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PAPERS

ON SUBJECTS CONNECTED WITH

THE DUTIES

OF THE

CORPS OF ROYAL ENGINEERS.

R. E.

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M.DCCC.XLV.

CONTENTS.

APPENDIX.

LIST OF PLATES.

I have inserted in the present Volume two Papers extracted from a mass of documents furnished to me by Colonel TURNBULL, of the United States' Engineers, which contain some valuable Reports upon the works now carrying on in America, under the direction of Officers of Engineers. To one of these Papers in particular,—'the account of the System of Drainage of Low Lands in Holland,'—I wish to call the attention of my brother Officers, not so much on account of the importance of the subject there treated upon, although that can hardly be rated too highly, as from a desire that the example thus held out may induce Officers to consider the many subjects of professional interest which foreign countries may furnish, and to remember that the notes and memoranda upon such subjects, though made for their own private information, would be as valuable to others as to themselves. Professional information should be looked upon as a species of common property, held by the individual for the benefit of the corps at large; and as no opportunity should be lost of increasing the amount of this common property, so the readiest means should be taken of communicating to others their share therein; and I trust that Officers will avail themselves of the 'Professional Papers' for this purpose.

W. D.

PROFESSIONAL PAPERS.

I.—*Report on the Application of Forts, Towers, and Batteries to Coast Defences and Harbours. By Colonel* Lewis, *R.E.*

In the application of works of defence for the security of a maritime frontier, the configuration of the land and local peculiarities must regulate the nature of the defence; nevertheless, fashion, or some prevailing whim, or the accidental success of a work, has regulated the style of fortification, rather than the peculiar fitness to the ground or object to be gained: hence towers have been multiplied on the coasts of England and Ireland, &c.; a description of defence invented by Montalembert has been adopted in France; and a similar description of construction for the defence of the harbours of the United States, of circular batteries of two and three tiers of guns.

The annexed Plans to this Report are offered as examples adapted to coast defences.

The success of our naval operations against Algiers and Acre suggests new modes of arrangement for sea defences; and the invention of the heavy artillery by Paixhans, and their use in naval warfare, has also rendered the adoption of a similar description of heavy ordnance for the land service necessary. But the success alluded to at Algiers and Acre is only to be feared when line-of-battle ships can anchor or pass within 800 yards, and the sea defences are entirely exposed to their fire, and where deep water enables those large vessels which can concentrate the fire of 40 to 60 guns on a small space, to approach close to a battery.

These naval advantages may be parried, by the construction of an outer line, and casemated batteries placed to flank the anchorage or channel; or by having an interior or second line of batteries (see Plate V.) on a higher level, the fire of which can be concentrated on any vessel or vessels: and it is on this second line of defence that the heavy ordnance lately adopted can be, it is conceived, advantageously placed, as the great range of those heavy guns compensates for the distance added by the batteries in the second line.

The new 68-pounder and 84-pounder guns seem not to be generally suited to coast defences, because they cannot be fired over a 6-foot parapet in consequence of the difficulty of lifting such heavy shot, and because hollow shot cannot be fired red hot, their diameter being altered by that operation; but when this ordnance can be advantageously placed upon a height to be fired *en barbette*, it has now become necessary to use it, in order to cope with the present naval armament.

But the most efficient artillery, as adopted for all circumstances, is the old long 32-pounder land service gun; all calibres below that diameter should be disused for sea defences.

This description of gun (32-pounder) can be fired from a traversing platform of the regulated pattern of wood or iron over a 6-foot parapet; and when rapidity of fire is essential, for flank defence to prevent a debarcation, the new sea service 32-pounder gun will serve, and thus prevent an admixture of ordnance in one battery.

In those batteries placed within range of anchorage, two or three heavy mortars should form part of the armament; and when vessels are necessarily under fire above 30 minutes, by the peculiar course of the navigation, reverberatory furnaces for heating shot should be in the battery.

Every battery should be supported by a keep or tower, or defensible guard-house, adequate to contain the men necessary to work the guns. But there are some defects in the existing arrangements, as the tower is generally too small, and the guard-houses are not shot-proof, and are exposed when constructed on a shore only a few feet above the level of the sea. It is on the open coast that the skill of the engineer is put to the test: when the shore is precipitous, there is little danger and little difficulty in the construction of a work.

On the home stations for the defence of low coasts, the tower has been generally introduced, mounted with one, two, or three pieces of artillery.

BATTERIES.

The first Plate is a project of the author of this Report, for a battery of seven 32-pounder guns, to be mounted on traversing platforms, or of five 32-pounder guns and two heavy pieces (68-pounders) carrying hollow shot; or of five guns and two heavy mortars; the latter placed, instead of the two guns, on each flank of the battery.

The keep or tower is calculated to hold the men necessary to work the ordnance, having a howitzer on the summit, and the tower and battery are proposed for an open low line of coast, and where anchorage is rarely practicable within 1200 yards; for it may be observed as a rule, the depth of water generally corresponds with the nature of the shore,—an abrupt cliff promising deep water, and *vice versâ*.

The figures 1 and 2 of Plate II. offer an example of batteries upon a precipitous or rocky shore; and, as before observed, little invention is required for such a site; but as a protection to the entrance of a harbour, it is well constructed. The disadvantage of a battery upon a height is the loss of the ricochet, so very destructive to shipping. (See extract at the end of the Report.)

This advantage is secured to the battery as shown in Plate V. of a fort, where a double level is taken up, and thus combining a good command, with the fire à fleur d'eau.

The advantages of the traversing platforms of the regulated pattern are sometimes lost sight of, by an incorrect mode of working the guns. The author has observed of late years that the artillery in our service mount up the platform to load and sponge the guns, instead of performing that operation over-hand: formerly the rule was, that none but the man who pointed the gun or served the vent should be exposed; latterly a new platform has been proposed, called an affût-de-place, intended to fire only on a parapet 4 feet high, with extended embrasures: this may be applied in many circumstances, and serves as an intermediate carriage between the barbette and the ordinary traversing platform; but the latter, it is conceived, cannot be superseded by it in general utility.

