay or plaster of Paris.

It is advisable (as stated in the body of the Report), to have the fuzes ready fitted with pieces of insulated wire about two feet in length, twisted together as shown in Fig. 10. The ends of the wires, after they are passed through the connecting holes in the fuze-head, should be tightly fixed in their position by the introduction of a short piece of copper wire.

The phosphide of copper fuze for firing cannon (Fig. 9) differs slightly in its construction from the mining fuze. The fuze-head is longer than in the latter, and of such a form that the double covered wires (which are fitted into it in the manner already described) are completely enclosed in it, the lower extremity of

* This description of double wire has been prepared by the Gutta Percha Company for this particular purpose in considerable lengths (300 yards), from which the pieces of requisite length are cut off as required. The insulation of the two wires has been found perfect throughout the whole length manufactured at one time.

its central perforation still remaining free to receive the top of the quill or copper-tube charged with powder, like the ordinary tube arrangement for firing cannon.

The priming material contained in the fuze is prepared by reducing separately to the finest possible state of division the sub-phosphide of copper, sub-sulphide of copper, and chlorate of potassa, and then mixing these powdered substances very intimately, in the proportions of 10 parts of the first, 45 of the second, and 15 parts of the third, by rubbing them well together in a mortar, with the addition of sufficient alcohol to thoroughly moisten the mass. The mixture is afterwards carefully dried, and may be safely preserved in closed vessels until required.

III.—List of Implements, &c., required for Operations with the Magnetic Exploder.

1. Magnetic Exploder.

The cost of a thoroughly sufficient instrument is inconsiderable, but varies naturally with its size and power.

The large lever-magnet referred to in the Report was purchased by the War Office for £70, but an efficient magnetic exploder will cost, according to the number of magnets of which it is composed, from £16 upwards.

2. Insulated Wire.

In addition to the main wire, a quantity must be provided sufficient for making the various branch connexions. The wire which may be employed is of two kinds:—

a. Copper wire of 16-wire gauge, covered with a coating of gutta-percha of $\frac{1}{4}$-inch diameter. The cost of this wire is at the rate of from £27 to £29 per mile. (Although the use of a somewhat thinner wire is admissible, it is considered desirable for all general purposes to use a wire of the above diameter.)

b. Copper wire of same gauge as the last, coated with India-rubber, and provided with an efficient protective hemp covering. The diameter of this wire would be about $\frac{1}{4}$-inch, and its cost would not exceed £25 per mile.

A wire of this description is considered to possess undoubted advantages over gutta-percha covered wire. The very uncertain durability of gutta-percha, when exposed to the action of air and light, renders the excellent insulation which it affords to wire, as long as the coating continues perfect, a matter of uncertainty after the wire has been in use for a comparatively short period.

The coating frequently becomes in time so rigid, and almost brittle, that it is readily injured by use, and will sometimes not bear a slight bend without cracking. Some of the wire employed in the experiments referred to in this Report, and the coating of which was originally perfect in condition, is now quite unfit for use, the gutta-percha having become brittle, and in some places pulverulent. Other pieces of wire, procured at about the same time, and used with the above, are apparently still in good condition.

ABEL'S

AGNET FUZES,

for

MINES AND ORDNANCE.

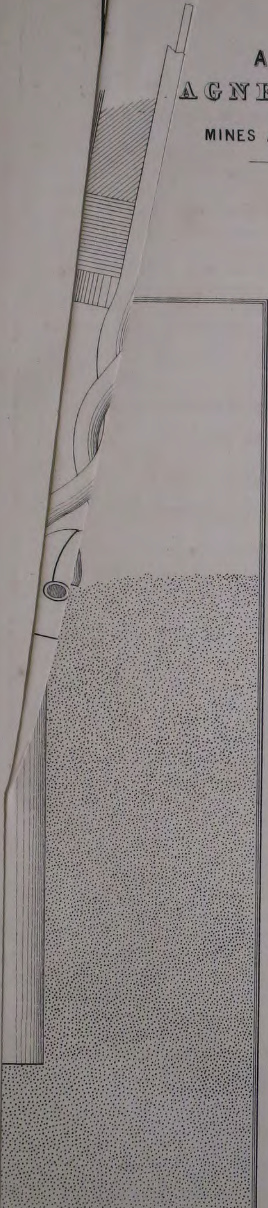
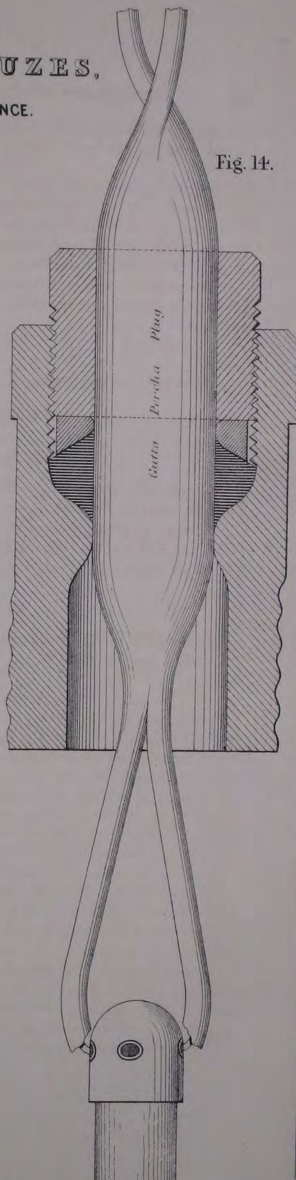


Fig. 14.



The India-rubber coating also appears to suffer some change after long exposure to air and light. This change is, however, apparently not detrimental to its plasticity. The hemp coating, with which the wire above referred to is provided, to protect the India-rubber from injury in use, will also in all probability prevent it from suffering change. Under any circumstances, however, there is very little doubt that much greater dependence can be placed upon the permanent insulation of wire coated with India-rubber. The comparatively low temperature at which gutta-percha becomes very soft (the average temperature of tropical climates being quite sufficient to produce that result) is a defect which gives the India-rubber another important advantage over that substance.

Other good insulating materials have recently been prepared, with special reference to their employment in hot climates. The experience gained up to the present time with respect to their durability is, however, too limited to allow of their being positively recommended for employment.

3. The magnet fuzes. The cost of the fuzes is calculated at threepence halfpenny each.

4. Copper wire of 16-gauge, for earth and other connexions.

5. Fine copper binding wire (25-gauge).

6. Oiled canvas, or other cheap waterproof material.

7. Vulcanized India-rubber tubing, $\frac{3}{8}$-inch internal diameter.

8. Twine.

9. Pliers (for cutting and twisting wires.)

10. Knife (common, for cutting gutta-percha, &c.)

11. Box of cement (mixture of beeswax and turpentine, or any other good soft cement of a similar kind.)

12. One or two small files (for cleaning wires, after removal of gutta percha.)

13. Wooden pickets.

14. Small pieces of thin wood for stiffening connexions (any wood obtained on the spot will do.)

PAPER XII.

ON THE DESTRUCTION OF BRIDGES.

By GEN. SIR J. BURGOYNE, Bart., G.C.B., &c.

The following translation of an Austrian account of the attempted destruction of the bridge over the Ticino at San Martino, near Magenta and Buffalora, during the campaign of 1859, is of interest*.

" General instructions were issued to the Austrian Engineers in 1858, for mining the new bridges and viaducts in readiness for blowing them up, as well as a special order to prepare a project for destroying the old bridge at San Martino. It was therefore proposed to bore cylindrical holes 8 inches in diameter horizontally across it, over two of the arches, according to a plan recommended in the instructions.

This operation was however considered objectionable, because it might affect the stability of the arches, and the explosion would not be certain to destroy the bridge, for the chamber of the mine having but little brickwork over it, the explosion might take effect in an upward direction only. It was therefore subsequently proposed to sink two shafts, each 30 inches square, in the direction of the longitudinal axis of the central pier of the bridge which was to be destroyed. From the bottom of each shaft, galleries, 30 inches high and 24 inches wide†, were to run in both directions, that is four galleries in all. Each gallery was to terminate in a chamber, to contain 62 lbs. of gunpowder, and the centres of these were to be 9 feet from each other, the line of least resistance being equal to half the thickness of the pier, or 6 feet 4 inches.

The Committee of Engineers, ordered to report on this plan, made a third proposal. The shafts, galleries, and chambers were to be replaced by four cylindrical holes 7 inches in diameter, bored vertically, at the bottom of each of which there was to be a chamber 6 inches in diameter. Seventy pounds of 40°

* The destruction of this bridge was of the greatest consequence to the Austrians, for when they retreated from it, leaving it in such a state as to be passable for troops, the French were enabled to cross in sufficient numbers to win the battle of Magenta before their opponents were concentrated. Between the Ticino and the town of Magenta however they encountered another obstacle, viz., the Grand Canal, which would have checked them for a long time if properly defended; but although the four bridges across it were mined, only two of them were blown up; and near one of these the Austrians left some planks which enabled the French easily to restore the roadway. The great importance of proper arrangements for destroying bridges thoroughly and with certainty is thus forcibly illustrated by the operations of one day.—Ed.

† These dimensions appear too small for shafts and galleries, the Austrian inch being very little longer than the English inch.—Ed.

powder were required for each hole, or 280 lbs. for each pier, this calculation having been based on the presumption that the co-efficient g should be taken at 0·255, the same as for compact rock.

The Committee were induced to make this proposal because they considered the making of shafts, galleries, and chambers, too difficult, and likely to affect the stability of the bridge, an apprehension shared by all the architects who were consulted.

Finally these three projects were thoroughly considered, and reported on as follows:—

1. Considering the strength of the bridge, and the great thickness of its arches, which were built of granite, as well as the weakness of the filling in above them, the destruction of an arch could not be expected by boring a cylindrical hole 8 inches in diameter horizontally through the keystones, nor could the use of jumpers be recommended to make these holes, for fear of weakening the arches too much.

2. The making of shafts and galleries would be a tedious and difficult operation, which would endanger the solidity of the bridge, and the chambers would moreover be liable to be flooded when the water was high, and could not be charged and tamped without difficulty.

3. The cylindrical holes proposed by the Committee of Engineers deserve the preference, provided that they were made more than 7 inches in diameter.

This proviso was made because it was considered that the diameter of cylindrical chambers for blasting must not be very small, as the effect of an elongated charge placed in a narrow hole is not equal to the effect of the same quantity of powder placed in a cubical chamber, and that consequently a charge concentrated in a chamber of large diameter must have a greater effect than an equal charge lodged in a narrow hole.

In accordance with these recommendations a diameter of 12 inches was adopted for the holes proposed by the Committee, whilst the canisters placed in them were to be 10 inches wide and 3 feet high, and were to contain 70 lbs. of powder. In other respects the proposals of the Committee were adopted, and four charges were ordered to be placed in each of the two piers nearest to the abutment on the east side of the river. (See Plate.)

In consequence of the alterations proposed on the spot, and subsequently sanctioned, the charge of powder in each hole, the diameter of which was 12 in., only reached to b, instead of being $6\frac{1}{2}$ feet high, and reaching to a, above the centres of the voussoirs, as would have been the case had the diameter of the holes been 7 inches.

Suitable implements for boring the holes were wanting, and none could be procured at the moment, owing to the breaking out of the war. The chambers were blasted therefore with gunpowder, and the holes made were much larger than necessary, and of very irregular shape. To meet this evil and produce the necessary width and smoothness, a pole had to be let down into each, and the interval between it and the masonry was filled up with bricks. The expenditure of powder used in this blasting was very much regretted subsequently, when another supply could not be procured, and it would then have been of essential service.

The manner in which the holes had been made necessarily diminished the effect of the mines. The powder was deposited within a mass of unequal consistency, consisting of granite, mortar, and bricks, and fissures moreover had been made in the masonry during the blasting, which, though scarcely perceptible, allowed the gas to escape prematurely, thus considerably weakening the general effect.

When orders arrived during the night of the 2nd June to blow up the bridge, the chambers were filled with 70 lbs.* of powder in each, and partly tamped with sand; but it has not been ascertained whether the upper part was properly filled with clay and fragments of stone.

On ignition five only of the mines exploded, with a rather strong detonation, including the four in the first pier but only one in the second.

After this unexpected failure the remaining charges were at once examined, and being found intact, were successfully exploded by means of electricity, and it was expected that the arches would then fall.

The second detonation equalled the first, but the arches did not fall. The masonry below them had been destroyed, and they had sunk at the keystones two or three feet; the road across the bridge formed a concave line, and was full of fissures, and the balustrades, formed of blocks of stone, had been precipitated into the river.

The annexed photograph shows the condition of the bridge after the second explosion, the first pier, where all four mines had exploded, being full of fissures, whilst the second pier, where one mine only exploded during the first ignition, and the three others during the second, has suffered much loss.

As there was no powder in reserve two guns were ordered to batter the parts of the bridge most injured, in order to cause the arches to fall, but without success.

The extraordinary hardness of the granite arches, the masonry of which had grown, as it were, into one mass, and was moreover probably secured with iron cramps and stone dowels not visible on the outside, explains how the arches could suddenly sink two or three feet without being ruined, in spite of the destruction of the masonry below the arches and the material change in the positions of the voussoirs consequent upon it, which, when we consider the condition of the first pier, could scarcely be otherwise explained†.

There is no doubt that if a larger quantity of powder had been placed rather higher, the arches would have fallen. Probably the result would have been the same if the quantity of powder actually used had been placed in a narrower hole, as originally proposed, when it would have reached up to *a*, instead of being concentrated lower down in a wider hole.

This latter opinion is justified by the success of the blasting operations at Vienna, in 1858. A charge of powder 5¼ feet high, with a tamping of 45 inches and a line of least resistance of more than 4 feet, placed in a bored hole 9 feet deep and 2¼ inches wide, then effected the demolition of part of a strong wall 11 feet high and some centuries old. We are justified therefore in believing

* 86 lbs. English.

† From the photograph it appears that a layer of masonry 2 or 3 feet thick was blown out from the pier and that the arches sank on to a new bed.—Ed.

that charges of powder 6 inches in diameter, and reaching up to *a*, would have had the desired effect upon the arches of this bridge, though the charges 10 inches in diameter and 3 feet high proved abortive.

The unsatisfactory result cannot however be ascribed solely to the extraordinary firmness of the masonry, which was provided for by the charge being calculated by the highest co-efficient, but rather to the existence of other injurious influences. It could not be ascertained whether the powder used actually had the supposed strength of 40°; the holes were bored in a manner which necessarily lessened the effect of the mines; and the tamping and ignition took place in the dawn of the day, and may not have been managed efficiently.

It would have been desirable no doubt completely to destroy this bridge, but as far as immediate consequences were concerned the condition of the imperfectly blasted arches compelled the enemy to throw a bridge across the river close to it, not being able to cross by it owing to the damage it had received."

I attribute this failure to the Austrian Engineers, who are able and scientific, having aimed at too much refinement in the operation; a refinement which may be very proper where all necessary time and means are available, but is scarcely practicable in a campaign;—thus, the account here shows, in one part, a want of the implements necessary for making the openings as determined upon; a deficiency at last in the requisite quantity of powder; doubts expressed as to the powder having the particular degree of strength calculated upon; and a failure in the ignition of three charges out of eight; all of which difficulties, it is apprehended, might have been provided against by adopting a more simple off-hand manner of proceeding.

In destroying a bridge in a campaign, the system should vary with the time and means available;—it is rare that that which is most correct, theoretically, can be adopted; and, generally, every disadvantage may be counteracted by employing *plenty of powder*. The object being destruction, it is of far less consequence to have that in the extreme than to fail in obtaining what is required.

In campaigning it is an established principle (or at least it ought to be) to do as little injury to the country and to the inhabitants as can be consistent with what is absolutely required for military progress and success.

As regards the plan for the destruction of this bridge, had the mines fully succeeded, they would have brought down three arches, while probably one would have been quite sufficient for the object of a temporary impediment to the enemy; and by confining the attempt to one the means available would have been more ample; but even by the very system adopted, if the charges had been confined to one pier, and been effective, two arches would have been destroyed, with scarcely more than half the means required for acting on the two piers, and the operations would have been far more simple for firing the four charges instead of eight; with the same quantity of powder also, the charges would have reached the point *a* in the section, to which so much consequence is attached.

But I should have been inclined to adopt a different course altogether, and to have run a gallery, as small as men could work in, say from 3 to 4 feet high by about 3 feet wide (either from the outside or from the bottom of a shaft sunk from the surface of the path or roadway), over the most solid part of the pier, that is at the level of the springing of the upper surface of the arch stones, with returns to the haunches of the arches, where two charges might be placed at equal distances between the two faces of the bridge; then tamping the galleries as substantially as circumstances would allow, I should feel no doubt that the quantity of powder, which I calculate as having been more than 680 lbs. English, would have effectually destroyed the arch, by acting as globes of compression, although the lines of least resistance would have been in other directions.

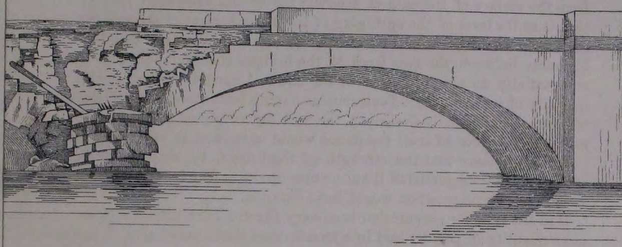
It is quite clear that the strength of the bridge, by construction and being cemented by time, rendered it quite unnecessary to fear taking any such liberties with it as this preparation would have entailed.

Had the time for preparation been very short, I have little doubt but that the same quantity of powder laid in a trench over about one-fourth of the width of the bridge, in the middle, and in one mass on the very crown of the arch, would have made an opening of considerable width at least, if it did not bring it all down, particularly if circumstances would have admitted of applying a loading of heavy stones from the parapet, over the charge.

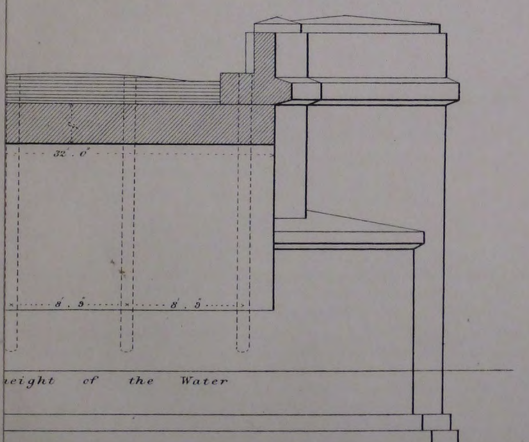
There must have been some want of a power of co-operation between the services of the Artillery and Engineers, when a deficiency of powder for the mines, by the use of a part of it in blasting the holes, is mentioned as a possible cause of the failure, considering that a quantity, probably larger, was subsequently expended in an attempt to complete the destruction by the fire of Artillery.

J. F. B.

A PHOTOGRAPH.



TION AT THE CROWN OF THE ARCH.



PAPER XIII.

A LUNAR TIDAL WAVE IN LAKE MICHIGAN,

DEMONSTRATED BY

BREVET LIEUT. COL. J. D. GRAHAM,

UNITED STATES TOPOGRAPHICAL ENGINEERS.

COMMUNICATED BY COLONEL NELSON, R.E.

Chicago, Illinois, July 19th, 1860.

To the Secretary of the American Philosophical Society, Philadelphia :

Dear Sir,—I have made all the necessary astronomical observations and electric signals for determining the latitude and longitude of twelve additional positions in the West; but have been so pressed with my public duties that I have not been able to take up their computation. When I can find time to do so, I will communicate them, as heretofore, for the "Society's Proceedings." I find that, in several instances, they will give results differing much from those given in the published maps.

I have now nearly completed a paper, which I intend to offer for publication in the "Society's Transactions," on the Discovery and Demonstration of the Existence of a Semi-Diurnal Lunar Tidal Wave on Lake Michigan. It is based on 9,184 observations made on the tide-gauge, at Chicago, of the elevation of the surface of this lake, between the 1st of January and the 1st of July, 1859.

The observations were carried on uninterruptedly, both day and night (except in a few instances, when violent storms would have rendered them inaccurate), at intervals of half an hour, as a general rule, and sometimes at intervals of fifteen minutes of time apart.

From this series of observations we deduced the half-hourly (and in two places the quarter-hourly) co-ordinates of altitude of the lake surface, compared with the time (before and after) of the moon's meridian transit, as follows. Here each co-ordinate, expressed in decimals of a foot, is derived from a mean of 340 observations.

TABLE 1.

Showing the half-hourly (and in two places the quarter-hourly) co-ordinates of altitude of the average semi-diurnal lunar tidal wave at Chicago, on Lake Michigan, derived from 9,184 observations made between January 1st and July 1st, 1859.

Mean solar interval of time before or after the moon's meridian transit.		Observed elevation of the Lake surface in decimals of a foot.	
	H. M.	FT. DEC.	
Before the moon's meridian transit.	5.35	0.000	Lunar mean low water.
	5.30	0 004	
	5.00	0.008	
	4.30	0.016	
	4.00	0.030	
	3.30	0.040	
	3.00	0.053	
	2.30	0.078	
	2.00	0.087	
	1.30	0.089	
	1.00	0.115	
	0.30	0.130	
	0.00	0.140	Moon in the meridian.
After the moon's meridian transit.	0.30	0.146	Lunar mean high water.
	0.45	0.143	
	1.00	0.134	
	1.15	0.134	
	1.30	0.130	
	2.00	0.116	
	2.30	0.112	
	3.00	0.082	
	3.30	0.066	
	4.00	0.048	
	4.30	0 040	
	5.00	0.032	
	5.30	0.024	Slightly discrepant, owing to a preponderance of unfavourable winds at this period.
	6.00	0.030	
	6.30	0.012	
	6.50	0.000	Lunar mean low water.

The accompanying profile, marked Fig. 1,* shows the mean semi-diurnal tidal wave at Chicago, projected from the foregoing co-ordinates, embracing every vicissitude of winds and weather, &c., which occurred during the whole six months' observations. It shows the altitude of this mean tidal wave to be, at its summit, .146 of a foot, equal to $1\frac{3}{4}$ inches; and the average time of high-water is thirty minutes after the time of the moon's meridian transit.

On a close examination of all the observations embraced in the series, we find 189 which we think ought to be rejected, because influenced in an extraordinary degree by unfavourable winds. This would reduce the number of observations in the series to 8995; and each co-ordinate of altitude would depend on a mean of 333 observations, and stand as follows, viz.:

* These are not reprinted, as they can be deduced from the Tables.—Ed.

TABLE 2.

Showing the half-hourly (and in two places the quarter-hourly) co-ordinates of altitude of the average semi-diurnal lunar tidal wave at Chicago, on Lake Michigan, as derived from 8,995 observations, made between January 1st and July 1st, 1859.

Mean solar interval of time before or after the moon's meridian transit.		Observed elevation of the Lake surface in decimals of a foot.	
	H. M.	FT. DEC.	
Before the moon's meridian transit.	5.35	0.000	Lunar mean low water.
	5.30	0.005	
	5.00	0.004	
	4.30	0.013	
	4.00	0.030	
	3.30	0.041	
	3.00	0.054	
	2.30	0.078	
	2.00	0.090	
	1.30	0.098	
	1.00	0.108	
	0.30	0.127	
	0.00	0.148	Moon in the meridian.
After the moon's meridian transit.	0.30	0.153	Lunar mean high water.
	0.45	0.148	
	1.00	0.137	
	1.15	0.134	
	1.30	0,132	
	2.00	0.113	
	2.30	0.107	
	3.00	0.084	
	3 30	0.056	
	4.00	0.040	
	4.30	0 031	
	5.00	0.025	
	5.30	0.023	
	6.00	0.024	
	6 30	0.010	
	6.50	0.000	Lunar mean low water.

The accompanying profile, marked Fig. 2, shews the character of the mean semi-diurnal tidal wave projected from the modified general result given in the foregoing Table 2. It gives, for its altitude at its summit 0.153 of a foot, equal to $1\frac{84}{100}$ inch; and thirty minutes after the time of the moon's meridian transit is still indicated as the average time of lunar high water. We would adopt this mean result in preference to that shown in Table 1, and in the drawing marked Fig. 1.

From one day before to two days after the periods of the moon's conjunction and opposition to the sun, the observations upon the tide-gauge were made, continuously, both day and night, at regular intervals of fifteen minutes of time apart. This was for the purpose of ascertaining, as near as possible, the time of lunar high water at the period of the spring tides, and also the elevation of the tidal wave at its summit, when influenced by the combined attraction of the sun and moon, acting in the same or nearly in the same direction.

For this object a separate tabulation was made of all the quarter-hourly co-ordinates which occurred from about twelve hours before to twenty-four hours after the period of each conjunction and opposition of the sun and moon, from the new moon of January 4th to new moon of June 1st, inclusive.* In this way we hoped to obtain, at each conjunction and opposition, three semi-diurnal tides, each of which would sufficiently approximate in character to a semi-diurnal spring tide, and a mean of all would tend to eliminate errors arising from the disturbing forces, caused by irregularities in the strength and courses of the winds.

We were fortunate enough to obtain good quarter-hourly observations, for as many as twenty-four of these spring tides, as follows, viz.:

At the conjunction of January 4th..........	3 tides.
" opposition of January 18th..........	3 "
" conjunction of February 2nd	3 "
" opposition of February 17th	3 "
" conjunction of March 4th....	3 "
" opposition of March 18th............	1 "
" conjunction of April 3rd	None; too stormy.
" opposition of April 17th	3 tides.
" conjunction of May 2nd	1 "
" opposition of May 16th	1 "
" conjunction of June 1st	3 "
" opposition of June 15th	None; too stormy.
" conjunction of June 30th	None; too stormy.
Total............	24

A direct mean of each quarter-hourly co-ordinate of altitude obtained from these twenty-four observed spring tides, is shown in the following Table 3, and the mean spring tidal wave, projected therefrom, is shown in the accompanying profile, marked Fig. 3. The whole number of observations incorporated in these is 1,200, and each co-ordinate is here derived from a mean of 24 observations.

Thirty minutes after the time of the moon's meridian transit appears, again, as the time of high water at lunar spring tides, and we have .254 of a foot, equal to $3\frac{48}{100}$ inches, United States measure, as the difference of elevation of the lake surface between high and low water of spring-tides.

We designate, as the *establishment* for the port of Chicago,

H. M.
$\frac{1}{4}$ foot, 0 30.

It is probable that if the effects of unfavourable winds, and all other disturbing forces which produce irregular oscillations in the elevation of the lake surface, could be fully eliminated, a semi-diurnal lunar tide would be shown, at the periods of the maximum springs, as great as one-third of a foot, or four inches.

The time of low water, and the times of duration of the flood and ebb tides, are given approximately. The extreme rise of the lake tide being so little, and hence the time of the turn from ebb to flood—attended frequently by disturbances of the winds—being often uncertain within half an hour, it can only be determined with precision by means of numerous observations made at short intervals of time, say three to five minutes apart, from about one hour before to one hour after the turn of the tide from ebb to flood.

* The winds were so boisterous, and caused so great perturbations of the lake surface, at the periods of the opposition of June 15th, and the conjunction of June 30th, that we were obliged to reject the observations made at those periods, in making up the co-ordinates of altitude for the spring tides.—J. D. G.

TABLE 3.

Showing the quarter-hourly co-ordinates of altitude of the average semi-diurnal lunar spring tidal wave at Chicago, on Lake Michigan, as derived from 1,200 observations, made at and near the several periods of conjunction and opposition of the sun and moon, between January 3rd and June 2nd, 1859.

	Mean solar interval of time before or after the moon's meridian transit.	Observed elevation of the Lake surface in decimals of a foot.	
	H. M.	FT. DEC.	
Before the moon's meridian transit.	6.00	0.000	Low water of lunar spring tide.
	5.45	0.006	
	5.30	0.014	
	5.15	0.029	
	5.00	0.035	
	4.45	0.042	
	4.30	0.049	
	4.15	0.057	
	4.00	0.079	
	3.45	0.081	
	3.30	0.089	
	3.15	0.091	
	3.00	0.101	
	2.45	0.121	
	2.30	0.129	
	2.15	0.145	
	2 00	0.153	
	1.45	0.169	
	1.30	0.178	
	1.15	0.187	
	1.00	0.195	
	0.45	0.216	
	0.30	0.225	
	0.15	0.226	Moon in the meridian.
	0.00	0.233	
After the moon's meridian transit.	0.15	0.248	
	0.30	0.254	High water of lunar spring tide.
	0.45	0.241	
	1.00	0.229	
	1.15	0.226	
	1.30	0.221	
	1.45	0.221	
	2.00	0.201	
	2.15	0.179	
	2.30	0.161	
	2.45	0.140	
	3.00	0.120	
	3.15	0.112	
	3.30	0.103	
	3.45	0.093	
	4.00	0.072	
	4 15	0.066	
	4.30	0.072	Slightly discrepant, owing to a preponderance of unfavourable winds at this particular period.
	4.45	0.067	
	5.00	0 059	
	5.15	0.046	
	5.30	0.040	
	5.45	0.042	Slightly discrepant, owing to a preponderance of unfavourable winds at this particular period.
	6.00	0.050	
	6.15	0.027	
	6.28	0.000	Low water of lunar spring tide.

In conclusion, we present the foregoing observations as solving a problem which has been generally heretofore denied or doubted, and as proving the discovery of a semi diurnal lunar tidal wave, of the dimensions herein described, on Lake Michigan; and hence we infer a similar one on the other great fresh-water lakes of North America.

J. D. GRAHAM, Member of the Society.

PAPER XIV.

NOTES ON THE CONSTRUCTION OF EARTH-WORKS IN FORTIFICATIONS.

BY MAJOR GALLWEY AND LIEUT. INNES, R.E.

ON THE CONSTRUCTION OF EARTH-WORKS AT FORT ELSON, NEAR GOSPORT, BY MAJOR GALLWEY, R.E.

The ditch of Fort Elson, which is sunk about 16 feet below the general level of the country, is excavated in the upper strata of the London clay, which consist of red and blueish clays with occasional seams of loamy sand. Portions of this clay become almost liquid when acted upon by water; and in this lies the great difficulty of managing it as earth is ordinarily used in the construction of forts.

The escarp wall at Fort Elson is built "en décharge," as has been explained in Vol. IX of this Series, page 64, by Major Lovell.

The counterscarp was originally formed of earth at a slope of 45°, and is 24 feet high, 16 feet being excavated and 8 feet made; but some slips having occurred, it was reformed at a slope of $\frac{4}{5}$, leaving a berm of 2 feet at the natural ground line.

During the past year, however, (principally in the winter), the part of the counterscarp facing the south has slipped throughout. The damage done to this face may be partly attributed to the dip of the strata from north to south, which conducts the drainage of the land to the surface of the slope, the other faces of the counterscarp, where the drainage is naturally conducted from the face of the slope, being uninjured. Judging, however, from the extensive slips which have occurred in railway cuttings in the London clay, and which during the past winter (as I am informed) have cost the London and South Western Railway Company £5,000 in repairs, it is impossible to trust to any ordinary slope when dealing with this soil, so far as "cuttings" are concerned.

Having formed this opinion some time since, I obtained authority to expend a small sum in the formation of a concrete facing or revetment, so as to arrive at some remedy for the insecurity of the counterscarp.

A portion of the slope (about 50 feet in length) has been accordingly faced with a shell of concrete to the height of 16 feet, the thickness at top being 2 feet 6 inches, and at bottom 3 feet 6 inches. The foundation, which is 3 feet in depth, projects 4 feet beyond the foot of the slope, so as to afford a good resistance to the thrust in the direction of the face of the slope. The earth was also benched in two or three places to counteract the tendency to slide, and weep-holes were formed by laying drain-pipes 2 inches in diameter in the concrete as the work proceeded.

The concrete was composed of one part of blue lias lime, finely ground, and six parts of shingle from Stokes Bay, and was formed in layers one foot thick, and brought to the profile by means of flat rammers. The face was left rough, in order to test the work as much as possible, but it will always be advisable to protect such scarps by rendering them with stiff gritty mortar.

More than a year has elapsed since this experiment was made, and although the counterscarp on either side of it has slipped, the part supported by the concrete facing remains standing, and appears perfectly sound and firm; and as there was an unusual amount of rain during last spring and summer, followed by a winter of great severity, the method adopted for securing the counterscarp may be considered successful.

I have lately noticed the mode generally adopted on the London and South Western Railway in repairing slips in cuttings. The toe of the slope is strengthened by throwing in large masses of rubble chalk well packed; and vertical drains, about 4 feet deep and 3 feet wide, are also cut in the direction of the slope, about 20 or 30 feet apart. This seems a good method, and is economical where chalk can be obtained readily.

A great source of weakness in the slopes of cuttings is the usual drain that is made at the foot of the slope, which, being always saturated with moisture, presents no resistance to the tendency to slide. A drain along the centre of the road to receive the drainage of both slopes would be preferable.

The formation of parapets in the upper beds of the London clay requires much care in consolidating the mass, by ramming the earth in layers about one foot thick, and using green brushwood, gorse, &c., in forming the slopes, which should not be at a less angle than $\frac{4}{5}$ or $\frac{2}{3}$ where space can be afforded. The slopes of the parapets at Fort Elson are all at 45°, and have given considerable trouble, owing principally to the shrinking of the clay in dry weather and its swelling or expansion after wet, which renders it quite impossible to build on it such works as interior revetments or curbs for racers, with ordinary foundations. The expense magazines in the traverses on the terreplein had in consequence to be built on a grillage of timber supported on piles driven 3 feet below the natural level of the ground.

The ordinary hurdle, which is made of two sizes, generally 6′ 6″ × 3′ and 8′ × 3′ 6″, will be found of great assistance in the formation of slopes. Care should be taken to procure them *green*, so as to give the parapets the longest possible time to consolidate before the decay of the brushwood of which they are made.

A trial was made of these in the formation of the exterior slope of the cavalier in Fort Elson, which is inclined at $\frac{4}{5}$ and has a vertical height of 26 feet. Continuous rows of the 8-feet hurdles were laid "header and stretcher" at vertical intervals of 5 feet, the outer edges projecting 3 inches to receive the flat sodding.

The hurdles were inclined inwards at an angle of about 20° or 25°, so as to afford a good resistance to the thrust of the earth.

It is now more than eighteen months since the earthwork of the cavalier has been completed, and there has been no appearance of a slip.

Hurdles are also useful for strengthening interior revetments, cheeks of embrasures, slopes of traverses, and other works generally built with sod work.

The cost of hurdles delivered on the works at Gosport is 8s. a dozen for the smaller size, and 11s. for the larger.

Notes on the Exterior Slopes of Fortifications at Dover.

By Lieutenant Innes, R.E.

It has been usual in constructing fortifications to assume that the natural angle of the soil is 45°, and to give the exterior slopes that inclination. In chalk countries, however, the natural angle of the soil is not much more than 34°, and to make it stand at the steeper angle it becomes necessary to ram it carefully, to sod the exterior, and to put numerous horizontal layers of brushwood into all long slopes. These precautions add a good deal to the cost, and even with them serious slips often occur; whilst in slopes formed at the natural angle, as in railway embankments, they are very rare, although the earth is merely shot out of the carts.

It also seems certain that under fire all exterior slopes would be brought down to the natural angle of the soil of which they are made, and it would therefore seem best to construct all such slopes at this natural angle, as determined by experiment, instead of at an uniform angle of 45°.

The only disadvantage is the loss of interior space, but this would be compensated by greater stability and a considerable saving of money.

I am informed that in the embankments on the new line of railway between Dover and Chatham the chalk stands at slopes varying from $\frac{4}{5}$ to $\frac{2}{3}$, and the clay at a slope of about $\frac{1}{2}$.

PAPER XV.

The Practical Details of Photo-Zincography, as applied at the Ordnance Survey Office, Southampton, for the Production and Multiplication of Facsimiles of Ancient Manuscripts, Maps, and Line Engravings.

By COL. SIR HENRY JAMES, R.E., F.R.S.,M.R.I.A.