The Blockhouse Fort at Portsmouth (Plate II.) is one of the best specimens of military architecture we have, as explained in figs. 3 and 4 of that Plate; and except where vessels of war can lay within 600 yards, can be applied with great advantage for the protection of harbours, and for the sea faces of a maritime fortress.

TOWERS.

A series of examples are given of this description of coast defence as applicable to peculiar sites. The original martello tower was on the coast of Corsica, where it drove off a line-of-battle ship and a frigate, and gave that description of defence a reputation in our service; and it has been pretty generally applied on our open coasts.

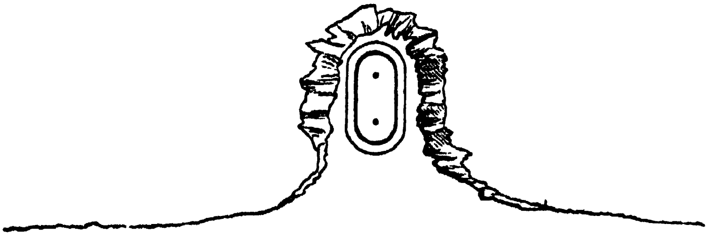
The one-gun tower, Plate III. figs. 1, 2, 3, 4, and 5, has the advantage in an unapproachable site, where the coast is inaccessible to boats, of being able to maintain its fire without the risk of being touched, the tower itself being so small an object; and under these advantages, they can be placed for the security of a roadstead or bay; but the number of men which each will hold is so insignificant that a boat's crew will drive the garrison out.

This insecurity caused the adoption of the three-gun towers, figs. 10, 11, 12, 13, and 14, Plate III., a work in every respect superior in form; and these, when placed about a mile apart, offer a formidable, although expensive defence.

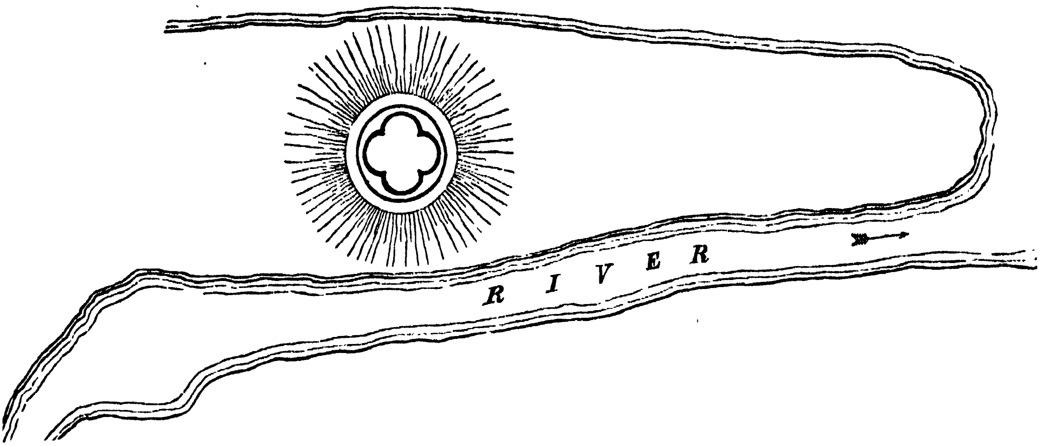
The armament was a long heavy 24-pounder gun and two 24-pounder iron howitzers.

The cost of the one-gun towers may be considered as about £1200, and the three-gun towers about £3000.

Figs. 6, 7, 8, 9, of Plate III., are examples of towers armed with two pieces of ordnance; they seem adapted to narrow promontories, where flank defence for the protection of small adjoining bays is important, as thus:



The four-gun tower is shown in figs. 1, 2, 3, and 4, Plate IV., and in fact it is a species of fort, and forms a powerful battery: it has been applied thus, for the protection of a river and line of coast.



It has also been applied on an island as a *counter battery*, to secure a land front, and take the approaches to it in reverse.

Every tower should have a machicouli over the entrance door, which is not generally the case.

Picket Towers.—This description of defence was projected by the author for the defence of the eastern frontier of the Cape of Good Hope, and generally adopted as a keep and flank defence to the barrack enclosures of the outposts to the frontier line. They were intended to be armed with a field-piece, but two or three of the picket towers have had 24-pounder iron howitzers mounted on the top. These towers are probably too slight for sea defences, except under peculiar local circumstances.

Plate IV. Figs. 6, 7, 8, and 9, describe the picket towers as executed at the Cape of Good Hope, where the cost averaged £500 each; but in that colony, work costs from 30 to 50 per cent. more than in Europe. The garrison for these towers was one gunner and seven infantry soldiers.

The scale in the drawing of the batteries and towers is 30 feet to an inch to all, to enable the reader to observe the relative force and capacity of each.

FORTS.

For the protection of harbours and bays, examples are given in Plates V. VI. VII. VIII. and IX.

Plate V. (figs. 1, 2, 3, 4,) of a circular battery, has been applied where the guns are required to converge from the fort to the entrance and to the anchorage, where the passage is circuitous: the circular form, the deep counterscarp, heavy masonry, and being well traversed, give this battery a power which no ship of war under sail could destroy; and even at anchor would be a formidable opponent: the cost of this work was £32,692.

Figures 1, 2, 3, 4, 5, of Plate VI., describe Fort Wellington at Ostend. The late Major-General Sir Carmichael Smyth seemed to be so impressed with the merits of this fort, that he proposed it frequently in his project of defence for the Canadas, and estimated it at £50,000.

Fort Tignè, at Malta, explained in Plate VII., in former days was considered by our officers as the perfection of a small fort without flank defences: it has every resource within itself; and being countermined, is capable of a considerable resistance. Forts of this description are generally considered shell-traps, but the preceding examples here given, are so well traversed and casemated, and afford such airy and roomy barracks, they may be considered free from that defect.

Plates VIII. and IX. describe an unexecuted project by Captain Nelson, submitted originally as a tête-de-pont in North America, but since modified for sea defences; or for réduits forming a principal support to a permanent intrenched camp: the idea of the machicoulis was taken from the old castle of Siegburg on the Rhine. The figures 1 and 2 are adapted for coast defences, or as a fort constructed for the protection of a harbour. The gorge of the réduit en machicoulis, marked A, in that case being the land front, the work has been constructed to combine a converging fire of 20 pieces of artillery at 150 yards, in the event of the exterior and interior works being armed. Figures 3 and 4 of the same plan, reversing the arrangement of the works, are proposed with a counterscarp, without artillery in the casemates, and can give only a converging fire from 13 guns at the same distance.

In the first project, the escarp, being constructed en décharge, is sufficiently strong to resist the fire of artillery from shipping, with an earthen counterscarp and glacis sufficiently high to cover the lower casemates and caponières.

The internal arrangements of the battery (see figs. 6 and 12, Plate IX.) are so regulated that every casemate in each story concentrates on guns in the réduit.

The barrack accommodation of Captain Nelson's plan will afford cover for

400 men and officers in proportion, with ample magazine room for stores, provisions, and ammunition.

It is conceived that there is considerable ingenuity in this project, and talent in the construction and the arrangement, and skill in the application of De Laubat's and the Prussian systems, as well as novelty in the introduction of the machicoulis[1] for the defence of the escarp.

The only observation the author has to make for the purpose of removing a prevalent error, is to express his doubts as to the probable resistance after the exterior work is taken. The redoubt, however, is essential, in the event of escalade or surprise, and adds materially to the accommodation for the troops and stores. The probable expense of Captain Nelson's project is £60,000.

It should be observed that the forts are drawn on the plans on a uniform scale of 100 feet to an inch, so that the comparative force is easily comprehended.

In concluding these remarks upon the application of works to coast defences, which are intended rather as reminiscences of what the corps has observed in their various course of duties; and in offering these plans, which have never been before embodied in one Report, the author has to observe, that even with the improvements in naval architecture, the application of steam to vessels of war, and the invention of the Paixhans' guns, still coast defences, judiciously placed, should maintain their superiority: the success of our fleets at Algiers and Acre are exceptions, affording disadvantages not frequently the fate of the defenders of works on shore.

During a course of duty in the Mediterranean, the author had an opportunity of witnessing several conflicts between our ships of war and the French batteries; and in the event of another maritime war, the difference will be seen between experienced artillerists, and those that defended the walls of Algiers and Acre. The fire of ships which can approach between 400 and 800 yards, may be rendered nugatory by a glacis or counterguard, and by giving the parapet of the battery an adequate thickness of earth; and if the guns of the battery are silenced, the heavy mortars are still available. But ships of war rarely anchor for the purpose of silencing batteries without receiving on their approach some severe blows, with the chance, if the helm is crippled, of being wrecked.

Batteries placed on low points for the protection of a navigable river, or the entrance of a harbour, should be casemated, like that at Blockhouse Point, Portsmouth, as before suggested.

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[1] It is presumed that the machicoulis is strong enough to resist field guns.

In the application of works of defence for coasts and harbours, the following considerations are necessary. The probable object of an attacking force is for predatory objects, or for conquest; or to procure an easy access to the capital of the kingdom, province, or colony: in the former case,[2] for a long line of open shore, batteries or towers should be supported by moveable columns, combined, of cavalry, artillery, and infantry; and since the construction of railroads, a facility of support is given to coast defences which counterbalances the advantage an enemy may possess by steam navigation: and indeed as soon as *private* companies cease to find it profitable, the railroad system should be taken up by the Government, to connect the open shores between Yarmouth and the Thames on the north, and the Thames and Weymouth on the south.

It being supposed that circumstances have determined the extent to which a maritime point is to be fortified, the author will conclude this Paper by a reference to two or three leading principles that should determine the sites of the works.

In Plan.—The first thing to be decided on is the course by which vessels *must* approach. If along certain well defined and narrow channels, the task is very simple: but, if a wide choice is left to the enemy, then all that remains is to provide a fire that can be turned in any direction;—generally by a circular or like divergent construction.

Too great attention can hardly be paid to the arrangements for heating shot, so that they may be supplied rapidly and abundantly on very short notice.

The author is not an advocate for distributing guns in small detached batteries if it can be avoided: unless under particular circumstances, guns should be placed to destroy and cripple, and not to teaze, which last is nearly all that batteries of 2 or 3 guns are capable of performing.

He does not conceive it possible to prevent the passage of a large vessel with wind and tide entering a harbour or passing the heaviest battery, except by a chance shot carrying away the rudder at a critical point which may throw her on a rock or shoal: neither can a vessel do more than silence a well-constructed battery for a time, during the period she can pour in her broadside.

In Elevation.—The following extract from the 'Aide-Mémoire d'Artillerie' will be found useful in determining the heights of works above the sea level:

"Nous croyons qu'il convient d'établir des principes qui ne sont pas encore

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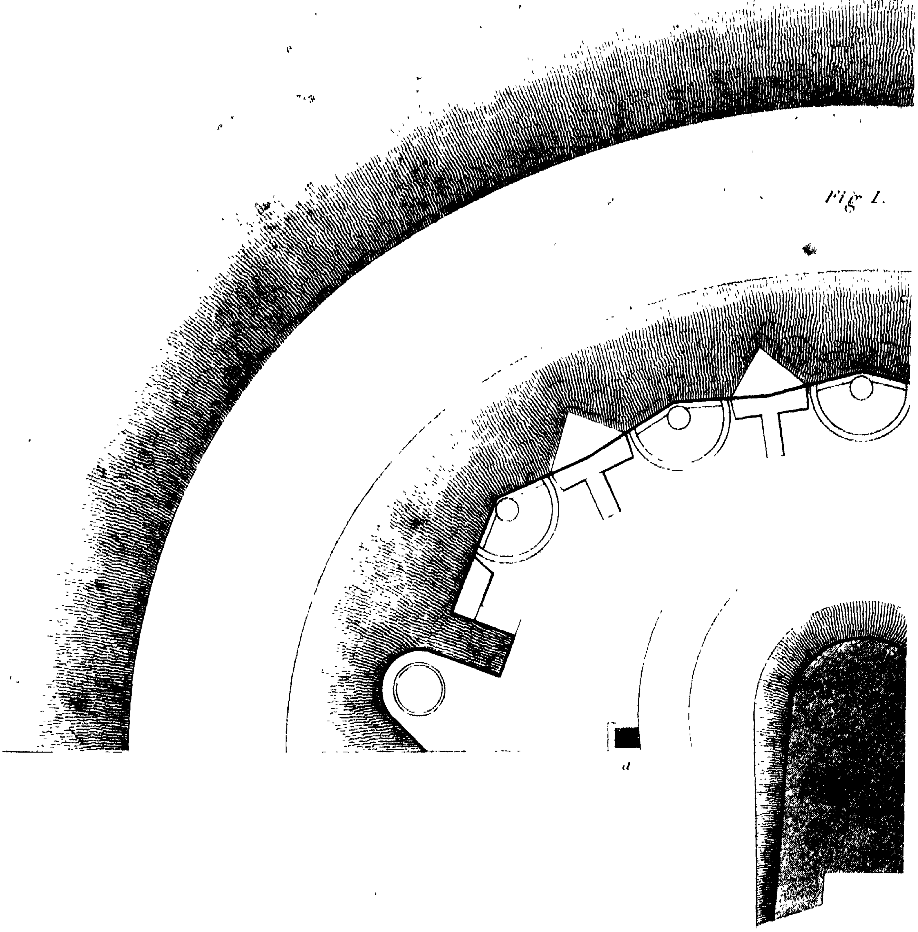
[2] The latter cases, involving the construction of fortresses, are not within the scope of this Paper.

NAWAB SALAR JUNG BAHADUR

EXAMPLES OF BATTE

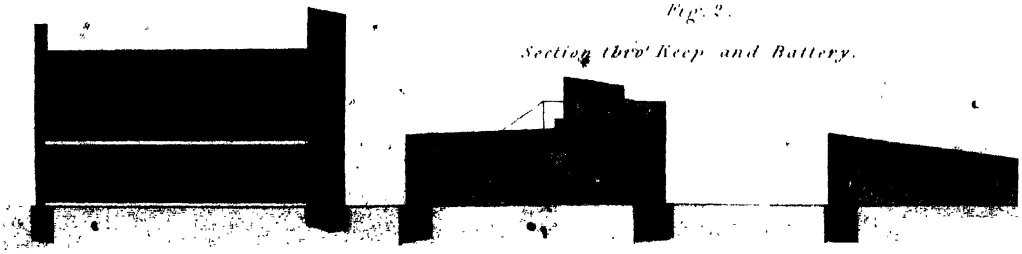
Fig. 1.



Plans and Sections of a Battery for Five 32 Pr. Guns and Keep.

Fig. 2.

Section thro' Keep and Battery.



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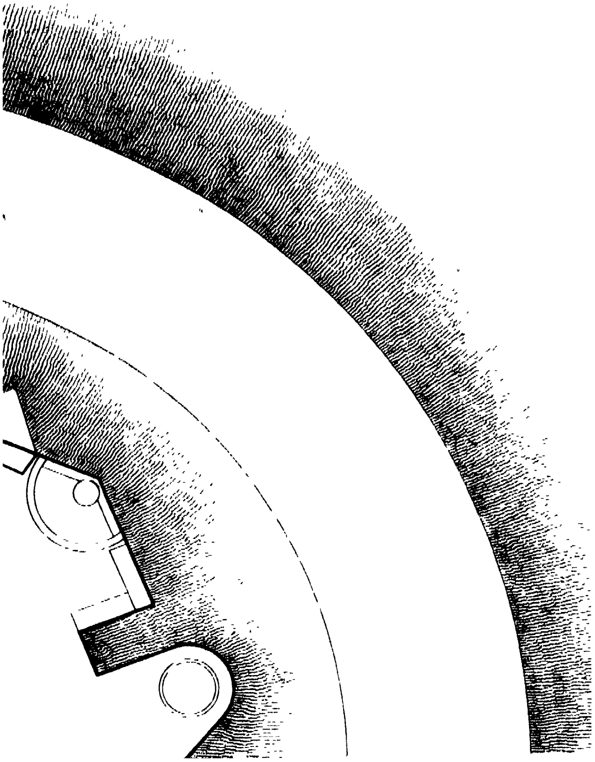
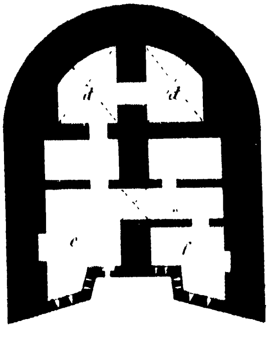
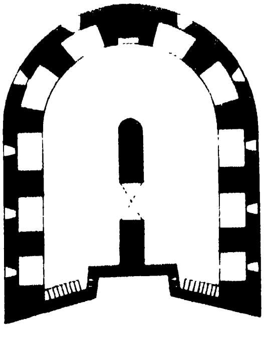


Fig 3.



Lower Floor

Fig 4



Barrack Floor

a Expense Magazine
b Reverberatory Furnace
d Magazine
e Guard Room
f Officers Quarters