By the term photo-zincography is meant, as the name implies, the art of producing a photographic facsimile of any subject, such as a manuscript, a map, or line engraving, and transferring the photograph to zinc, thereby obtaining the power of multiplying copies in the same manner as is done from a drawing on a lithographic stone, or on a zinc plate.

The first part of the process concerns the production of a negative photograph on glass of the document, of exactly the same size as the original. This is obtained by the ordinary wet collodion process, and too great care cannot be taken to obtain one as perfect as possible, as every defect will be transmitted through each step of the process till it affects the final result. As affecting success at this stage, the lens used should be as perfect as possible, and fully capable of projecting an image of the size required without sensible distortion. Lenses are used at the Ordnance Survey Office of various diameters, depending on the size of the document to be copied—the largest being 8 inches in diameter, 41 inches in principal focal length, and capable of producing negatives free from sensible distortion 16 inches square, a stop 1 inch in diameter being placed 8 inches in front of it.

The distance from the lens to the ground-glass of the camera, when adjusted so as to copy a subject to the same size, is 7 feet 3 inches, and from the lens to the subject of course the same.

The readiest means of adjusting the camera and lens in their proper position relatively to the object and to each other, when it is required to produce a negative the same size, is to ascertain by actual measurement with a proper scale a lineal dimension of the subject (as its width or length), and so to regulate the distance of the lens from it, that when the image is focussed on the ground-glass it shall equal, in its corresponding dimension, that already read on the scale. This can easily be done by a system of repeated trial and correction of error. When the lens and camera are in adjustment, the glass plate is covered with the sensitive coating—exposed, developed, and fixed in the ordinary way; when fixed it is immersed in a saturated solution of chloride of mercury (corrosive sublimate). When well whitened by the action of the salt, it is removed, washed with water, and then with a solution of hydrosulphate of ammonia, consisting of ten parts of water to one of hydrosulphate of ammonia of commerce.

In this manner the ground of the negative is rendered extremely dense, without affecting the clearness of the detail. When dried and varnished it is ready for use.

We now come to the preparation of the sensitive paper. The quality of the paper used is a point of much importance. Various samples have been tried, but that which has been found best suited for the purpose is a semi-transparent kind, with a smooth surface, known by the name of engravers' tracing paper.

A solution of gum arabic, or gelatine, is prepared by dissolving three parts by weight of gum arabic in four parts of distilled water. We generally use gum, but the gelatine takes a stronger hold of the paper.

Boiling water is then saturated with bichromate of potassa, and eight parts of the solution of gum arabic, or gelatine, is mixed with ten parts of the solution of bichromate of potassa, both being kept at a temperature of about 100°.

The paper is evenly coated with the hot mixture with a flat camel-hair brush, and dried. It is then exposed under the negative in the usual way. The time required for printing may be said to vary from ten minutes in diffused light, to two minutes in the sunlight, though there are days on which an exposure of twenty minutes would not impress a sufficiently marked image; but at such times it is not advisable to print if it can be avoided, as the results will hardly be good. The period of exposure is determined by the appearance of the print: when all the detail appears distinct it should be removed.

The next step of the process is the coating of the whole surface of the print with an even and thin layer of a greasy ink, which is composed of the following ingredients:—

Middle Linseed Oil Varnish................	$4\frac{1}{2}$ oz.
Wax....................................	4 oz.
Tallow..................................	$\frac{1}{2}$ oz.
Venice Turpentine........................	$\frac{1}{2}$ oz.
Gum Mastic	$\frac{1}{4}$ oz.
Lamp Black	$3\frac{1}{2}$ oz.

A portion of the above is dissolved in oil of turpentine, so as to make a solution of the consistency of thin cream, which is easily applied to the surface of the print with a brush.

It should here be observed that the extent to which the greasy ink is diluted is, in a great measure, determined by the nature of the subject photographed; if it is of an open nature, such as a bold engraving or etching, the solution may be considerably thicker than when the subject is finer. Experience is the only guide in determining this point.

The turpentine is allowed to evaporate for half an hour, and the print is then floated, back downwards, on hot water for a few minutes, and then removed and laid face upwards on a porcelain slab.

The surface is gently rubbed with a sponge dipped in warm gum water, and the ink readily leaves the surface at those parts which have been unacted on by light, while it adheres tenaciously to the detail.

As soon as the lines are quite clear the print is placed in a flat dish and washed first with warm, and finally with cold water. When dry, it is ready for transferring to zinc or stone.

There are two methods of transferring to zinc, varying according to the quantity of ink on the photograph.

If a very small quantity has been applied on account of the closeness of the subject, the print is transferred by the "Anastatic" process.

For this purpose the surface of the zinc plate is polished with emery powder, and made as smooth as possible. The print is placed, for about ten minutes, between sheets of paper which have been damped as uniformly as possible with a mixture of nitric acid and water, in the proportion of five parts of water to one of concentrated acid. A sheet of paper damped with the acid is laid on the zinc plate, and both are passed between the cylinders of a copper-plate printing press, and the acid being forced on to the zinc, slightly etches the surface. The paper is then taken off, and the film of nitrate of zinc formed on the plate is carefully cleared off with a handful of blotting paper. The print is next laid on it face downwards, and both are passed once through the press. The paper is then pulled off, and the transfer is gummed and brought up by going lightly over the surface with a sponge dipped in printing ink softened with olive oil. As soon as all the detail appears strong, it is etched with a very weak solution of phosphoric acid in gum water, the strength of the acid solution being so regulated that a drop placed on a smooth plate for three minutes slightly tints or dulls the polish. The transfer is then ready for printing in the usual way.

If a larger quantity of ink has been applied, the mode of transferring is somewhat different. The plate is prepared by rubbing the surface with fine sand and water, and a zinc mullar, to give it a grained surface. The print is laid, for ten minutes, between sheets of paper damped as uniformly as possible with water; it is then laid face downwards on the plate covered with two or three sheets of paper, and passed once through an ordinary lithographic press. The sheets of paper being removed, it is damped at the back with gum water, till its adhesion to the plate is so lessened that it can easily be pulled off. After the transfer has been gummed, brought up, and etched as in the Anastatic process, the ink is cleared off with turpentine, and the design is rolled up, with printing ink. Impressions can then be taken from it. The photographic print can be transferred to stone in the same manner as to grained zinc, the surface of the stone being prepared as for ordinary lithographic transfers.

Having described the methods of transfer, it is necessary to treat further of the considerations which determine the quantity of the ink used, and consequently the mode of transfer.

The quantity of ink which it is necessary to apply to the photograph, to make a successful transfer to grained zinc, is greater than that which is necessary for stone, and the Anastatic process requires the least of all.

The action of the warm water, in which the print is immersed, on the insoluble gum, is to cause it to swell, and the ink which overlies the lines formed of insoluble gum expands likewise. It is evident, therefore, that if the subject photographed is of a close nature, as a fine engraving, the amount of enlargement of the ink lines may be sufficient to bring them into contact while the print is in the water, and when once they have coalesced they will not again separate when the gum resumes its natural size, on the drying of the print, and there will be a continuous shade of ink instead of lines. In such a case, the quantity of ink applied should be as small as possible, and to enable a light but even coating to be laid on, it must also be thin; and, as a consequence of the small quantity of ink used, the transfer must be effected on a smooth plate, by the Anastatic process, because to make a successful transfer to a grained plate or to stone, a larger quantity of ink is necessary.

On the other hand, as impressions taken from a grained plate or from stone are, as a rule, better than those from a smooth plate, and as a larger number can moreover be struck off—if the subject photographed is so open that there does not appear to be any likelihood of the lines coalescing in the water—it is better to apply the ink in a greater quantity to the print, as a certain quantity is a *sine quâ non* for the employment of the latter mode of transfer.

PAPER XVI.

ACCOUNT OF THE MANUFACTURE OF A NEW CEMENT,

INVENTED BY CAPTAIN H. SCOTT, R.E.

In the 6th Vol. of the Professional Papers, New Series, a short account is given of a new cement, and of the experiments which led to its discovery. Since that volume was published, this cement, and a modification of it for internal plastering, have been successfully employed in several of the works executed by the War Department, and the manufacture of both kinds has been commenced in different parts of this country.

The processes for making them having been patented the right of working the processes in the British Isles has fallen exclusively into the hands of private firms, but it had been considered that they might also be employed in the colonies, where no barrier exists to their free use; and in cases when the works which an officer has to carry out are of sufficient magnitude or importance to justify the expense of the means for commencing the manufacture, the following description of the nature and mode of preparing the cement and plaster may prove useful. It will likewise, it is hoped, afford to officers employing them in the prepared state at home, that information which the inventor is now frequently requested to supply.

Preliminary Remarks.

1. When pure lime is moistened with water it slakes with violence, evolving great heat and crumbling to a soft white bulky powder. This is a hydrate of lime containing nearly $\frac{1}{4}$ of its weight of water which has been solidified. The increased bulk is so great as in some instances to treble its volume, but in proportion as the lime is impure from the presence of clay the increase of volume is notably less.

2. It is a common opinion among builders that the hardest and densest limestones yield the strongest and most durable mortars, and at first sight such a supposition seems reasonable, but when it is stated that the increase in volume of the pure and dense limes from slaking exceeds that of the pure and porous limes, and that they both fall into an impalpable powder of similar quality, when moistened with a suitable quantity of water, it can be readily understood that this opinion may be fallacious, as indeed it really is; what, however, is correct with respect to limes which slake with great heat to a bulky powder, is quite true, as a general rule, of cements, which set without these phenomena.

3. The invention, which is the subject of this paper, consists in submitting quick lime, heated to a very feeble glow, to the action of sulphurous acid; and the effect on it is to prevent its slaking to a powder, and to cause it to set as cement without notable increase of volume. The original density of the limestone does therefore, in this case also, affect the strength of the cement prepared from it.

4. Pure lime is soluble in water, and always remains so, unless reconverted into a carbonate by the action of the air; and in proportion as the mortar made with it is more porous, the solvent action of the water affects it more rapidly. It is manifest, therefore, that a process which prevents the great porosity arising from the increase of bulk in the lime on slaking, will cause the solvent action of the water to be slower. This is the chief advantage which the process bestows on such lime if employed in water, but, as it will be seen from what follows, this advantage carries with it very important consequences, and will enable hydraulic cements to be made from materials with which, otherwise, little could be done with certainty, excepting at a great expense.

5. No limestones will yield limes having hydraulic properties unless they contain a proportion of clay intimately mixed through them*. The action of the clay varies according to its chemical composition and physical condition, but no limestones will yield limes which can be said to be eminently hydraulic unless they contain 20 per cent. of clay and upwards; and according as the quantity of clay is smaller, so more and more of the mass will remain soluble; and thus more and more of the lime which would become insoluble, if time were given it, through a chemical combination with the clay, is also dissolved out. The sulphur process, therefore, as it delays the solution of the pure limes, will, in the case of limes naturally mixed with clay (by the density which it imparts to their mortars), not only retard the action of water upon the mass generally, but will give time for the clay to combine with all the lime which it has the power of taking up, before the water can dissolve much of the latter. Many

* See Appendix II, III, and IV.

limes, however, which contain only 20 per cent of clay will yield hydraulic cement; and some will yield hydraulic limes if burned at a low temperature, but hydraulic cements if the temperature of burning is raised.

6. It is well known that burnt clay, brick dust, metallic slags, and substances of a like nature give more strength to both pure and feebly hydraulic lime mortar, but they will not often render them insoluble with sufficient rapidity to resist the solvent action of water, if immersed in a pasty state. From the greater quickness, however, with which limes set after they have undergone the sulphur process, and also from the greater density in the mortars made from them when thus converted into cements, time is given for the indurating action between the lime and the clay to take place before the water has seriously damaged or disintegrated the mixture. The advantages of the process are therefore equally great, whether applied to limes naturally hydraulic, or to those which it is desired to make so by the addition of burnt clays.

7. Though the tendency of limes to slake to a powder with heat is very much reduced by the effect of the sulphurous acid (paragraph 3), it is not destroyed. 1st. The moisture of the air will gradually affect and spoil them, and though more slowly, will produce in them the same phenomena as in the unprepared limes. The injury so caused is less in degree, and makes slower progress, with the hydraulic than with the pure limes. 2nd. The phenomena attending ordinary slaking will be produced in the cements prepared from the pure and slightly hydraulic limes, if allowed to remain in large heaps after they have been made into mortar. Heat is gradually generated under such circumstances, and a return to the condition of ordinary lime is thus brought about. 3rd. The phenomena of ordinary slaking occur when the cements from the pure and slightly hydraulic limes are applied as mortar to dry absorbent surfaces. The mortar is thereby drained of its water before the combination of the cement and its equivalent of water is complete, and, instead of solidifying, the mortar crumbles to a powder.

8. Sir Charles Pasley, in his valuable treatise on limes, calcareous cements, &c., remarks: "I have no doubt that the blue lias lime would unite stones together nearly as powerfully as the best cements are capable of doing, if it did not swell in all directions when the attempt is made to combine the two processes of slaking and setting, which take place simultaneously in cements, without increase of bulk, and consequently without forcing them to split or detach themselves from stones or bricks." The results obtained have demonstrated the correctness of Sir Charles Pasley's opinion with respect to the lias lime, and have shown that the principle involved in his remark holds good more widely than he has expressed. The pure limes that he characterizes as "only better than none," when they have been subjected to the action of the sulphur fumes, slake and set simultaneously, and are converted into cements adapted for dry situations, and, by mixture with calcined clays, into hydraulic cements. The feebly or slightly hydraulic limes, which in their ordinary condition are suitable for dry walls, are in the same manner converted into cements fit for wet situations, and, by mixture with calcined clays, into excellent hydraulic cements. Both the hydraulic and eminently hydraulic limes, which in their natural state are fit for water works, are thus converted into cements, which are superior to all the water cements excepting only Portland of the best description.

9. These cements are adapted for inside and outside work as well as for masonry and concrete. Since however there is more labour required to trowel them to a fine face for papering and painting than in trowelling the ordinary lime and hair "fine stuff," it is better, excepting where great hardness is required, to employ a modification of them for this purpose. The plasterer finds them what he terms "fiery" under the trowel, that is not sufficiently plastic and retentive of water. When chalk can be had this can be ground down with the cements to supply the qualities wanting, or, in the absence of chalk, some of the same sort of lime as is used in the manufacture of the cement may be slaked to a powder and mixed in with it. To distinguish such mixtures from the cements, they have been termed "plasters" in the trade, and are so termed also in the following description of their manufacture.

Preparation of the Cement.

10. The limestone to be employed in the manufacture of the cement is burned to quick-lime by any of the ordinary processes, avoiding over-burning as usual. Limes burned until they assume a blue or greenish tinge require peculiar and very careful treatment to fit them for the purpose.

11. The quick-lime is either wheeled in barrows or carried in baskets into an oven of the form shown in the accompanying plan, and is laid on the perforated arches, forming the floor, to the depth of 1 ft. 6 in. on the crown, and 2 ft. over the haunches. With large sized lime this depth may increase a few inches, and when the lime is very small it must be somewhat decreased; or in other words, the lime must not be so closely and deeply packed as to impede the draught too much. The lime dust produced in burning the lime becomes useful in making the hatches of the oven air-tight, and if there is any excess it may be ground down with the cement without sensibly deteriorating its strength.

12. When the oven is loaded, the charging hatch is closed with a double 4-in. dry brick wall, the included space being filled in with lime dust. The whole may be made air-tight at top by means of the opening (see Plan) through the crown of the arch. Iron doors can be employed, and with a saving of labour, but the brick wall will generally be found more convenient.

13. The small hatch, intended to assist in cooling the oven in order to draw the charge, is better closed with an iron door on hinges, the whole being made tight with a mixture of moistened clay and sand technically termed "pug."

14. If the lime employed is pure or feebly hydraulic lime, it is advisable to allow it to remain with a current of air passing through it for a period which will vary, generally, with the temperature of the air and the draught through the oven. The object of this is that the moisture carried through by the air may open or split the lime a little, and otherwise facilitate the combination of the sulphurous acid during the subsequent process, without, however, causing it to fall abroad. Whatever the nature of the lime operated upon, such exposure renders the process more certain, and should be employed whenever the tendency to slake with heat is not readily destroyed without it. The period of exposure will vary from 12 to 48 hours.

15. After this exposure, a fire of coke or coal is kindled by means of a faggot of brushwood on the fire bars, and a slow fire is kept up until the lime immediately over the arches shows a dull glow, such as is barely visible when viewed in the dark through the pipes shewn in the side of the oven. The firing is then raked out, and after the lapse of a quarter or half an hour, according to the size of the oven, the ash-pit is closed, and the chimney top covered with a slate stone, or plate of iron, until it is judged that the heat throughout the mass of lime is pretty well equalized. When coal is used, there is sometimes a little difficulty in preventing the smoke escaping through the fire doors after each fresh feeding of the fire, but this may be obviated with a little care and more frequent feeding. The flame of the coal heats the charge more equally. A mixture of coal and coke may also be employed.

16. The time required for heating the lime depends on so many circumstances, as the size and charge of the kiln, the closeness with which the lime is packed, the nature of the fuel, the draught, &c., that it is scarcely possible to say beforehand how long it will take. The same remark applies to the equalizing of the temperature in the charge. The production, however, of the dullest possible glow, as above explained, will sufficiently indicate when the first point is attained, and after the burner has made himself acquainted with the action of his oven, the amount of fuel expended, together with the time occupied, will prove a sufficient guide without the use of the viewing-pipe at all. He will soon learn, also, the time he should allow for the equalization of the temperature. Neither point requires great nicety. These instructions have in several cases enabled manufacturers to make the cement without further assistance.