EXAMPLES OF

Plan and Section of a

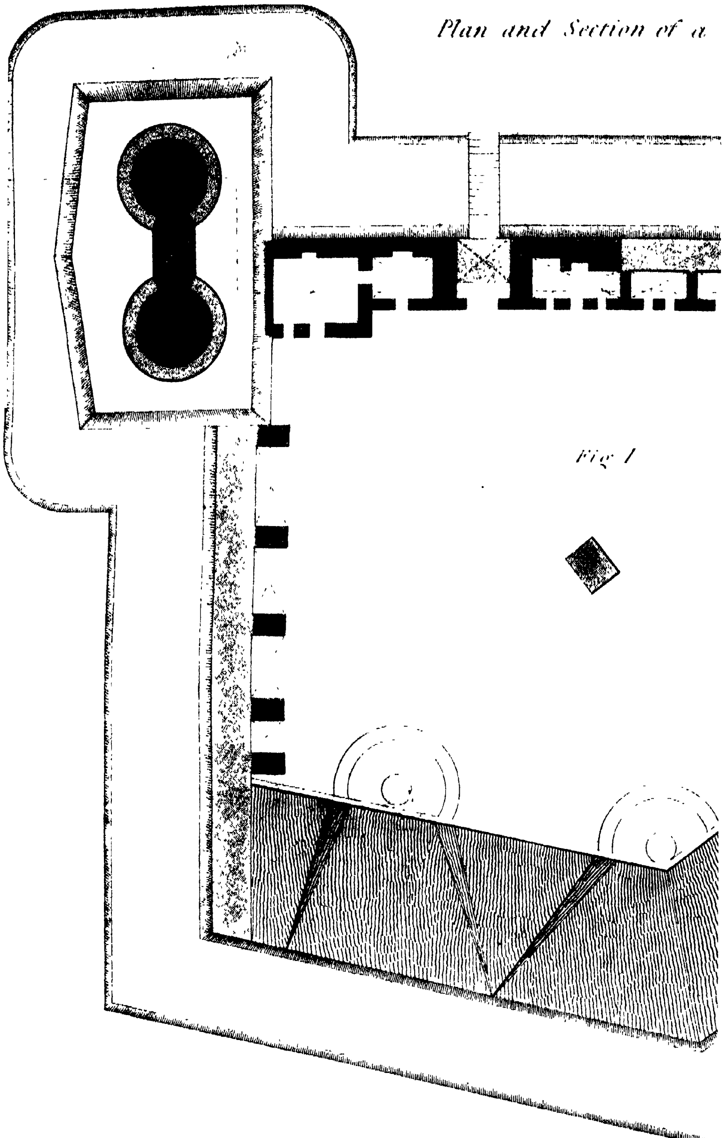


Fig 1

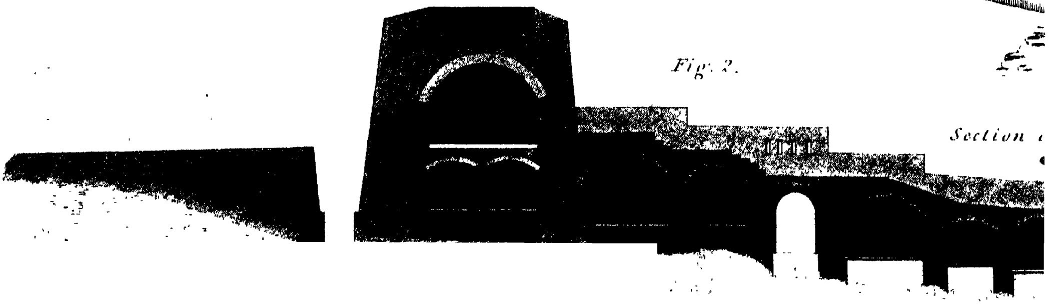


Fig: 2.

COAST DEFENCES.

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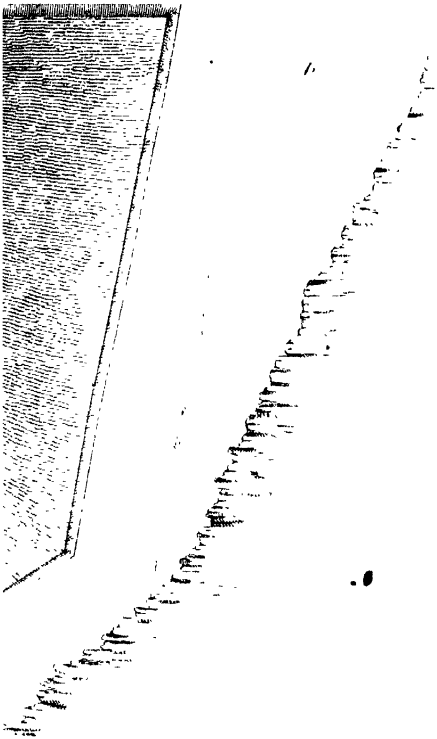
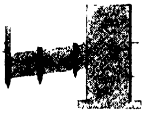
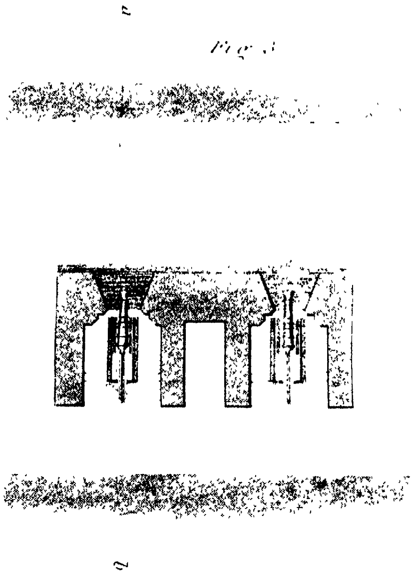




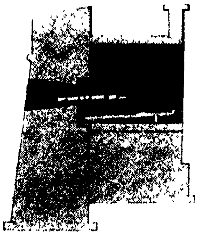
Plan and Section of
Block House Portsmouth

Fig 3

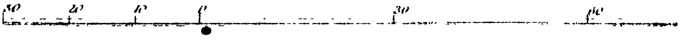


Section on the line a b

Fig 4



Scale 30 Feet to 1 Inch



EXAMPLES (

an and Section of a Tower
armed with One Gun

Section thro' a b Fig 1

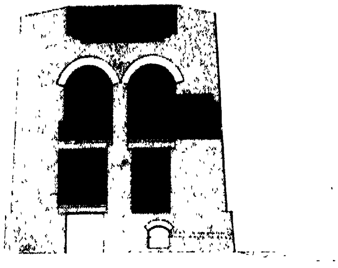


Fig 2

Barrack floor

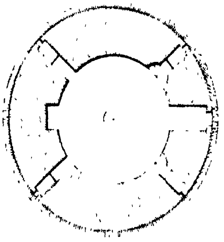


Fig 1.

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7

Section

Section and Plans

2 Pieces

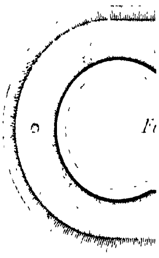
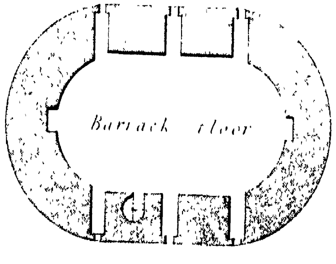


Fig 8



Plans and Section of 3 Gun Tower

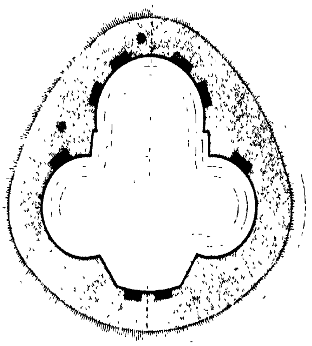
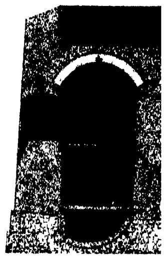


Fig 10

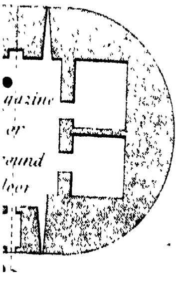
Section thro



Fig

Fig 12.

Fig 9



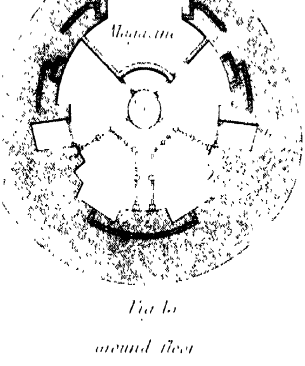
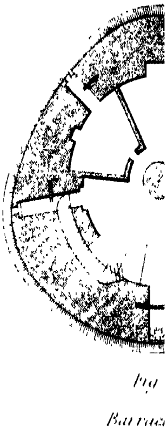


Fig 13

Ground floor



Fig

Barrac

PLANS AND SECTION OF A PICKET TOWER

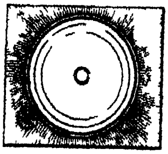


Fig 6

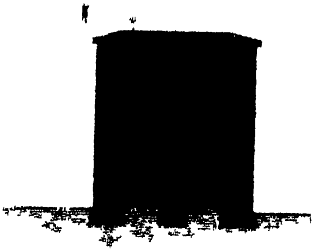


Fig 7
Section thro a b Fig 8

Barrack floor

Fig 8

Magazine floor

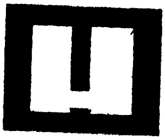


Fig 9

PLANS AND SECTION OF TOWER MOUNTING 4 GUNS

Fig 1

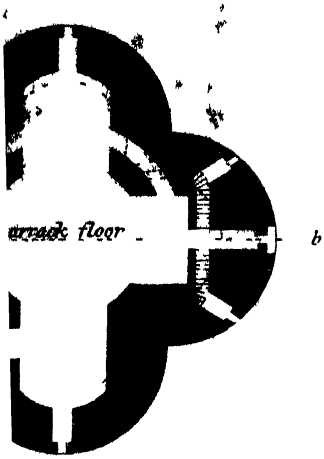
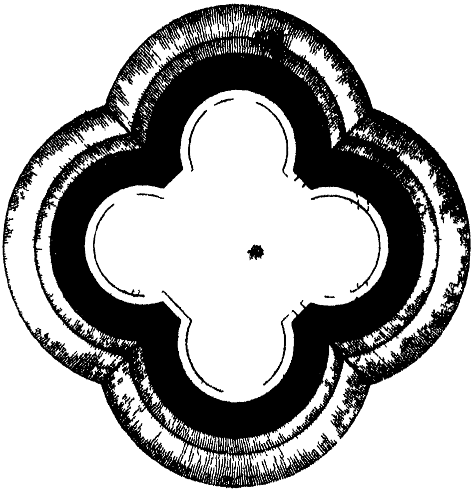


Fig 2



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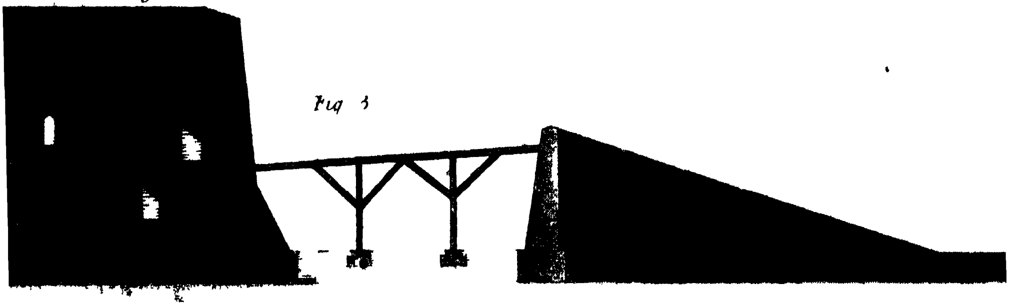
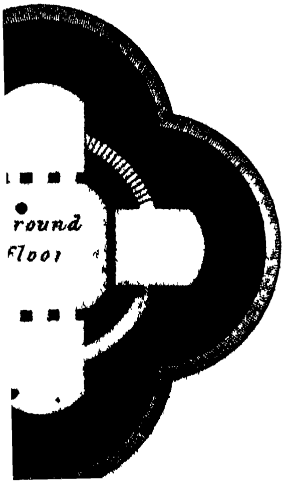




Plan and Sections of a Circular Fort

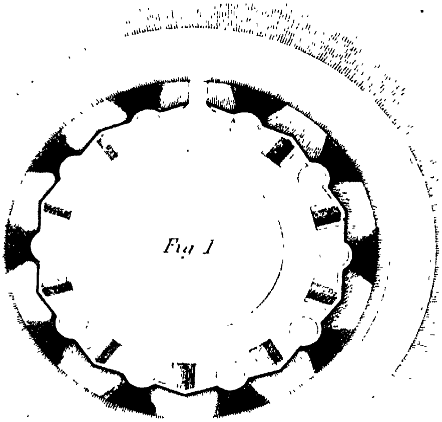


Fig 1

Fig 2

Fig. 3.