17. When the heat in the oven is judged sufficient, and to be sufficiently equalized, the ash-pit and chimneys are opened, and iron pots containing coarse unpurified* sulphur are pushed in on the fire bars, and placed in a manner to distribute the fumes of the burning sulphur equally. The pots may be made of wrought iron, of sufficient capacity to hold about 25 lbs. of sulphur each, the allowance being 15 lbs. to each yard of lime. A few red hot cinders are thrown into each pot as it is pushed in, to ignite the sulphur. In 10 or 15 minutes, the sulphur will be fully ignited, and its fumes will begin to escape through the chimneys very freely; the chimneys should then be closed again perfectly, using a little clay or lime dust to make the cover tight. The fire doors and ash-pits are also to be plastered at the crevices, with the exception of a small opening at the bottom of each of the latter, which opening is to be regulated by the amount of air which may be required to continue the combustion of the sulphur without allowing the sulphurous acid fumes to escape; and such escape is at once detected by the smell.

18. When the sulphur is all consumed, which may be ascertained by looking into the oven fire door from time to time after some hours have elapsed, the wall closing the charging hatch is thrown down, and all other openings made free to the passage of air, to cool the charge and oven sufficiently to allow the former to be removed.

19. The grinding is then commenced; a few trial samples are made up with water, and an examination made at the top, middle, and bottom of the charge, to obtain information as to temperature for future guidance. If the lime from

* See Appendix V.

the bottom of the charge when moistened remains quite dead on the outside of the lumps, a sort of crust* having being formed there, and at the heart of the lumps retains its usual properties, this is a proof that the bottom portion, if not the whole charge, was too hot when the sulphur process was commenced; if the upper layers still retain the usual characteristics of the unprepared lime, no crust being visible on the bottom portions, this shows that the heat at the top was not great enough, and probably that the temperature throughout was too low. Some pieces will always be found insufficiently prepared, but their effect is lost in the mass, and the samples should be three or four in number from each part of the charge, top, bottom, and centre, avoiding a selection of pieces near the walls. If, in any case, the mass is found insufficiently prepared, and the lower layers are crusted, the upper half may be removed and employed as ordinary lime, and the lower half be ground down as cement. If the process should be judged to have been quite ineffectual, the removed portion of the charge can be replaced with fresh lime, and the operations of heating the lime to a faint glow, and of burning sulphur under it, be repeated; with ordinary care, however, a failure† can hardly occur, and should the sample specimens set firmly "in pats," 6 inches square and ½ an inch thick, but yet grow too hot in setting to be safely trusted in work, a few days exposure on the floor of a shed will render the cement fit for use. It is better however that "in pats" of the above size, made up with water to a stiff consistency, and without admixture of sand, the warmth in setting, even when the cement is quite fresh from the oven, should be barely perceptible.

20. The grinding of the cement is the most serious part of the manufacture. Should the extent of the works justify a considerable outlay in grinding apparatus, the flour mill‡ construction is to be preferred, horizontal crushing rollers being used to reduce the lumps of cement to a size which the eye of the runner mill stone can readily take. It is better also to sift it through a sieve, the coarse particles being again passed through the stones. For grinding on the small scale, a pair of vertical wheels of iron or stone, turning on a pivot between them by horse power must be resorted to, the sifting apparatus being either attached by suitable machinery to the gearing of the wheel, or worked by manual labour. The wire gauze used for the sieves should have 30 meshes to the inch. The construction of both description of mills is well understood by mill-makers.

21. When the cement is prepared from the pure and feebly hydraulic limes and it becomes necessary to impart to them properties which will enable them to resist the action of water, artificial or natural puzzuolanas must be resorted to. If such substances are ground down with the cement to a fine powder, and intimately mixed with the cement, 1 part of puzzuolana§ will give to 2 parts of pure lime cement, by weight, the necessary degree of resistance, but if mixture by hand labour is alone available, and the puzzuolana is not in a fine state of division, its quantity in proportion to the cement should be increased, the amount of sand used for the mortar being correspondingly diminished.

* See Appendix VI. † See Appendix VII. ‡ See Appendix VIII.

§ See Appendix II, III, and IV.

22. The clays best adapted for the manufacture of artificial puzzuolana are such as are greasy to the touch. The temperature at which they ought to be calcined depends upon their chemical composition, but the action of the constituents is complicated, and actual trial must be resorted to for the determination of the most efficient degree of calcination. To make the trial, a portion of the clay under examination may be moulded into a cylinder 5 or 6 inches long and 1½ inches in diameter, or thereabouts. This cylinder, when dried, is to be exposed, the one end in a violent fire, the other on, or near, the outside of it. When the more highly heated end begins to vitrify, the cylinder is withdrawn from the fire and divided into three or four portions, according to the general appearance and colour of the different parts. By pulverising each part, and mixing this puzzuolana with the cement, in the proportion of 1 part of burnt clay to 2 or 3 parts of cement, by measure, it is easy to determine by actual trials in water, what degree of calcination gives the best results. To prevent the cylinder from breaking in the fire it is moulded round a wire. As a general rule it will be found that clays containing limes and other metallic oxides, especially alkalis, become energetic at low temperatures, though they may also succeed when burned at a violent heat. The poorer clays will give good results only when calcined at a very high temperature, and they have the further disadvantage of being difficult to reduce to a powder.

23. Their calcination on the large scale may be carried on in a common lime-kiln, of an inverted cone shape. The clay is to be made ready for burning by roughly moulding it into rounded balls, of the size of an apple, which are left to dry in the air. A rather thick layer of coals is placed on the bars at the bottom, and on this a layer of balls of clay, then another layer of coals is placed, and so on, thus filling the kiln with successive layers of fuel and balls of clay. When the kiln is about two-thirds full, faggots of wood are to be placed beneath the bars and lighted, and as the combustible is consumed, new layers of balls and fuel must be supplied above. The appearance of the clay will at once shew, on removal from the bottom of the kiln, whether sufficient or too much fuel is being used; and since the withdrawal of the burned clay at the bottom and the addition of fresh clay and fuel at the top may be continuous, the proper proportions will soon be ascertained. These remarks on clays apply equally if the burned clays are to be used with ordinary lime. The method of ascertaining the proper degree of calcination for them was employed by M. Courtois, Engineer of the Ponts et Chaussées, and that described for burning them on a large scale is recommended by General Treussart, who made much use of such artificial puzzuolanas.

Preparation of the Plaster.

24. In the manufacture of plaster, if chalk is to be used, the chalk is first dried in small pieces in one of the ovens used in preparing the cement, and the cement and the dried chalk* are then ground down in equal proportions. If slaked lime is used, lime of such a nature as will slake to a fine powder is immersed in water, in pieces of the size of apples, for a few seconds, until bubbles of air no longer rise from it in large quantities. It is then thrown into a heap

* See Appendix IX.

in a covered place, and there left until the following day that the slaking may be complete. The immersion can be conveniently effected by means of a bucket with a perforated bottom. The slaked lime is next thrown into a hopper which communicates with the sieve of the mill into which the cement passes after leaving the stones, and it is allowed to run from the hopper in such quantities as will, in measure, equal the quantity of cement thrown from the mill stones in the same period of time. If this mode of procedure is inconvenient, the lime may be sifted, by itself, from the unslaked portions, and then be mixed with the cement in a revolving drum furnished with arms, which, by suitable machinery, turn in a contrary direction to the drum; or, after sifting, the slaked lime may be mixed with the cement in equal measures, by simply turning the two powders over and over with a shovel until the incorporation of the ingredients is sufficiently brought about. The particular method of mixing them must depend on the magnitude of the works on which the plaster is to be employed; the first is the most efficient, and for a manufacturer the cheapest; it enables the workmen also to protect themselves better from the dust and inconvenience which must always be caused where fine and impalpable powders are moved rapidly by manual labour.

25. The prepared cement and plaster are packed either in cases or bags, according to the period that must, or may possibly, elapse before their employment. The cask of course affords the best protection, and is to be employed when the material may remain in store for some time. The cements prepared from limes that are strongly hydraulic may generally be packed in bags with safety, as they suffer far less from the action of the atmosphere than when prepared from the pure and feebly hydraulic limes.

26. Before proceeding to the preparation of the cement on a working scale, it is recommended that preliminary experiments be made on the limes available, as it possible that there may be some either not suitable for the process, or so little improved by it as to render its adoption unadvisable. The preceding remarks will render such experiments easy, but in constructing a small oven for the purpose, the vertical dimensions given in the drawing of a working oven must not be reduced in the same proportion as the horizontal. The extrados of the lime arch must not be nearer to the fire bars than 3 feet, or the lime will be unequally heated; nor less than 3 feet below the crown of the soffit of the covering arch, or the result will be uncertain, apparently from insufficiency of air. An oven 4 feet 6 inches long by 2 feet 6 inches wide will suffice, the depth of the layer of lime placed in it not exceeding 9 inches.

Instructions for using the Cements.

27. The cements are to be kept dry and free from contact with the air (see paragraphs 7 and 25).

28. The cements prepared from feebly hydraulic lime, which is easily reduced to a fine powder, will carry more sand than such as are prepared from pure or eminently hydraulic limes. That which is prepared from the grey chalk lime will make good work with as much as 5 parts of clean washed sand to 1 of cement, but, as a general rule, for cements prepared by the sulphur process, the quantity of sand should not exceed 3 parts of sand to 1 of cement,

for brickwork or masonry; 4 parts of sand to 1 of cement, for plastering. In damp situations the quantity of sand must be reduced, and for mortar to be at once immersed in the state of paste, it should not exceed $1\frac{1}{2}$ of sand to 1 of cement powder. When artificial and natural puzzuolanas are employed, the quantity of sand used is not to constitute more than two-thirds of the mortar for damp situations, nor more than one-half for water work. For tide work, when there is a wash of water, these cements are not so applicable as the quick setting Harwich and Sheppey cement, or other cement of similar properties.

29. For plastering, the loss by extra labour, in applying a "short" mortar, will probably prevent more than 4 parts of sand being used, if the sand is clean and sharp; with loamy sand, it would be possible to use a larger proportion of sand without much extra labour, but such sand ought not to be employed. The plaster should be laid on in two coat work. Much more labour is expended in trowelling the cement to a fine smooth surface, than in trowelling lime and hair, and therefore for all internal plastering, excepting when great hardness is required, the plaster (prepared as described in paragraphs 10 and 24), should be substituted for it, as before stated. For trowelling, 1 part of sand to 1 or 2 parts of cement should be employed.

30. The surfaces to which the cement is to be applied must be thoroughly wetted beforehand. Its full adhesive properties are not developed unless the surfaces are *just ceasing to drip*, when the mortar is laid on. The workman will disobey every injunction in this respect if he can do so without detection, and it would probably be a beneficial plan in many cases, if the Engineer in charge of works employed men paid by Government to perform the duty of wetting the bricks before they are laid. The little adhesion found frequently to exist between bricks and mortar, and also the numerous failures of cement coatings and their rapid decay, may generally be attributed to the neglect of that clause of the specification which provides for wetting the materials to which they are applied, but which, unfortunately, cannot provide that the superintendent of the work shall be duly impressed with its importance.

31. For concrete, from 6 to 10 measures of ballast to 1 measure of cement powder may be used according to circumstances. In small bulk and in dry situations the cements will stand well with the larger quantity of ballast; for water work, and damp sites, the smaller proportion is to be used. The concrete is made and used in the manner practised with ground lime and with Portland cement.

32. Since the cements take some time to set, the workmen will generally endeavour to mix large quantities into mortar at a time; so long however as the mortar can be used up before it commences to warm and set, (which it will do more rapidly as the mortar heap is more bulky), no evil effect follows. The cements made from the pure and feebly hydraulic limes may, if mixed with three or four of sand, remain before being used from 30 minutes to an hour, but the less the proportion of sand the shorter must be the period. The hydraulic limes yield cements which neither warm so readily nor set so quickly as the cement made from the purer limes, and they remain for a longer time after being made into mortar without injury. The quantity of any cement which it is advisable to mix at one time will make itself apparent in the first day's work.

Instructions for using the Plasters.

33. These are not recommended for external work, unless employed in summer time, and in situations where they are not affected by the moisture which rises from the ground by capillary action. Their chief use is for internal work, when they can generally be applied more cheaply, and with far more satisfactory results, than lime and hair.

34. For rendering and floating coats on brick and stone walls, 3 parts of sand may be used to 1 of cement; for the setting coat, equal parts of sand and plaster, or a less proportion of sand according to the finish required to be given to it; for fine trowelled work, 1 of sand to 2 of plaster may be used. The use of loamy sand detracts greatly from the strength with which the plaster sets when mixed with clean sharp sand.

35. On lathwork, not more than 2 parts of sand to 1 of plaster are to be employed for the rendering and floating coats; and the usual quantity of hair, is, in this case, to be mixed in with it, or there is a loss in point of labour. The under coats should have set and dried before the finishing coat is applied, or the warping or twisting of the wood will cause the trowelled surface to crack. The plaster will adhere more strongly to walls if they are wetted, but can be used on new work without any special precaution in this way. The rendering or the floating coat must *always* be wetted before the finishing coat is applied, and it is better, on brickwork, to follow on with the coats as fast as possible.

APPENDIX.

I. The philosophy of the alteration effected in limes by the sulphur process is not understood. The sulphurous acid apparently converts a portion of the lime into sulphite, and this absorbs oxygen and passes into a sulphate. The sulphate of lime, so formed, in some obscure way produces the change; perhaps it does so by transmitting its equivalent of sulphuric acid from one particle of lime to another, until the whole mass has set, particle by particle, as sulphate; but this is mere conjecture. A small quantity of finely powdered plaster of Paris or gypsum (*i. e.* unburned plaster of Paris, or *hydrated* sulphate of lime) and some other sulphates, produce similar results when intimately mixed with quick lime; but the mechanical difficulties of making on the large scale intimate mixtures of substances differing greatly in their relative amounts, has hitherto prevented the adoption of this plan for manufacturing the cement. Attention was again directed to the effect of a mechanical mixture of plaster of Paris by Mr. Abel, Chemist to the War Department, who had kindly given his assistance in the endeavour to trace the nature of the change in the action of lime produced by the sulphur process. A trial made by the inventor with plaster of Paris on his first discovery of the change which lime underwent when dully ignited over coke or coal had not been successful, probably owing to the freshness and purity of the lime experimented on, and the idea was entirely abandoned until a discussion arose on the possibility of the small quantity of sulphate of lime formed in the process (about 5 or 6 per cent) producing the effect in great measure by its own property of setting when mixed with water. This led to further experiments, when, finding from Mr. Abel's experiments that the mechanical addition of plaster of Paris did produce an effect similar in kind to that which resulted from the sulphurous acid, but still impressed with the idea that it could not do so notably, in virtue of its own setting properties, the inventor tried the effect of gypsum and crystallised sulphate of magnesia, sulphate of iron, &c., which are quite inert in this respect. As these substances produced similar results notwithstanding their entire want of setting properties, it was evident that the true solution of the phenomenon was not yet found, and the above conjecture has been hazarded.

II. M. Vicat's classification of limes, according to the quantity of argillaceous constituents, has been generally received, and has been adopted in this paper (see Vicat on Cements, sec. 1, cap. 1, Smith's translation). It must, however, be regarded as only approximately correct, since their hydraulic energy will vary with the nature of the clay and the temperature at which the stone is burned. In the strongest cement the bases of the clay, viz., alumina, iron, potash, and soda, equal $\frac{1}{2}$ the silicic acid by weight. In the best cements the relative proportion of the argillaceous to the calcareous constituent is nearly as 36 to 64, or 24 to 76 in the unburned stone. A larger proportion of clay deteriorates the quality of the cement. If it forms $\frac{1}{2}$ of the whole, the cement is better used as puzzuolana (see paragraphs 6, 22, and 23), and when the clay exceeds $\frac{2}{3}$ of the whole it will no longer set hard under water without admixture of lime, either in its ordinary state or prepared by the sulphur process. Such puzzuolanas, however, as contain a large amount of lime must bear a greater proportion to the lime, or the lime converted into cement, with which they are mixed, than when the puzzuolana contains little or none of that ingredient. The point to be obtained is a due proportion between the argillaceous and calcareous constituents of the mortar, and supposing the clay to be impalpable, and equally disseminated through the lime, the proportion of 36 to 64 is best; but according as the mixture is imperfect, or the puzzuolana coarse grained, or of poor quality, and therefore not so fit for chemical combination with the lime, its quantity must be increased. When argillaceous limestone, finely powdered, has muriatic acid or nitric acid poured on it, all the lime is dissolved out, and the clay is left as a residue. To determine the amount of this residue accurately, requires a slight knowledge of the manipulations of practical chemistry, but a very rough experiment will afford an approximate result.

III. Clay, after calcination, especially in contact with lime and other metallic oxides, is more readily attacked by acids; the iron, alumina, &c., with some of the silica, are dissolved, but the mass of the silica affected by the acid remains a transparent jelly-like residue. Heat assists the decomposition.

IV. Impure clays are after calcination the most soluble in muriatic acid, and will generally be found preferable for artificial puzzuolanas, because they become energetic at low temperatures, and therefore require less fuel, and also because, being slightly calcined, they are easier to grind. Impure clays containing 10 per cent of lime and upwards, in some instances at least, become energetic as puzzuolanas when calcined gently,—diminish in their energy as the temperature is raised,—and again recover it when heated to incipient vitrification.

V. The same effect will be produced by calcining iron pyrites, or other metallic sulphuret, beneath the lime. The cement was first made indeed by the sulphurous acid set free from the combustion of ordinary coal and coke containing a little pyrites, and it could be readily manufactured with coal having a large amount of this impurity.

VI. The action of the sulphurous acid on the lime is perhaps greatly assisted by what is termed surface action, for it finds its way readily to the heart of large masses unless the heat is too great, when the combination goes on very rapidly on the outside, and the dense crust thus formed stops the action.

VII. On the first establishment of the manufacture of this cement, Messrs. Lee employed lime burners upon it, but they had apparently, from their long practice in lime burning at high temperatures, become unable to bring themselves to work at a lower heat; at first they brought the charges to a bright red heat, and, when that tendency was conquered, fancied the lime was hot enough, when no ordinary observer could perceive anything approaching to a glow. A pensioned corporal of Sappers (Corporal A. Wright) was then employed, and found no difficulty whatever in the matter. The quantity of fuel required to heat the lime must vary with the nature of the fuel, and the size and condition of the oven. At the Messrs. Lee's works they used $\frac{2}{3}$ of a bushel of coke per yard of lime.