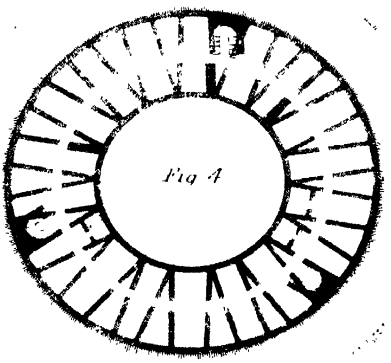


Fig 4

AST DEFENCES.

Plan of a Fort at the Entrance of a Harbour

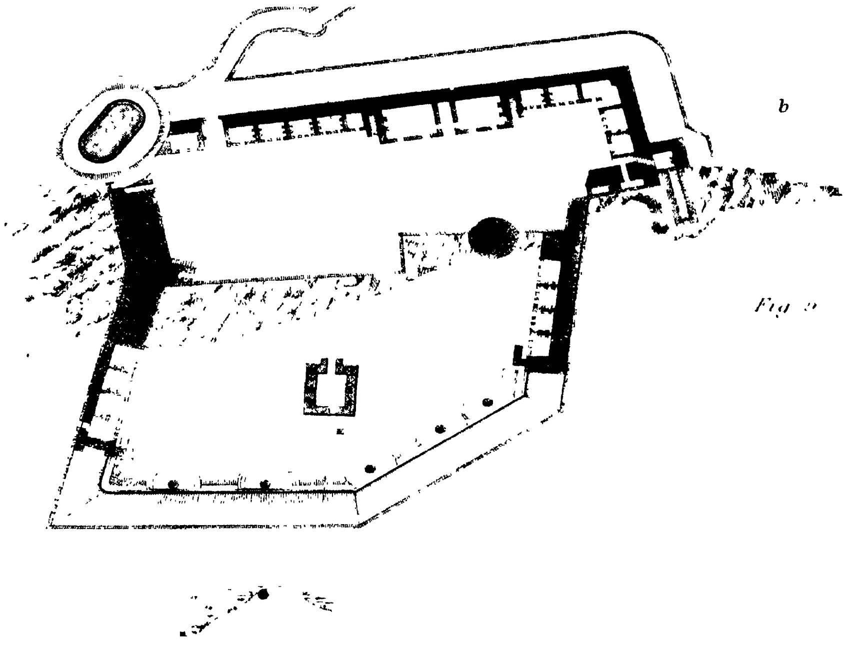


Fig. 2

Fig. 6

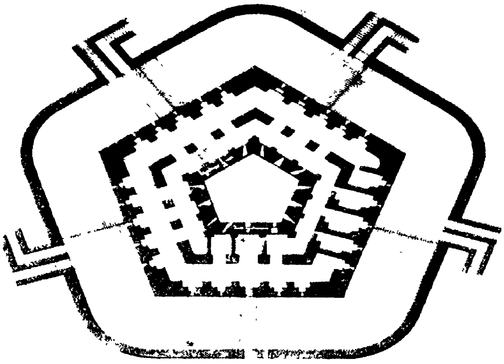
Section and Elevation on line a b

Section thro'

EXAMPLE

PLANS

Middle Floor of Fort.



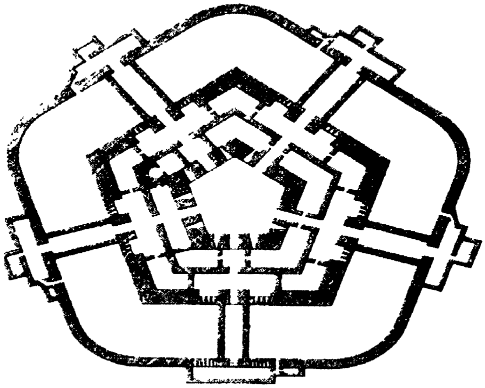


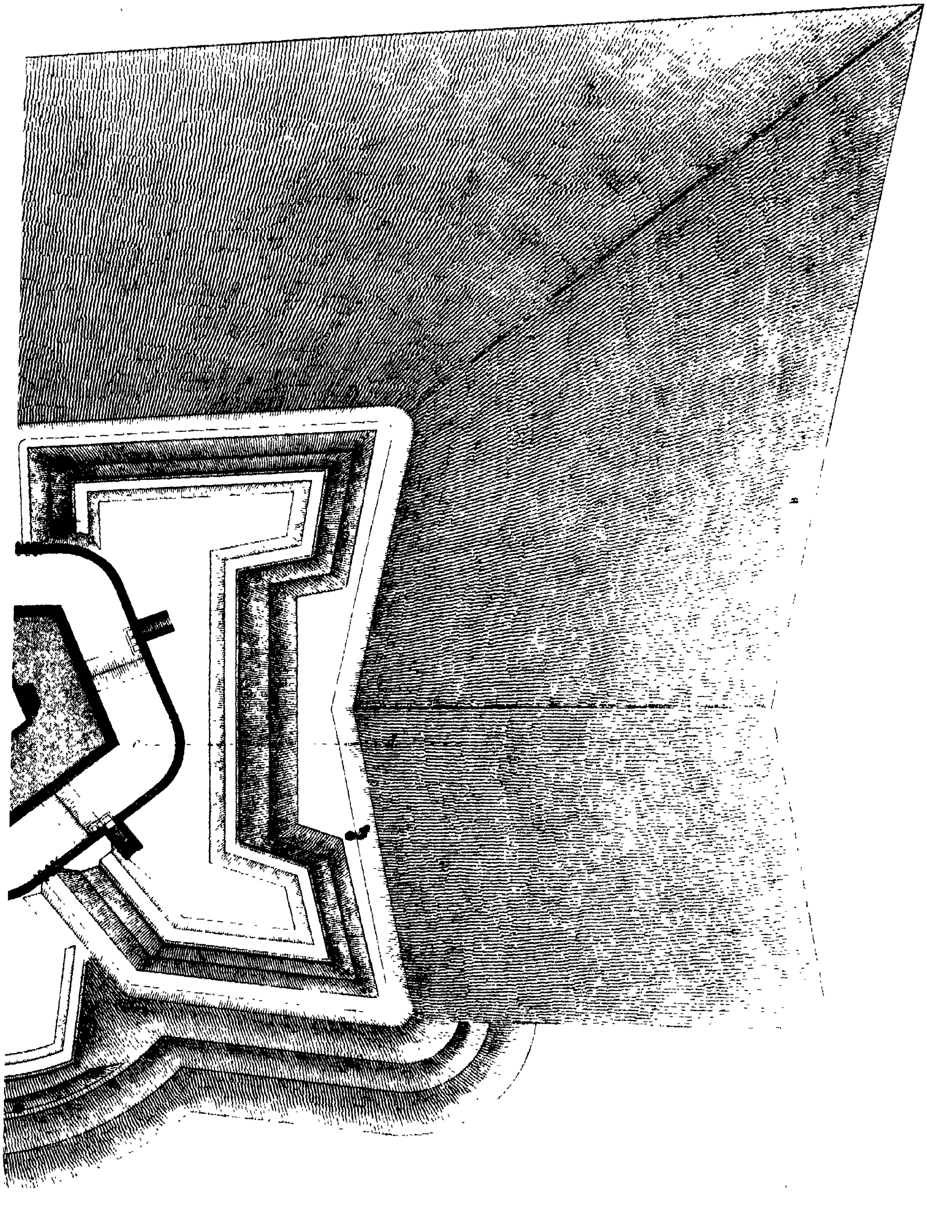
Fig. [illegible]