VIII. In the mill at Messrs. Lee's works, 40 cubic yards of cement, yielding each 18 imperial bushels, are ground in 8 hours. The cement being prepared from chalk, and burned in a flare lime kiln, is however very soft. In the horse mill, with a cylindrical stone set on edge working in a trough, it required, per diem, to grind and pack 12 casks (containing each 5 bushels), $\frac{1}{4}$ day of a man and horse to crush the cement, and 1 day of two labourers to sift and cask it. Had it been sifted by a machine turning on an axis, instead of by a sieve having a forward and backward movement, the quantity casked per diem by two men would probably have been much larger.

IX. It is considered probable that the calcareous paste found by Colonel Nelson at Bermuda, and doubtless existing in other coral islands, would serve the purpose of chalk.

APPENDIX X.

On the Cements made in England by Captain Scott's Process, and on their Properties and Uses.

The foregoing description will, it is hoped, enable an officer at a foreign station to manufacture and use the cement and plaster without much difficulty. Since, however, their action is not similar in all cases, but varies with the nature of the lime employed in their manufacture, and the peculiarities resulting from those available for the purpose in this country are now known from experience, more precision can be given to the instructions for using them than when the nature of the lime is unknown, and may possibly yield cements of very different characters. In the latter case only such general instructions could be given as analogy rendered of probable application, but, for this country it will now be attempted both to lay down precise rules for guidance in their use, and for judging whether the material supplied by the manufacturer is of proper quality and in proper condition. Although it may lead to some repetition, these instructions will be sufficiently complete to obviate the necessity for making reference to what has preceded when seeking information only on the manner of using the cement and plaster in Great Britain and Ireland.

The character of the cements prepared from different limestones varies with their chemical constitution and physical nature. Within certain limits it improves with the amount of clay which it naturally contains, but the results are influenced also by the quality of the clay and by the density of the stone. In this country the Lias limes have given the best results, and the marly chalks follow, those being most suitable for the purpose which contain from 10 to 25 per cent of clay. In Ireland, the West of England, South Wales, and the Midland Counties, the Lias should be specified as the lime to be used in the manufacture; and in the neighbourhood of London, and on the South-East Coast, the marl chalks. In every case it would be advisable to state the amount of argillaceous constituents which the cement is to contain, and by reference to the Superintendent of the Chemical Branch of the War Department it can always be determined whether the specification is being complied with in this respect. For London, Chatham, and Dover, two qualities can be had. The one (B) containing from 8 to 12 per cent of argillaceous constituents, which is very suitable for all dry work. The other (A), containing from 18 to 24 per cent, which is the better of the two for pointing, for external stucco, for foundations, damp and massive masonry, and for hydraulic purposes generally. Notwithstanding its superiority, this has not been much used, because with the present arrangements of the manufacturers (Messrs. Lee, Son, and Smith, of Halling) its employment is attended with a trifling extra expense, which, however, would disappear with a fair demand.

The Messrs. Rickman and Co., of Lewes, manufacture from a chalk, which, for hydraulic purposes, yields a cement intermediate between the above two qualities, and this is the cement which is now supplied to the South-East Coast, Portsmouth, and Gosport. It should not contain less than 15 per cent of argillaceous constituents. The cements made from Lias lime should contain upwards of 18 or 20 per cent. To assist in conveying an idea of the peculiarities and salient features of the cements made by the process, the results of the comparative experiments which have been tried with them will now be given. The earliest of these, included in Tables I to VIII, were made at Chatham by Corporal Grey, R.E., under the direction of Captain Schaw, R.E., and on his temporarily quitting the R.E. Establishment, under that of Lieut. Moncrief, I.E., and of the inventor. The whole of the cements, and the Lias lime experimented on in this series, were sent by the manufacturers with the knowledge of the use intended to be made of them, and it is therefore to be presumed that they were all at least of fair quality. The Scott's cement was of the description (B) containing from 8 to 12 per cent of argillaceous constituents, prepared by Messrs.

Lee. The bricks employed were ordinary stocks, all rubbed to the same dimensions at their smaller ends, by which they were united in pairs, the area of the joint being made 4 inches by $2\frac{1}{2}$, and its thickness about one-fifth of an inch. The mortar was worked to the same consistence in all cases excepting in the first half of the experiments made with Scott's cement, without sand, and with 1 part of sand to 1 of cement, when the mortar was very fluid and the joint thereby somewhat weakened. The pairs of bricks were pulled asunder by weights; and in some instances the mortar separated cleanly from the brick, but more frequently the fracture occurred through the mortar, whatever the nature of the cement experimented on. The force of adhesion to the brick, however, as compared with that of the cohesion of the particles of mortar, was less as the quantity of sand in it was larger. When cemented together, the pairs were arranged on the ground in rows under the cover of a shed open at the ends; the weather was warm and dry, the experiments having been commenced in the June of 1857; the sand was clean, of good size and sharp; and the bricks were invariably wetted thoroughly before they were cemented together.

TABLE I.

Showing the weight in lbs. which fractured the joint after 11 days from the date of its being made :—

Name of Cement.	Composition of Mortar.							Remarks.
	0 sand. 1 cemt.	1 sand. 1 cemt.	2 sand. 2 cemt.	3 sand. 3 cemt.	4 sand. 4 cemt.	5 sand. 5 cemt.	6 sand 6 cemt.	
Messrs. White's Portland.	...	504	433	303	420	238	265	With 0 sand, the bricks generally broke first.
Messrs. Lee's Portland.	...	701	533	...	...	...	...	Do.
Medina. . . .	400	352	278	201	149	83	75	With 5 and 6 sand only 4 trials.
Roman. . . .	400	279	178	154	149	73	...	With 6 sand, the joint broke with weight of scale equal to 23 lbs.
Atkinson's. .	...	385	175	79	49	...	...	
Bath	...	261	135	128	...	...	...	
Lias Lime . .	119	80	124	29	37	42	...	With 6 of sand, the joints broke in handling.
Messrs. Lee's Scott's cement B quality. .	292	286	308	328	281	194	184	

N. B.—The numbers are means of trials varying from 5 to 15 in number.

TABLE II.

Showing the weight in lbs. which produced fracture after the joint had been made 30 days :—

Name of Cement.	Composition of Mortar.							Remarks.
	0 sand. 1 cemt.	1 sand. 1 cemt.	2 sand. 1 cemt.	3 sand. 1 cemt.	4 sand. 1 cemt.	5 sand. 1 cemt.	6 sand. 1 cemt.	
White's Portland	...	...	667	505	521	356	365	With 0 and 1 sand, the bricks generally broke first.
Roman	499	424	236	...	...	...	...	
Medina	512	538	370	...	...	...	...	
Lias.	124	...	...	...	...	...	...	
Scott's B quality	521	514	527	528	331	398	317	

N.B.—The numbers given are the means of 5 trials.

A very extensive series of experiments on bricks joined together as above with different cements, and separated in a similar manner after 13 months, had a shade of uncertainty thrown over them by the absence of clear distinguishing marks on the different pairs, to show the nature of the cement and the quantities of sand mixed with it. A necessity arose for their removal from the place where they were first deposited, and the sergeant who superintended their movement had quitted the Establishment before the experiments were complete, and the difficulty of distinguishing the quantities of sand in the specimens had been ascertained. The results are not, therefore, given in full, but though in individual cases there was a little difficulty in deciding what cement was under trial from appearance alone, yet there was ample proof that at the end of the 13 months Scott's cement with 1, 2, and 3 parts of sand had quite doubled the strength which it had gained after one month, and had preserved its relative position; and that with 3 parts of sand, the mortar joint was stronger than an average stock brick.

A second series of experiments was made on rectangular prismoidal blocks composed of cement and sand in different proportions. The blocks were 4 in. long and 2 in. square in section, and were broken by a stirrup over the block, acting transversely by means of weights attached below. The supporting stirrups were placed at a constant interval apart of 3 inches. A full description of this method of testing the strength of mortars is given in the works of General Treussart and Sir Charles Pasley.

TABLE III.

Deduced from the results on which Table I. was compiled, and giving the relative uncertainties of the cements with varying proportions of sand. The numbers are obtained by dividing the difference between the lowest result and the mean result in each case, by the mean result. The highest decimal therefore indicates the most uncertain mortar:—

Name of Cement.	Composition of Mortar.							Remarks.
	0 sand. 1 cemt.	1 sand. 1 cemt.	2 sand. 2 cemt.	3 sand. 3 cemt.	4 sand. 4 cemt.	5 sand. 5 cemt.	6 sand. 1 cemt.	
White's Portland	...	·5	·5	·5	·8	·6	·4	Without sand, the bricks generally broke.
Medina. . . .	·6	·4	·2	·5	·6	1·	·7	With 5 and 6 sand only 4 trials made.
Roman	·1	·3	·3	·5	·7	1·	...	With 6 sand, the joints would not bear handling.
Atkinson's . .	...	·1	·4	·0	·3	...	...	
Bath	...	·1	·2	·2	...	...	...	
Lias lime. . .	·4	·5	·2	1·	1·	1·	...	With 6 sand, the joints broke in handling the bricks
Scott's cement, B quality. .	·6	·2	·4	·1	·2	·2	·3	

It is worthy of remark that this table indicates that the quantities of sand generally specified for mortar of different cements are such as give nearly the least uncertainty in their use.

TABLE IV.

The numbers express the weight in lbs. which fractured the blocks by weighting them at the centre after they had been made for 1 month :—

Name of Cement.	Composition of Mortar.					Remarks.
	1 sand. 1 cemt.	2 sand. 1 cemt.	3 sand. 1 cemt.	4 sand. 1 cemt.	5 sand. 1 cemt.	
White's Portland	529	538	322	158	151	
Lias lime. . .	...	...	...	...	...	Would not bear the weight of scale (25 lbs.), excepting without sand, when the block bore 126 lbs.
Scott's B quality.	382	333	263	242	172	

N.B.—The numbers are the means of 5 trials.

TABLE V.

The numbers express the weight in lbs. which fractured the blocks after 13 months:—

Name of Cements.	Composition of Mortar.			Remarks.
	1 sand. 1 cemt.	2 sand. 1 cemt.	3 sand. 1 cemt.	
Roman. . . .	562	214	102	
Lias lime. . .	158	...	...	With 2 and 3 parts sand, the blocks broke with the weight of the scale (25 lbs.)
Scott's cement, B quality .	780	650	410	

TABLE VI.

Showing the quantities of sand generally specified in the case of each of the cements for dry brick-work; their relative resistances to fracture with these quantities; the relative uncertainty of satisfactory joints under such circumstances; and the approximate cost in London of a cubic yard of each description of mortar:—

Name of Cement.	Proportion of sand to 1 part of cement.	Comparative resistance to fracture.	Comparative uncertainty of satisfactory joints.	Cost of 1 cubic yard of mortar.	Remarks.
				s. d.	
White's Portland	3	1	·5	17 3	For comparative resistance, a mean with 2, 3, and 4 sands taken—the result with 3 being exceptionally low.
Medina. . . .	2	·72	·2	...	Not much used for mortar in London.
Roman	1	·72	·3	17 0	
Atkinson's . .	2	·46	·2	...	For comparative uncertainty a mean of results with 1, 2, and 3 sand taken. See Table V. This cement is principally used for casting.
Bath.	2	·35	·2	...	Little used in London.
Lias lime. . .	2	·32	...	10 0	
Scott's cement, B quality. .	3	·85	·1	10 6	Four parts sand to one of cement are used by Capt. Fowke.

In point of labour in laying the bricks, the cements would stand much on an equality with the proportions of sand given in the table, the Roman having the advantage when the amount of fair face work is considerable in proportion to the whole; but to counterbalance this advantage there is the necessity of mixing small quantities only at once, and the loss occasioned by the cement frequently taking a set before it can be used. The Lias lime is more troublesome to make into mortar, because it must first be slaked, and when slaked, it requires much labour in properly mixing. The bricks can, however, be more easily laid in it, and the joints be more quickly struck or made fair with the trowel in fair face work. It is considered also less necessary to wet the bricks, but it is doubtful whether Lias lime does not suffer quite as much from being applied to dry absorbent surfaces, as the cements do.

It will be seen that so far as careful experiments on a small scale will afford a criterion for judgment, the Scott's cement of B quality, though inferior to White's Portland in point of strength, offers many advantages for ordinary brick-work.

It must be borne in mind, also, that the Portland cement tried in comparison with it, though not the strongest made (that prepared for the Dover harbour works by Messrs. Lee, see Table I., being stronger) is nevertheless of such peculiar excellence and regularity of action as to enable the Messrs. White to obtain a higher price than other manufacturers. The Portland cement in the market is of very variable quality, depending much on the temperature at which it is burned. Properly burned Portland cement leaves the kiln in a state of flinty hardness, and the expense of grinding it to a powder forms an important item in the cost of production. The manufacturer endeavours to reduce the wear on his machinery as far as he can without risking the condemnation of the cement, and he does so by insufficient burning, whereby he not only obtains a softer material to grind, but saves fuel, and sells for the bushel a smaller quantity of cement. The French, from their knowledge of this, in their purchases of English Portland cement, reject all that does not come up to a certain standard of specific gravity, and many now regard weight as a test of quality of other descriptions of cement also, but in this they err.

In the preparation of Scott's cement there is no such opportunity of cheapening production at the expense of strength.

TABLE VII.

Showing the weight required to fracture concrete prismoidal blocks 2 in. square in section, and 3 in. between the points of support, when weighted in the centre in the same manner as before; the blocks were allowed to dry in the air for 17 days, and then were immersed in water for $12\frac{1}{2}$ months before being broken:—

Name of Cement.	Quantity of shingle used.	Resistance to fracture.	No. of experiments made.	Remarks.
Portland. . . .	4	862	6	Blocks of the same description averaged over 1,132 lbs. without fracture, when allowed to remain in the air for the whole of the above period.
Medina	4	335	3	
Lias	5	134	20	
Scott's cement, B quality . .	5	409	21	Blocks of the same description left in the air for 13 months fractured with 942 lb.

From these experiments it would seem that though the Scott's cement (B quality) loses more than half of its strength from its immersion, yet that it retained sufficient to show that it is much superior to Lias lime for water works, when it can set and take an outside skin in the atmosphere before the water covers it. In coffer-dams these conditions would to a certain extent be secured, but not fully so, for in heavy masonry, such as is required when coffer-dams are necessary, the joints would not harden so quickly as in small blocks, and would not dry before the water was admitted.

For the backing of a wharf wall it is believed that it would also be superior to Lias; but for immediate immersion, experiments indicate that it yields more on the surface than Lias when both are mixed with sand, though it consolidates better internally.

The results hitherto given, and the opinions expressed, have been confirmed by experiments carried on in the Chatham Dockyard by order of Col. Greene, Director of Engineering and Architectural Works to the Admiralty; and at Paddington, by Mr. Linn for Mr. John Fowler, C.E.

It will be perceived from Table VII. (see column of remarks) that Scott's cement, of B quality, has great strength in dry concrete. Captain Fowke has taken advantage of this in the construction of fire-proof floors, for the Kensington Picture Galleries. It is also well adapted for stucco, as will be seen from the following table of comparative results obtained by Captain Schaw.

TABLE VIII.

Showing the relative advantages after 4 years, in point of colour and of hardness, of different cements applied as stucco to a brick wall, the highest numbers expressing the best results in the case of hardness only:—

Name of Cement.	Colour.	Comparative Hardness. Composition of Mortar.				
	Order of merit.	1 sand. 1 cement.	2 sand. 1 cement.	3 sand. 1 cement.	4 sand. 1 cement.	5 sand. 1 cement.
White's Portland. .	3	100	85	80	75	70
Medina	4	90	70	45	40	30
Roman. :	5	65	45	25	15	10
Lias lime.	2	45	40	35	20	15
Scott's cement, B quality	1	100	75	70	65	50

The Scott's cement was of a more uniform tint throughout, as well as of a better colour, than the other cements. It had also, up to three parts sand, a harder surface, resisting scratching with a sharp tool better even than the Portland cement, though breaking sooner under the blow of a hammer. Both hardness of surface and toughness were carefully considered by Captain Schaw in assigning the numbers given in the table.

The Scott's cement of B quality appears then from careful experiment to give great strength in dry brick-work; to make concrete of great excellence for dry situations; and to make a very good stucco, of better colour and more uniform tint than any of the other cements in use, and to be, also, of cheaper application. For hydraulic purposes, notwithstanding the results shown by Table VII, the cement of quality A, which will next be treated of, is recommended in preference. In practice the cement of B quality has been employed with success on government works at Hythe and Dover; for an escarp wall at Tilbury Fort, by Capt. now Lieut. Col. Ord, R.E.; in the construction of magazines and side-arm sheds at Sheerness, by Lieut. Col. Montagu, R.E.; and as a stucco, by Capt. Inglis R.E., and others, at Woolwich. It has also been used very extensively at the Kensington Museum for brick-work and plastering, by Capt, Fowke, R.E., to whom the inventor is much indebted for valuable advice and information on many points connected with the manipulation both of the cement and plaster. The value, indeed, of the assistance which Capt. Fowke has given, especially in the early days of the invention, could be appreciated only by one who has endeavoured to introduce a new material, and knows by experience how difficult it is to fight against the prejudice of workmen, and how few will put themselves to the trouble of doing it.

The writer has also to thank Major Gallwey and Lieut. Col. Collinson, R.E., and he remembers with great pleasure the first trial made by the latter officer, in a shell room in the Arsenal, when the cement was made, a bushel at a time, and beaten to a powder for sifting, with wooden rammers. Lieut. Col. Collinson, also, as soon as the manufacture was established, employed the cement in works at Aldershot. The inventor's obligations to Captain Schaw will be evident from the part he took in the experiments which have been above tabulated.

The cement of A quality is very much superior for hydraulic purposes to that which has been described. No comparative experiments on its strength to resist fracture, similar to those tried with B quality, have been made, but Mr. Macdonnell, C.E., Superintending Admiralty Engineer in Chatham Dockyard, has reported to the Director of Admiralty Engineering Works, as the result of an experiment made by him, its great superiority to Lias lime for hydraulic purposes.

The experiment consisted in placing two wooden boxes $3' \times 3' \times 2'$ deep, filled with concrete of the materials under trial on the river shore, in a position where they were covered by the water for 18 out of the 24 hours of the day. The concretes consisted of 6 parts of ballast to 1 of Lias lime, and 6 parts of ballast to 1 part of Scott's cement A quality, and the wooden boxes were removed at the end of one month. By this time the Scott's cement had greatly the advantage in consolidation, and in a few tides afterwards the whole of the Lias block was swept away, whilst the other resisted even the severe winter frost, and still continuing to harden, is now almost like stone.

This cement would be better adapted than the first described for pointing, as well as for hydraulic purposes, and also in all situations when the work would remain in a damp condition though not actually in water. It is, however, equally suited for dry brick-work and for stucco, and it resists for a longer time the injurious effects of exposure before use to a damp atmosphere.

It has already been stated that the cement available at Portsmouth, Brighton, and the South-East Coast has hydraulic properties intermediate between these two qualities. The factory for it has only lately been established, but it has already been tried by Major Gallwey, R.E., who has reported very favourably of it.

Six pairs of bricks were cemented together with it, at Chatham, in the manner already described. The mortar was composed of 2 parts sand to 1 part of cement. They were separated at the end of three months. In one pair the bricks gave way first; in the case of the remaining 5, the average breaking weight of the joint was 436 lbs. The sample was from the first trial of the process made by Messrs. Rickman, and was not finely ground. The sand also was inferior to that which was used in the earlier experiments.

The cement from Lias lime was first used by Major Gallwey at Portsmouth, when the Contractor, Mr. Piper, had erected a small oven with the writer's permission, and employed the process for his own satisfaction.

In a trial made with it, in comparison with Portland cement and Lias lime, for concrete to be immersed at once in water, and in comparison with Medina cement for stucco, the following results were obtained. The numbers given are the means of the independent judgment (which almost coincided) of three officers, and express their opinion of the relative merits of the materials under trial. The numbers actually assigned by these officers have been raised proportionally, to keep to the system followed in Table VIII.

TABLE IX.

Showing results obtained at Gosport with Scott's cement in comparison with other cements, for concrete and for external stucco-work on brick, after three months :—

Name of Cement.	Composition of Concrete.		Composition of Stucco.			Remarks.
	6 ballast. 1 cement.	10 ballast. 1 cement.	1 sand. 1 cement.	2 sand. 1 cement.	3 sand. 1 cement.	
Portland. . . .	...	100	...	...	...	Only tried in concrete.
Medina No. 1 .	...	...	...	69·3	...	Sample obtained for these experiments.
Ditto No. 2 .	...	...	51·8	...	...	The stucco on the walls of the fort of the same date nearly.
Lias lime . . .	13·3	...	...	...	...	Only tried in concrete.
Scott's cement prepared from Lias lime. . .	50	5·16	100	77	61·6	

On comparing these numbers with the numbers assigned by Captain Schaw to Medina and Scott's cement of B quality (Table VIII) it will be seen that the Scott's cement made of Lias keeps its position as a stucco, whilst, for concrete to be immersed at once, it shows itself four times as strong as Lias lime after three months' immersion, and that, with a far larger proportion of ballast. This cement has also been experimented on in Chatham Dockyard with successful results. It retains its cementitious properties when exposed to damp before use, better than either of the preceding descriptions of Scott's cement, and in this respect is superior to Roman and Medina cement. Indeed, generally, the Scott's cement, whatever lime may be its basis, has the advantage over the other kinds of cement alluded to in this paper, of not entirely losing its binding properties by exposure in the state of powder or with long keeping; excepting after very lengthened exposure, it still acts better than the lime from which it was prepared, whereas the other cements, when exposed to the air, are soon no better than mud. On the other hand, when applied to very dry absorbent surfaces the failure of the cement of B quality is more entire: not only is there no adhesion, but the cement actually crumbles abroad and expands like slaked lime. It behaves, however, in this way, within 24 hours of its application. And it fairly admits of question whether such a peculiarity is a disadvantage. With all cements, it is specified that the surfaces it is laid on shall be well wetted, and no good work can be done if this is neglected, but, whereas generally constant watching alone will induce the workmen to comply with their orders in this respect, here they have no option, as neglect is immediately followed by detection.

In proportion as the quantity of argillaceous constituents, naturally present in the Scott's cement, increases, this peculiarity is less marked, and when prepared from chalk lime, containing over 30 per cent of such constituents, the cement suffers less from dry surfaces than any of the other cements experimented with. All cements suffer more, as might be expected, in proportion as the quantity of sand mixed with them is less.

Neither of the cements made by Scott's process are quick setting cements, and the most hydraulic are the slowest. They are not therefore so well adapted for tide work, or underpinning, as Roman and Medina, but for general building purposes, quick setting is a disadvantage. Bricks are continually displaced by the feet of the workmen or by planking, after the quick setting cements have lost the property of healing a fracture in the joint. Not only is this source of weakness remedied when the setting is slow, but the joint generally sets under pressure which gives it increased strength. Rapidity of set in samples of the same description of cement is a test of their freshness, and, therefore, to some extent, of their condition, but it affords no criterion of the quality of specimens of cements of different kinds, nor of the ultimate hardness they will attain.

On the Properties and Applications of Scott's Plaster.

The following remarks apply to the plaster as made by Messrs. Lee, Son, and Smith, of Halling, and Messrs. Rickman and Co., of Lewes. The former supply London, Chatham, Sheerness, Dover, and Shorncliffe. The latter firm supplies Hastings, Brighton, Portsmouth, Gosport, and Southampton.

It is principally used for internal plastering, but may be employed for external work executed in summer time on walls in unexposed situations, and when the damp of the ground cannot rise to, and saturate it.

The cost of the plaster at the above mentioned places is not one-fifth part of that of Parian and the other gypseous cements, and though it does not trowel to so transparent and marble-like surface as the more expensive qualities of them, yet it gets a harder glaze on its surface and would only be benefited by repeated washings, whereas they would lose their polish by such treatment. Scott's plaster, when hardened, consists mainly of carbonate and silicate of lime, both of which are insoluble. The Parian cement, and Martin's and Keene's cements, on the other hand, mainly consist of sulphate of lime and other more soluble substances. Hence for the wards of hospitals, where a hard, impervious, non-absorbent surface which will bear washing is a desideratum, the plaster, independently of its lower price, is much to be preferred.

It is a very difficult matter to ascertain precisely the fair cost of labour and material in plastering. Modes of executing the work differ very much, and no two men will use a similar quantity of sand. Some plasterers, when they have a loamy sand, will add much more of it in their "stuff" than when the sand is sharp and clean, and there is no exact standard for the degrees of finish to be given to the setting coat. The quantity of hair, also, specified in different cases, varies widely. From a careful experiment made by Sapper labour, in the offices of the new Mess Establishment at Brompton Barracks, under the superintendence of Captain Schaw, and from the testimony of those who have used it for some time, it would appear, on a comparison of Scott's plaster with lime and hair, that—

1. There is a considerable saving of labour with the Scott's plaster in making the mortar or "stuff."

2. In rendering on brick the labour in the two cases is about the same.

3. In floating on brick there is a considerable saving with the plaster in point of labour, because the Derby, or long float, does not frequently drag the "stuff" from the surface as is the case with lime and hair "stuff," nor does it leave cracks to be made good with the hand float.

4. When the setting coat is trowelled smooth for painting, more labour is necessary with Scott's plaster to put a polish on it; but when left as rough stucco from the hand float, the advantage lies with the Scott's plaster.

5. On lath-work, especially on ceilings, the use of Scott's plaster does not offer the same degree of advantage for three reasons :—

Less sand is used; hair must be mixed with the mortar; and from the absence of suction the coats cannot follow one after the other as quickly as on brick. On the other hand, when great strength is required, as for barrack ceilings, the lime and hair fails much more quickly.

6. The inconvenience of waiting for the different coats to dry is entirely obviated on brick-work, and almost so on lath-work, when the plastering is executed with Scott's plaster.

7. Two coats only, a floating and a setting coat, are required for the finest work with it.

8. In large and lofty buildings of many stories, there is a great saving of labour with it in the removal and erecting of scaffolding, since the whole of a flat can be finished at once and without any delay.

9. The work is not defaced by every accidental blow received during the completion of the building, as is the case with lime and hair plastering; nor is it necessary to make repairs after the carpenters have completed their linings, &c.

10. In point of hardness and durability there is no comparison between these two materials, the superiority of the Scott's plaster is so great.

11. A building can be occupied, painted, and papered much more quickly when the Scott's plaster has been used than when finished in the common method.

It is believed that, on the whole, its use is attended with no extra expense in the first cost, when the distance of carriage for the plaster does not exceed 30 or 40 miles, and with an ultimate saving from its greater durability and the speedier occupation of the building. On the question of the labour required to apply it, however, there are great discrepancies of opinion, and not in favour of the cheapness of the Scott's plaster, arising in great measure, perhaps, from the experiments tried in such instances having been on a small scale, the plasterers being quite unused to the materials, and both they and their immediate employers interested in representing the labour required on it to be great. Many of the experiments, too, have been made by day-work, and the results compared with work done by the piece, which method of ascertaining comparative prices of labour is hardly to be relied on.

Examination of the Cement.

When genuine and in good condition, the cement consists of a fine homogeneous powder of a tint similar to that of the unslaked lime from which it is prepared, and when injured by the air it gradually assumes a lighter tint approaching that of the slaked lime, and at the same time becomes more impalpable. When thus undergoing air spoiling, it approximates also in its action to that of the slaked lime, though for a very long time it will give a stronger mortar than the unprepared lime will.

Samples for trial should never be taken from quite the top of a cask of cement, nor should a cask be rejected because a small portion at the top or at an open stave has whitened, for this must frequently occur in the fair way of trade, and such injury will not sensibly affect the bulk when made into mortar.

Small sample bottles hermetically sealed would assist both to determine whether a supply was manufactured from the lime guaranteed, and in what condition it is as regards its age by a comparison of colour, since the process produces no alteration in this respect.

When air spoiled, the cements have taken up a considerable amount of moisture, and if a small portion of such spoiled cement (about 20 grains) be heated to redness in a glass tube in the flame of a spirit lamp, the water is driven off and condenses in the upper part of the tube, thus affording, by the quantity of water which collects there, some criterion of the exposure which the cement has undergone. It must be remembered, however, that excepting from absolutely fresh cement, some indications of moisture will always appear when it is so heated.

When a portion of the cement of B quality is made into a stiff paste with water, and this paste is moulded so as to form a cake about 6 inches in diameter and ½ an inch thick, it should set within 6 hours. Cement of A quality, and that prepared from Lewes lime, may take a little more time to set, and the cement prepared from Lias will require still longer. If the Lias cement takes even 24 hours to set it may do well, and its first set is not one of great hardness; a marked change, however, should take place about the seventh or eighth day. As has been already said, slow setting, when it does not arise from air spoiling, is not generally prejudicial in building.

Should the cake so made heat up and show signs of slaking to powder, the cement has not been sufficiently prepared. If these signs are restricted to the centre of the cake, a day's exposure to the atmosphere would remedy the defect, but this might be inconvenient to arrange, and it is safer to insist that the cement with this trial should not generate more than a trifling elevation of temperature.

If a portion of the cement is made up with water into a stiff paste, which is then moulded into the bottom of a tumbler or other vessel and covered with water, it should gradually stiffen and finally set; if, however, instead of acting thus, it becomes more bulky and swells up, the cement should be rejected. It is then little, if at all, removed from the condition of common lime, and might be used for it without disadvantage. The process may be ineffectual in converting the lime into cement, but it cannot spoil it.

The plaster, which is likewise to be in a state of fine powder, may be tested by ascertaining whether it has imbibed much moisture, and by the manner in which it sets in the air, as is recommended for the cement. If a cake of the size above specified does not become so hard in 12 hours as to be fairly termed set, the plaster is not what it ought to be. In 24 hours it should harden on the surface as firmly as plaster of Paris would do in the same time, and in two or three days the exposed portion of it should resist scratching with the finger nail.

If the Chemist to the War Department is referred to as to the goodness of a supply of cement or plaster, the sample sent him ought not to be taken from quite the outside of the bag or cask for reasons already assigned, and it should be forwarded to him in a well corked or stoppered bottle, with a label on it to inform him which of these materials it is intended for, and what description of lime has been guaranteed for its production.

Instructions for using the Cement.

The cement should be kept from the action of the air. Casks afford the best protection, but bags are cheaper and may be substituted for them whenever the consumption is rapid. As has been already stated, the cements prepared from the more argillaceous limes resist the action of the air best.

Cement of B quality may be employed as mortar for dry brick-work and masonry with as much as 4 parts of sand to 1 of cement, if the sand is sharp and good, and with 3 parts if it is loamy. For stucco also, these proportions should be used in the floating; and for the set, equal parts of sand and cement if the surface is to be trowelled smooth, or 3 parts of sand to 1 of cement for rough stucco. As much as 6 parts of sand have been used in mortar for brick-work, and 5 parts for plastering, but such quantities are excessive. Three parts are recommended.

In concrete work 8 or 10 parts of ballast are to be used for dry work, and 6 parts in foundations.

The surfaces, particularly in plastering, to which this cement is applied, must be well wetted; if laid on dry absorbent walls as a stucco, it may crumble and fail in 24 hours. In massive walls there will be fair adhesion, where no layer of dust intervenes, if the bricks are wetted in the stack. In a thin wall every brick should be dipped before it is laid; and whatever mortar may be used this plan alone is to be relied on.

The workmen must be cautioned not to mix too much mortar at one time. It ought neither to commence hardening nor even grow warm on the mixing board. Directly any tendency to warming makes itself perceptible, the quantity made up at one mixing should be reduced, so as to have less delay before it is put into the work. It has already been stated that this is not the quality of cement recommended for either damp situations or hydraulic work, but if so used, the quantity of sand in damp walls should not exceed 2 parts to 1 of cement, and for hydraulic purposes equal parts of cements and sand.

Cement of A Quality, Lewes Cement, and Cement prepared from Lias Lime.

Generally these cements resist absorbent surfaces better, but nevertheless, thorough wetting of the materials with which they are used is not to be dispensed with; 4 parts of sand to 1 of cement ought not to be exceeded on dry walls, whether for brick-work or stucco, and 3 parts are recommended. For damp walls 2 parts of sand to 1 of cement are sufficient, and in cases when immersion in water is to be immediate equal parts of cement and sand should be used.

In concrete, the cement prepared from lias lime and that of A quality will bear 10 parts of ballast, whether in air or immersed; the Lewes cement makes excellent concrete with 8 parts, but probably they would all answer better in water with 6 parts—the proportion usually employed with other cements and limes. They are well adapted both for dry sites and for hydraulic works.

It is to be understood that in all cases, as far as strength is concerned, it would be better to specify 1 part of sand in preference to 2, 3, or 4, but with so small a proportion of sand, a thorough wetting of the brick, or other surface it is laid on, is absolutely essential to secure the proper action of the cement.

Instructions for using the Plaster.

Like the cement, it must be preserved from the air; and here also the magnitude of the work and the consequent rapidity of consumption must determine whether it shall be allowed to be sent in sacks or not.

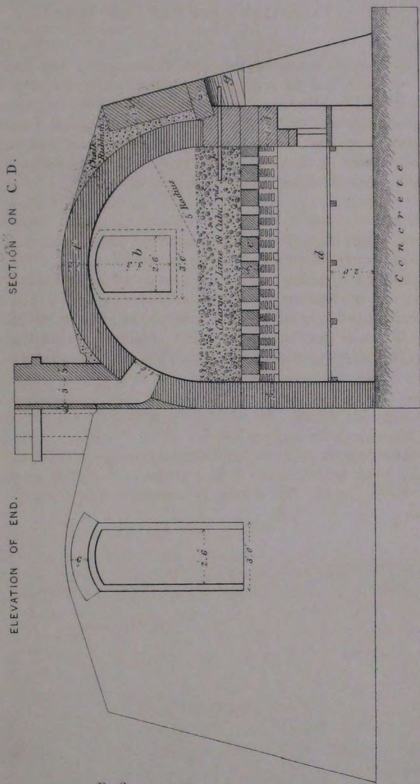
The rendering coat on brick may be executed with 2 or 3 parts sand (4 parts are sometimes used but are not recommended) and on lath 3 parts cannot be exceeded without loss in point of labour. On brick, no hair is needed; on lath, the quantity employed with lime and hair is to be used.

For the setting coats it is useless to lay down a precise rule, as every plasterer will manage to follow his own idea notwithstanding. Perfect surfaces, however, may be trowelled off with any proportion, between 3 parts plaster to 1 part of sand and equal quantities of plaster and sand.

On brick, the finishing coat is to follow on after the floating coat as soon as possible; and the floating coat after the rendering coat, if the latter should be judged indispensable in any peculiar case. On lath, it is better to allow the floating to consolidate before the "set" is laid on, as otherwise, strong laths will by their warping crack both the floating and setting coats.

No more mortar should be made at one mixing for a rendering or floating coat than can be used in one hour, though this time is often much exceeded without apparent injury. In setting, the mortar should not be left more than twenty minutes on the mixing board.

Old walls must be well wetted before applying the first coat. With green walls the work will be surer if this is done. On lath, when the floating is allowed to dry before the setting is commenced, wetting is of course indispensable.



References.

a. *Charging Hatch or Door.*
b. *Cooling Hatch.*
c. *Opening left to fill in between dry brick walls to close the Hatch.*
d. *Fire Bars.*
e. e. *Perforated Arches to support Lime.*
f. *Covering Arch to Oven.*
g. g. *Gas Pipes 2″ in diam.r to view the temperature*

This Plan shews a double Oven, or two Ovens back to back. A single Oven with one fire place will act equally well for a small supply.

PAPER XVII.

Report on the Siege Operations carried on at Juliers in September 1860, for the instruction of the Prussian Army, especially with reference to the effects of Rifled guns;

By LIEUTENANT COLONEL ROSS, Royal Engineers,

Accompanied by Extracts from a Report on the same subject by Capt. Giese, Prussian Royal Engineers,

Translated by Major General Hamilton, C.B.

Juliers is situated at the point where the road from Aix-la-Chapelle branches off to Dusseldorf and Cologne, and, before the railroads between these places were constructed, it was considered a position of some importance; but since the completion of these new lines of communication the same strategical value no longer attaches to it.

The town stands on the east or right bank of the river Roer, the communication over which is by a wooden bridge on square stone piers, covered by a strong hornwork as a tête-de-pont.

This hornwork is elaborately finished, having a loop-holed gallery all round the scarp, with two tiers of very well built casemates in the left demi-bastion; in the upper tier there are embrasures commanding the road from Aix-la-Chapelle, the lower tier having loop-holes which see into the ditch in front.

The works surrounding the town consist of four bastions connected by very long curtains, with wet ditches, and four ravelins, besides some other detached works. The scarp walls of all these bastions, and parts of some of the curtains, have been destroyed by mines, in furtherance of the views of the Prussian government with respect to the fortress.

The citadel, which is on the north side of the town, is square, and consists of four regular bastioned fronts with wet ditches, and an interior line forming a kind of cavalier. The scarps are on an average 42 feet high and 12 feet thick at the foot, with counterforts of the same depth. They are built of brick en décharge, with a gallery all round, and are in excellent condition; there are also three ravelins, which, as well as the bastions, are covered by counterguards; and between ravelin No. 2 and the counterguards 2 and 3, on each side of it, there is a detached wall covering the faces of Bastions 2 and 3. This wall is said to have been built by the French during their occupation of the place.

There are likewise, on the north side of the citadel, three advanced lunettes, also built by the French. When the Prussians regained possession of it, between

40 and 50 years ago, they constructed the detached wall and gorge of lunette B, as well as the different block-houses in this and in the other lunettes and outworks. (See Plan).

The position of Juliers is defective, inasmuch as it is completely commanded by the Merschen heights, situated at about 1,000 or 1,200 yards on the north side of the citadel; the Emperor Napoleon I. recognized this weakness, and during the time that the place was held by his army he caused them to be occupied by advanced works, the remains of which still exist.

For this reason the Prussian government decided upon levelling the fortifications around the town by mines. These demolitions were commenced in July last, but the siege operations against the north side of the citadel were commenced subsequently, and were undertaken for the purpose of affording the officers and men of the Prussian army an opportunity of seeing works of this description on an extensive scale.

The whole of the glacis round the town and citadel has been planted with trees up to the crest of the covered way, which were cut down on the front of the citadel against which the works of attack were directed, affording materials for making gabions, fascines, &c. The roots of these trees offered a great impediment to the Sappers in carrying on the siege operations.

It may be added that the fortifications of Juliers are said to date from a very early period, the greater part of the works having been built under the direction of a Spanish Engineer between the years 1535 and 1550.

Experiments in Breaching Block-houses.

On the morning of the 17th September, at 7 o'clock, the operations commenced by firing at two block-houses, one marked E, in lunette C, the other marked D in the ditch in front of this lunette, at a distance of 1,250 Prussian paces, with six guns; viz., two brass guns and four iron guns, all rifled, breech-loading, and of 12-pdr. calibre, carrying a conical shell*, exploded by means of a concussion fuze. The weight of the shell was 27 lbs.,† of the charge $1\frac{1}{10}$th lbs., of the iron guns 2,700 lbs., and of the brass guns 1,300; the elevation was $6°\frac{5}{16}$ths, and the full charge was $2\frac{1}{10}$th lbs.

* The weights given in this report are all in Prussian pounds, 100 of which are equal to 103 English pounds nearly; and the dimensions of the walls are given in Prussian feet, 100 of which are equal to 103 English feet nearly.—Ed.

† The weights of the shells used during these operations are thus stated in the Report made by Captain Giese of the Prussian Engineers:—

	6-pdr.		12-pdr.		24-pdr.	
	lbs.	loth.	lbs.	loth.	lbs.	loth.
Weight of iron of the projectile. . .	7	15	17	16	36	22
Do. of leaden envelope	5	14	10	14	17	2
Do. of metal fuze, &c.		4		5		5
Do. of bursting charge		15		28	2	0
Total weight of shell charged. .	13	18	29	3	55	29

The pound is equal to 30 loth. Ed.

The brass guns were originally of the old smooth-bored pattern, but had been converted into breech-loaders and had been rifled. The iron guns were new.

The block-house D measured about 25′ × 25′ exterior dimensions; the walls were of brick, $2\frac{1}{2}$ ft. thick, and were built with indifferent mortar; it was covered with splinter proof-timbers, with about two feet of earth above. It was so situated as to be quite concealed from the two brass guns which were directed against it, as explained by the accompanying section (Fig. 1).

The block-house E in lunette C was 64′ × 34′ exterior dimensions, and the walls were of brick, 4 feet thick; the mortar was of the same quality as in the other, and it was covered with splinter-proof timbers and earth like the other one. Inside of each block-house were strong wooden posts to support the roof. The annexed section (Fig. 2) will explain the position of this block-house with regard to the parapet which intervened between it and the four iron guns directed against it.

32 rounds were fired from the two brass 12-pdrs. under the above conditions at block-house D, of which 15 rounds appeared, from where the spectators were situated, to take effect upon it.

On inspection it was found that a breach about 4 feet wide had been made at the south-east angle; the splinter-proof timbers were very little damaged, but the building was rendered untenable, although the effect of so many shells was not so great as might have been expected; as however the block-house itself was entirely concealed from the spectators whilst the firing was going on, it is impossible to speak confidently as to the number of times that it was actually struck.

64 rounds were fired from the four iron 12-pdrs. at block-house E, of which 37 took effect, making a breach in the side next the battery 8′ × 6′ 6″; the splinter-proof covering was but little injured, and not much of the earth above it was blown away; only one shell had gone through the building and taken effect against the opposite wall: most probably it had gone through the opening. The penetration of single shots into the brick-work was about 9″.

The object of these experiments was to ascertain what effect could be produced by artillery firing with reduced charges and at high elevations, from a distance, at buildings concealed from the guns directed against them by intervening works, and situated at no great distance within those works; the results in both these instances were successful, as any troops occupying either of these buildings would have been driven out of them.

Experiments in Breaching Detached Scarp Walls.

The next experiments were commenced by firing with the same six guns at 800 Prussian paces, against the detached wall in front of the right flank of lunette B, the wall being concealed from the guns, as explained by the section (Fig. 3). During this series of experiments the guns were fired with the full charge, viz., $2\frac{1}{10}$th lbs., and with the same shell as before.

The part of the wall to be breached was marked out into squares of about 2 feet each side, by horizontal and vertical white lines; the wall was built en décharge, and of brick, the arches extending through to the front of the wall. During the first round from each gun no shell hit the wall, they all fell short, and burst upon striking the ground; of the next round four shells struck the wall and burst in it, producing a good effect, the penetration averaging from 12 to 15 inches.

After 5 rounds more from each of the six guns the corner stones at the left angle of the wall towards the bottom were much injured, part of the brick-work below the arch on the left was pierced, the embrasure in that arch carried away, and the bottom of the wall between the 2nd and 3rd arch severely shattered.

5 rounds more from each gun increased very considerably the opening that had been already made, and pierced besides the wall to the left of the embrasure in the centre arch: the top of the wall between the 1st and 2nd arches was also knocked away.

5 rounds more from each gun, or 102 rounds in all, enlarged very much the apertures made under the first and second arches, but the pier between them was still standing, although cut vertically in two.

The last 5 rounds, or 132 shots altogether, brought down the wall en masse, making a breach 32 feet wide, with a large lump of masonry (the remainder of the pier between the 1st and 2nd arches), left standing. (See Fig. 4, showing the appearance of the wall).* The firing then ceased.

18th September.—Commenced at 8.20 A.M. to breach the right face of the detached wall in front of lunette B; the wall was a continuation of that of the flank which was breached on the previous afternoon, and was of a similar construction (see section, Fig. 5). The ordnance used were four iron guns of 6-pdr. calibre, weighing 1,300 lbs., and two cast steel guns of the same calibre, weighing 800 lbs. All these guns were rifled and breech-loading; the weight of the shell was 13 lbs., and that of the charge $1\frac{1}{10}$th lbs.

The guns were placed in breaching battery No. 2, on the counterscarp opposite the wall, at a distance of 50 Prussian paces.

The wall was marked out into squares of 2 feet each side by white lines.

The first round from each gun was directed at 6 feet from the bottom of the wall, which was the level of the chemin-des-rondes inside. The six shells struck this line exactly, making the commencement of a horizontal cut extending about 70 feet along the centre of the space marked out; the penetration averaged 18″.

The guns were then fired together in salvoes, and after 25 salvoes, or 156 rounds, including the first six, the wall was nearly all cut through except at the counterforts, the height of the cut averaging 2 feet, and the depth 3 feet, the counterfort between the 2nd and 3rd arch being more injured than any of the rest.

The guns were then directed so as to make a vertical cut upwards on each flank of the breach, three guns at each flank.

The result of 4 salvoes, thus directed, was to bring down masses of the wall, more particularly on the left, the brick-work coming down in large blocks; two more salvoes cleared away the whole of the masonry within the 2nd arch, a great part of the counterforts between the 2nd and 3rd, and between the 3rd and 4th arches, as well as of the counterfort between the 5th and 6th arches.

* These drawings are not copies of those which accompanied Lt. Col. Ross's original Report. The latter having been mislaid, I have been obliged to make another set from rough sketches and photographs.—Ed.

The fire was now directed exclusively against the counterforts; after 4 more salvoes (222 rounds in all) the arch No. 2 gave way, and that part of the wall was opened; another salvo brought down great part of the 3rd arch, but the counterfort between arches 3 and 4 still stood; the next salvo (38th) brought down the remainder of arch No. 3, the half of the arch with the superincumbent masonry coming down to the left in one large mass and resting on the top of the wall; the vertical cut on the right of the breach was also much widened and deepened. After 7 more salvoes (276 rounds in all) the remainder of the wall came down, except part of the counterfort between arches 3 and 4, and the mass to the left which was resting against it. A practicable breach 70 feet wide was thus effected.

For the safety of the men who were to assault the breach in the afternoon, it was thought desirable to bring down the two masses left standing, which two more salvoes accomplished. The firing then ceased at half-past 1 P.M.

There was no visible difference between the effects of the fire of the iron and cast-steel guns.

The mortar was of good quality, although of a yellow colour, and the brick-work very tough.

The gabions in the embrasures of the breaching battery were scarcely at all damaged; the three first gabions in both cheeks of each embrasure were protected by hurdles which stood very well; it should be recollected however that the guns were of light calibre, and the charges small.

Fig. 6 shows the appearance of the wall after 234 rounds.

Breaching the Palisades.

The block-houses in lunette C, and in the ditch in front of it, having been destroyed by yesterday's fire, and two practicable breaches having been made in lunette B, it was decided that these two works should be assaulted this evening at half-past 5 o'clock and lodgements made in them.

Two storming parties, with the usual reserves, were accordingly posted in the trenches for this purpose, and at a given signal a party of Sappers descended into the ditch of lunette C and fixed two bags of powder of 70 lbs. each to the palisades at the foot of the rampart, which were exploded, forming an excellent breach in the palisades.

The storming party then advanced through the descent, preceded by Sappers carrying tools to clear away obstacles, and supported by a strong covering party, which extended along the edge of the ditch, and opened a brisk fire on the storming party entering the lunette. The defenders retired; a strong working party then followed to make a lodgement in the lunette, and to perfect the communication across the ditch.

At the same time a storming party, preceded by Sappers carrying tools and ladders, assaulted the breach in the right face of lunette B, and entered the work, getting up the exterior slope easily without ladders; they were followed by a strong working party of Sappers carrying gabions and intrenching tools. In 20 minutes a lodgement was formed and tolerable cover obtained.

Mining Operations.

19th September.—A mine was sprung by the besiegers in the gorge of lunette B with excellent effect.

21st September.—The third parallel having been completed, arrangements were made for crowning the covered way by assault, and also for destroying the block-house F in the salient of the covered way of the counterguard by a mine, it being supposed that the besieged still held this point, and defended it with great obstinacy. A gallery had accordingly been driven for this purpose from the advanced works on the crest of the glacis, and a charge of 150 lbs. was lodged under the wall of the block-house.

The attack was made at half-past 5 P.M., at which hour the mine under the block-house was exploded, not however with very good effect, the tamping apparently not having been quite sufficient; two storming parties then advanced, one against the block-house and covered way, the other against the palisades in the re-entering place of arms, each party supported by troops in the 3rd parallel. As soon as possession of the covered way had been obtained a working party followed, and immediately commenced the operation of crowning, which was completed under cover of the night.

22nd September.—Four iron breech-loading rifled 24-pdr. guns were this afternoon placed in breaching battery No. 2 to breach the detached wall in front of Bastion 2, and afterwards the left face of that bastion itself, through the opening made in the detached wall.

Weight of gun	between 53 and 54 cwt.
„ of shell.....................	57 lbs.
„ of charge	4 lbs.

25th September.—At half-past 8 A.M., the following operations were commenced in the presence of His Royal Highness the Prince Regent of Prussia:—

Three mines were sprung in the left face, and three others under the terreplein of the right face of Counterguard 2.

These mines were fired simultaneously, although they were intended for different objects; the mines behind the left face of the counterguard were to form a breach through which the work might be stormed, and the other mines were to make an opening in the counterguard, through which the right flank of Bastion 3 could be seen from the counter-battery No. 3 in front of the counterguard.

The first named mines were successful, and an excellent breach was formed; the other three were not so, apparently from the charges of powder not being sufficient; so that the breaching battery, after their explosion, remained completely masked, and a considerable quantity of earth had in consequence to be removed, in order that the battery might open fire on the following morning.

After these mines had been exploded, two surcharged mines of 1,500 lbs. each were fired simultaneously in the positions shown on the plan, with a view of destroying the countermines of the besieged. The craters were about 45 feet in diameter and about 10 feet deep.

Some stone fougasses were also fired.

As soon as all the mines were exploded the troops advanced from their several positions to assault the breach made in the counterguard, and to form a lodgement upon the edges of the craters made by the surcharged mines.

There was a little difficulty at first in getting into the ditch to assault the breach in the counterguard, as the debris from the mine had blocked up the entrance into the ditch from the descent; as soon as this obstacle had been overcome, the Sappers preceding the storming party advanced through the descent, carrying ladders and entrenching tools wherewith to level the breach; they shovelled some earth which had been blown down from the parapet over the debris of the brick-work, and the stormers advanced across, but upon a very small front. As soon as they had surmounted the breach to the level of the chemin-des-rondes, they turned to the right and left and collected in the chemin-des-rondes, where they were quite protected from any fire, and when a number of men had gathered together there they made a rush up the exterior slope of the parapet.

Breaching the Detached Wall in Front of the Bastion.

As soon as the counterguard was carried, the breaching battery No. 2 opened with the four guns already described against the detached wall in front of the left face of Bastion 2, at a distance of 60 yards. (See Fig. 7).

Of the first four shots that were fired, three penetrated about 2 ft. 6 in. each into the wall, and the fourth nearly 3 feet. The masonry at this point seemed rather weak, as the face of the wall peeled off round the opening made by the shell, an effect which I had not observed before.

The fire was then directed so as to cut a line horizontally about 9 feet from the bottom of the wall. The 56th shot made an opening through the wall.

After 117 shots, the wall gave way in large masses, an opening 62 feet wide having been made in it.

The firing commenced at 10 minutes before 10 A.M., and ceased at 10 minutes before 3 P.M.

The embrasures in the breaching battery stood very well indeed; the hurdles facing the three first gabions in the cheeks on each side were blown away after 15 rounds, but the gabions themselves required no renewal or repair.

Breaching the Bastions.

September 26th.—At 8.15 A.M. commenced firing from breaching battery No. 2 with the same guns as yesterday at the left face of Bastion 2, through the opening made in the detached wall; also from one brass 12-pdr. and two iron 12-pdrs. (already described) from battery No. 3 at the right flank of Bastion 3.

There were four guns in this battery, but the counterguard had not been cut away sufficiently to enable all four to be brought to bear on the flank.

The retired flank of Bastion 3 was breached by seven rounds from the brass 12-pdr.; and the two guns which had been placed in it were rendered useless. The wall was only 4 feet thick and the brick-work was very indifferent.

After 41 shots from the two iron 12-pdrs., the embrasure in the orillon was destroyed, and a breach was made in the wall above it 8 feet high and 8 feet wide; the firing at the flank was then discontinued.

The penetration of the first four shots from the 24-pdrs. into the left face of Bastion 2 was from 3 feet to 3 feet 6 inches each—the distance was 96 yards.

After 163 shots, the front of the wall was completely cut away, the length of the breach being 46 feet, and the height outside from 10 to 12 feet. The firing ceased at 3 o'clock P.M.

The annexed plan and section (Figs. 8 and 9) will explain the construction and dimensions of the wall, which was said to have been built more than 300 years ago, and yet the masonry was not so tough as might have been expected. In the course of the evening I went through the escarp gallery to the rear of the breach, and observed that the inside of the wall at the breach was in some places quite damp, (almost wet,) and the mortar was very soft and friable.

The embrasures of the breaching battery still stood very well; one fascine had been blown away from the top of the cheek of one embrasure, but the gabions were scarcely at all injured.

September 27.—At 8.15 A.M., commenced firing from breaching battery No. 3 through the right face of Counterguard 2, with the same three guns as yesterday, against the right flank of Bastion 3. The breach which had been made in the orillon yesterday had been repaired with sand-bags; and hurdles were suspended over the repaired breach from the top of the wall, to try whether they would not cause the shells to explode on striking them before they hit the wall itself. 30 rounds from these guns destroyed nearly all the sand-bags, and enlarged the breach; the hurdles seemed to produce no effect whatever; the firing at this flank then ceased.

At the same time the firing recommenced from breaching battery No. 2, armed as before, against the breach in the left face of Bastion 2.

After 40 rounds, the counterforts, which had been left partially standing yesterday, were entirely cut away, but the superincumbent masonry between the top of the breach and the top of the wall (about 15 feet high), did not appear to have been shaken or cracked in any way.

Twenty rounds more (223 in all, including the 163 shots fired yesterday) brought down a great deal of the lower part of this, and the earth began to fall through from the rampart above. 8 rounds more brought down the wall as far as the first white line below the cordon (2 feet below it). Twenty shots more brought down the cordon, and 8 shots more (259 in all) brought down the whole of the masonry of the wall, but the breach was by no means practicable, it being encumbered at the bottom, and for about half-way up the slope, with immense blocks of masonry; 35 more shots were fired at these, which broke them up considerably, and moreover brought down upon the face of the breach a large quantity of earth from the rampart above, so that the ascent became comparatively easy until within 10 or 12 feet from the top, when it became quite vertical against the retaining wall of the interior slope of the parapet. No shots were directed against the top of the breach for fear of injuring the town. The firing ceased at 5 minutes to 1 P.M., 294 shots having been fired at the breach during the two days. The appearance of the breach is shown in Fig. 10.

Results of the Breaching Experiments.

The following may be considered a summary of the breaching experiments that were carried on :—

Four 12-pdr. iron guns, and two 12-pdr. brass guns, weighing respectively 2,700 lbs. and 1,300 lbs. throwing a conical shell weighing 27 lbs. and fired with a charge of $2\frac{1}{10}$th lbs., at 800 Prussian paces* made a practicable breach 32 feet wide in a brick wall 3 feet thick, with counterforts 4 feet thick, 4 feet wide, and 16 feet from centre to centre, the wall being 16 feet high, and built en décharge, after firing 126 rounds. The first six rounds fired are omitted from this calculation as they did not strike the wall, the wall being entirely concealed from the guns.

No difference was observable between the effects of the brass and iron guns. The bursting charge of the shells was $\frac{14}{15}$ths of a lb. The penetration was 15 in.

Six 6-pdr. guns, four of iron and two of cast steel, weighing respectively 1,300 lbs. and 800 lbs., throwing a conical shell weighing 13 lbs., and fired with a charge of $1\frac{1}{10}$th lb., at 50 paces, made a practicable breach 70 feet wide in precisely the same description of wall as that above described, after firing 276 rounds, the battery being situated on the counterscarp opposite the wall.

No difference was observed between the effects of the cast-steel and iron guns.

The bursting charge of the shell was half a pound. The penetration of the first single shots averaged 18 inches.

Four 24-pdr. iron guns, weighing between 53 and 54 cwt., throwing a shell weighing 57 lbs., and fired with a charge of 4 lbs., at a distance of 60 yds. made a practicable breach 62 ft. wide in a loop-holed brick wall 24 ft. high and 6 ft. 6 in. thick, after firing 117 rounds, the wall being seen from the battery. The bursting charge of the shell was 2 lbs. The penetration of the two first single shots was 2 ft. 6 in. and 3 feet.

The same guns, after firing 294 rounds with the same charges, and at a distance of 96 yds., made a breach 46 feet wide in a brick wall 40 feet high and 12 feet thick at the foot, with a batter of about 4 feet. The wall was 12 feet thick and built en décharge, with counterforts 6 feet wide, and 16 feet from centre to centre, connected by two rows of arches one above another.

The penetration of the first single shots was 3 feet to 3 ft. 6 in.

All the above mentioned guns were rifled breech-loaders.

In concluding my report, I trust that I may without impropriety express my sense of the courteous attention I received from Prince Ratziwill, at the head of the Engineer Department; from Lieutenant General Von Puttkammer and Lieut. Col. Neumann, both attached to the Artillery Commission, as well as from all the Prussian officers I met with during my stay at Juliers; and I hope that Major General Hamilton, C.B., Military Attaché to the British Embassy at Berlin, whom I was directed to join, will permit me to tender him my best thanks for the friendly assistance he afforded me on every occasion.

A. ROSS, Lieut. Col. Royal Engineers.

* 100 Prussian paces = 80 yds. nearly.

NOTE BY THE EDITOR.—It may be useful here to endeavour to compare the results of the experiments described in Papers I and XVII, with those obtained from similar ones made at Woolwich in 1824 and at Bapaume (see page 91 of the Corps Papers), as well as with the average calculated by Sir W. Denison for the breaching operations recorded in the "Journal of Sieges in Spain;" and these are shown in the following table; but it is to be regretted that we have so little information about the nature of the masonry in most cases as to render it difficult to make a complete comparison.

No.	Nature of Ordnance.	Place.	Nature of wall breached.	Distance of Battery.	Total weight of projectiles fired.	Width of breach.	Weight of projectiles per foot lineal of breach.
1	Smooth bored.	Spain.	Rubble revetment	500 yds.	254,400 lbs.	100 ft.	2,544 lbs.
2	Do.	Metz.	Good rubble revetment 20 ft. high, with counterforts. .	34 ,,	9,040 ,,	100 ,,	90 ,,
3	Do.	Bapaume.	Revetment with counterforts, 36 ft. high and 10 ft. thick, *i.e.* 8 ft. 6 in. of chalk, and brick facing 18 in. . .	53 ,,	3,888 ,,	72 ,,	54 ,,
4	Do.	Do.	Casemated flank, the front wall of which was 11 ft. thick, *i.e.* 9 ft. 6 in. of chalk, and brick facing 18 in. . .	85 ,,	4,704 ,,	30 ,,	157 ,,
5	Do.	Woolwich.	Independent brick wall, 7 ft. thick between the piers, and 21 ft. high.	500 ,,	660,100 ,,	100 ,,	6,601 ,,
6	Rifled.	Eastbourne.	Brick Martello Tower—wall only (6 feet thick) . . .	1,032 ,,	2,953 ,,	20 ,,	147 ,,
7	Do.	Do.	Ditto ditto wall and arch.	1,032 ,,	10,850 ,,	24 ,,	452 ,,
8	Do.	Juliers.	Counter-arched full revetment 40 ft. high and 12 ft. thick between the piers.	96 ,,	16,758 ,,	46 ,,	364 ,,
9	Do.	Do.	Independent brick wall 24 ft. high and 6 ft. 6 in. thick.	60 ,,	6,669 ,,	62 ,,	107 ,,
10	Do.	Do.	Independent counter-arched brick wall, 3 in. thick between the piers, and 16 ft. high	40 ,,	3,588 ,,	70 ,,	51 ,,
11	Do.	Do.	Independent counter-arched brick wall, 3 ft. thick between the piers, and 16 ft. high.	640 ,,	3,564 ,,	32 ,,	111 ,,

REMARKS.—The fire was direct in all cases except Nos. 5 and 11, in which the walls were completely hidden from the batteries, the inclination to the horizon of the lines of flight of missiles just clearing the protecting mass of earth and striking the wall low enough to effect a breach (*i.e.* their "terminal angles") being in the latter case 5°. It may here be remarked that this angle is very different from the terminal angle at which missiles must strike a kaponier placed in a narrow ditch, and so that it cannot be breached except by those which pass close to the crest of a glacis at a distance of only 50 feet in front of it and 25 feet above the point required to be hit, as the terminal angle must in that case be about 26°; and experiments are therefore needed to prove the effect of elongated missiles especially, fired under such circumstances necessarily with very reduced charges.

NOTES ON THE EFFECT OF SHELLS FIRED FROM RIFLED GUNS AND WALL PIECES AGAINST SAPS, &C.

September 21.—Experiments were carried on this morning with a view of testing the effects of the Prussian 6-pr. cast-iron breech-loading rifled gun, against approaches and parallels.

For this purpose, portions of the following kinds of works had been constructed in a line, in a convenient position at the foot of the rising ground on the north side of the fortress.

1st.—An unrevetted or Turkish double sap, as it was termed.

2nd.—An ordinary double sap revetted with gabions, with one row of fascines.

3rd.—A single sap lined with sand bags.

4th and 5th.—Portions of second parallel revetted with gabions, and crowned with three rows of fascines.

6th.—Another portion of sap similar to No. 3.

7th.—Two common gabions filled with earth.

8th.—Two gabions of sheet iron $\frac{1}{16}$th inch thick, filled with earth.

Deal planking was placed immediately in rear of each, to shew the effect of any shells or splinters which might pass through.

The sap-rollers were stuffed with fascines and had a *wooden head* at each end.

The guns were placed at 1,000 paces from this line of works. The weight of the shell was 13 lbs., that of the charge 1·2 pounds, and the shells were exploded by means of concussion fuzes.

Several rounds were then fired from the guns at the earth-works (but not at the gabions.)

The single sap appeared to offer very little resistance, the shells bursting in their passage through it, dislodging the gabions and sand bags, and the splinters shattering the planking in rear.

The double sap was not so much injured in the first instance, but after three or four rounds the splinters of the shells came through, producing considerable effect on the planking, as well as on the reverse side of the sap.

The unrevetted or Turkish double sap resisted the first round, which was however fired rather low, and probably struck the ground under the loose earth. The second round however penetrated, and the splinters of the shell struck the planking.

The portion of the second parallel resisted the first two shells, but afterwards the splinters penetrated through into the planking, as in the case of the sap.

The deal planking shewed that no men could have lived in these trenches while the fire was going on.

The gabions, both iron and common, were then fired from at a range of 450 paces, with two wall pieces, or "amusettes," as they were termed, carrying an elongated iron projectile, weighing about 1 lb., its diameter being 1·35 inches. These pieces are short breech-loaders, 3 inches of the breech only being rifled with four grooves, and having one turn of the spiral in six inches. They were fired from the shoulder, being fitted with springs to check the recoil, and were ignited by a needle, like the ordinary Prussian musquet. The ball is encased in thick cardboard, to make it fit the rifle grooves.

The shots from these pieces all penetrated both descriptions of gabions, except in one instance, where a sheet iron gabion was struck fairly in the centre, and the shot did not penetrate it.

A. ROSS, Lieut. Col. Royal Engineers.

EXTRACTS FROM THE REPORT OF CAPTAIN GIESE,

Prussian Royal Engineers;

TRANSLATED BY MAJOR GENERAL HAMILTON, C.B.*

Demolition of the Works of the Town of Juliers.

The charges were placed by means of shafts sunk from the banquettes, and were so regulated as to be just sufficient to throw down the scarp revetments without endangering the town in rear or the ground in front. Twenty pounds of powder were allowed for "each foot of least resistance," or 200 lbs. for a line of least resistance of 10 feet. Fifty feet of hollow space were left in each chamber to increase the effect. The powder cases were inserted *in* the counterforts, and two feet above the level of the ditch.

The first tamping of each mine was close to the counterforts, and was effected by means of strong beams. This operation was repeated at each turning of the gallery; and between two turnings the tamping was strengthened with moist sods, which were forced in up to the tops of the galleries and shafts.

Four non-commissioned officers, 30 sappers, and 16 labourers, performed the whole tamping in eight hours, using 550 cwt. of materials.

The ignition was effected by means of two galvanic batteries of 72 cells each, joined together; six of the mines were fired simultaneously. The communicating wires were isolated in the tamping by means of gutta percha.

Breaching the Left Face of Counterguard 2, by Mining.

This was effected for the purpose of making a lodgement on the counterguard at a distance of 18 yards from its salient.

Three mines were formed, as shewn in Figs. 11 and 12. They were fired simultaneously, and a thoroughly practicable breach 18 feet broad was made.

Mine of Demolition to open the Right Face of the Counterguard, so as to unmask the Counter-Battery.

The quantity of powder calculated to be necessary, viz., 30 centners (cwt.) in eight mines, (3 on each side and 2 in the middle), was reduced to 12 centners in three mines, with the view to the greater safety of the buildings in the citadel and the town. Three galleries were driven from the lodgement made in the counterguard, in an inclined direction, and a charge of 400 lbs. was lodged at the end of each, the intervals between the charges being 26 feet.

Owing to the smallness of the charges, the parapet only was thrown down, and the terreplein slightly lowered, so that only the upper part of the wall and the cordon of the distant flank could be seen from the battery.

During the night, the counterguard was lowered 6 feet by the sappers, so that the sills of the embrasures of the flank could be plainly seen from the battery.

* We have to thank General Hamilton both for obtaining and translating this Report—Ed.

Explosion of two Surcharged Mines.

From a lodgement made in a previously formed crater, two inclined galleries were driven forward, and two charges, each of 15 centners (cwt.,) were placed 18 feet deep. They were fired by means of galvanic apparatus, and they produced two craters, respectively 50 and 56 feet in diameter, $9\frac{1}{2}$ and $10\frac{1}{2}$ feet deep, and 24 feet apart. The mass of earth was thrown upwards to the height of 60 feet.

Explosion of Four Stone Fougasses.

These were constructed in the covered way, on one side of the blockhouses which were to be stormed, and were directed against the craters of the mines, and against the supposed column of attack. They were each charged with 20 lbs. of powder, and 20 stones about the size of the fist. The "cone of dispersion" of each was about 100 paces long and 60 to 80 paces broad.

Firing against an Earthen Battery.

The guns were placed near to, and in front of lunette C, and were directed against an enfilading battery on the Mertchen Heights, on ground 50 feet higher and at a distance of 1,150 paces. The battery was at a considerable angle with the line of fire.

Two 24-prs. and two 12-prs. fired eight shots each, after which two embrasures were rendered temporarily unserviceable.

Two 6-prs. fired eight shots, which produced little effect on the third embrasure.

Two 6-prs. fired five shots more against the same embrasure, without producing any considerable effect.

Firing against a Parapet of Sand Bags 7 feet thick at the top.

Shells were fired from a 24-pr. with a charge of 4lbs., at a range of 1,150 paces, the bursting charge being 2lb. Out of 10 shots there were 7 hits. The sand bags were knocked off to the depth of 2 feet. Some of the fragments of shells penetrated 7 feet. The sand bags were thrown 20 feet high, and 40 paces distant from the parapet.

Crowning the Craters of Mines by Sapping.

The method hitherto employed for crowning the craters with gabions does not now appear to answer the purpose, for the gabions are no sooner placed than they are easily thrown over, and the crater itself could not be held under a continued shower of shells and stones.

In consequence of the experience gained at Sebastopol, it appears necessary to have recourse to another method in effecting such lodgements. Every two sappers work together, standing against and protected by the inner slope of the crater, and about 7 feet below its upper edge. (See Figs. 13 and 14.) They throw the earth to each side of them and to the front. Having reached the edge of the crater, No. 1 sapper turns to the right, and No. 2, as soon as there is room for him, to the left, until the sap and breastwork are completed along the whole of the front of the crater. The trench in which the sapper works will be made at once of the width of $1\frac{1}{2}$ to 2 feet, and will afterwards be widened. The depth will be regulated according to the cover that is required.

Passage of the Wet Ditch.

Fascines were thrown in up to the level of the water; and on the top of these, to render the surface level, sand bags were thrown. These were also employed to form a "blindage" to cover the front, and to strengthen the exterior of the two lateral breast-works, which were formed of two double rows of gabions, leaving a clear space of from 7 to 12 feet between them. (See Fig. 15.)

The fascines were 6 inches thick, 4 to 6 feet long, and had three bands. When weighted with bricks, which were enclosed inside them, they weighed 30 to 35 lbs. each, and could be easily thrown by one man to the front or to the sides.

A gabion filled with brushwood, and weighted with three stones, weighed 87lbs., and would float. When they were completely filled with stones, they of course sank, but owing to their bulk and the irregular positions which they took up when thrown over, they were found to be of no use in forming the dam.

The sand bags, which weighed from 25 to 35 lbs., could be thrown backwards over the head, and over the front parapet.

During the progress of the work, a breast-work of sand bags covered the opening from the descent into the ditch. Two or three men were simultaneously employed in throwing over this breast-work, to the front and to the sides, as many fascines as were sufficient to raise the dam for several feet in length to the level of the water.

The sand bag breast-work is then gradually advanced, by throwing the sand bags over to the front, so that a gabion may be placed at each side. The fascines, which have been hitherto lying one over the other in an irregular manner, are, upon the advance of the sand bag parapet, pressed together, enough of the sand bags being left on the top of the dam as are required to bring it to a level above the surface of the water.

Penetration of the Projectile fired from the New Wall Piece*.

Experiments were made with iron gabions, the diameter of which was 21 inches, and height 30 inches. The thickness of the plates was $\frac{1}{24}$ inch, and the weight was 26 to 28 lbs. They were made of two half-cylinders fastened together by bolts.

At 400 paces, the penetration into these gabions, filled with earth and gravel, was 16 inches. The shot never penetrated the centre at 400 paces; and at 150 paces, when the shot struck the centre it only penetrated to the opposite side of the gabion; whilst the common gabion was shot through at 400 paces.

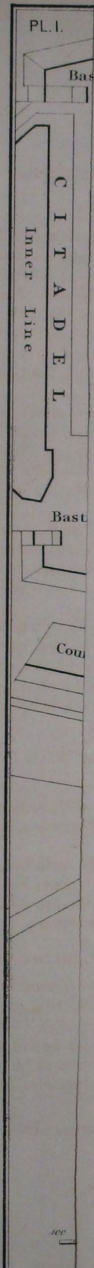
Firing at Loopholes to determine the chances of hitting them.

1st, against *vertical* loopholes, the interior openings of which were 12 inches high and 4 inches wide, with the needle musket at 50 paces, 10 shots and 10 hits, and at 200 paces 10 shots and 5 hits.

2nd, against *horizontal* loopholes, the opening being 36 inches long and 4 inches high, at 50 paces, 10 shots and 4 hits, and at 200 paces, 10 shots and 4 hits.

The conclusion was prejudicial to the use of the vertical loopholes, in consequence of the very slight *lateral* deviation of the balls.

* This is the "amusette" referred to by Lieut. Col Ross. (See page 169).—Ed.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TO THE

VOLUMES OF THE PROFESSIONAL PAPERS AND CORPS PAPERS

PUBLISHED SINCE THE FIRST INDEX WAS PRINTED, IN 1845,

IN THE 8TH VOLUME OF THE QUARTO SERIES.

N.B.—The principal words in the title of each Paper must be looked for on the left of this Index. The letters C. P., standing in place of the number of the volume, indicate the "CORPS PAPERS," published in three parts in 1849-50; and the letter Q distinguishes the volumes of the "QUARTO SERIES," published previously.

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