Lower Floor of Fort

Section of the Sea Front on the

AST DEFENCES.

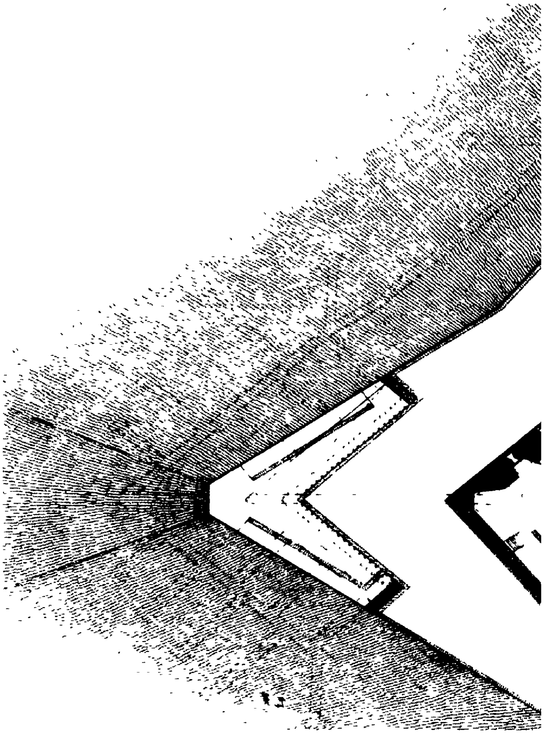
WELLINGTON.



Section of the Land Front on the line . . a

EXAMPLES

PLAN AND SECTION



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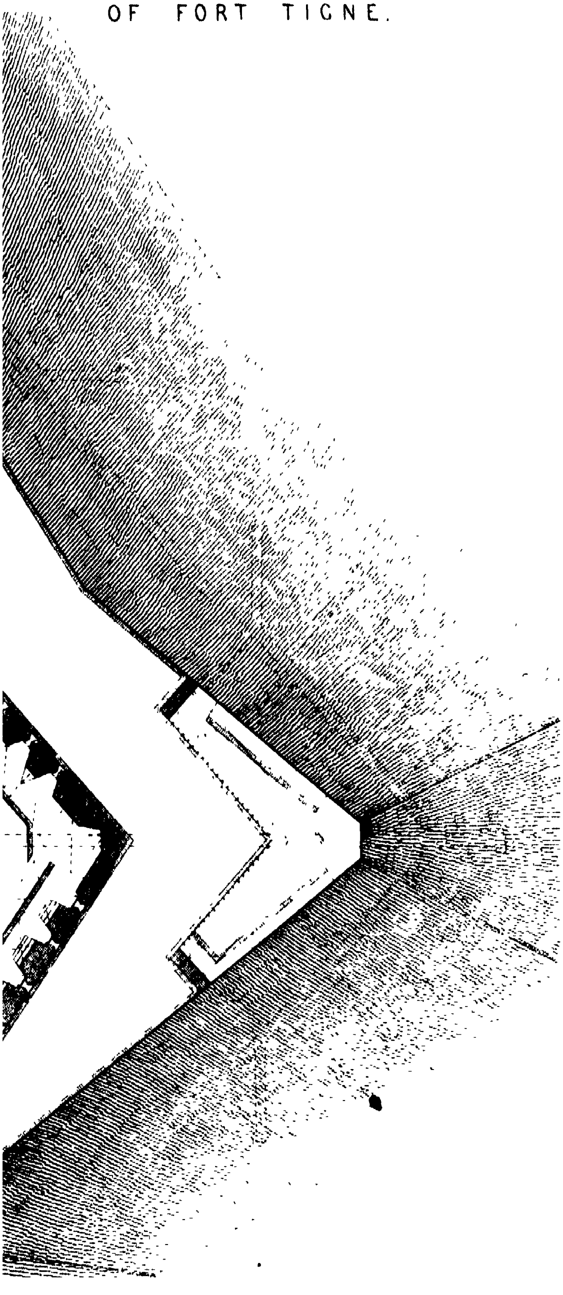

EXAMPLE

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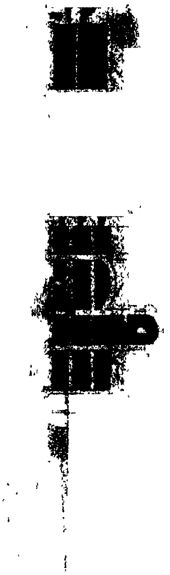
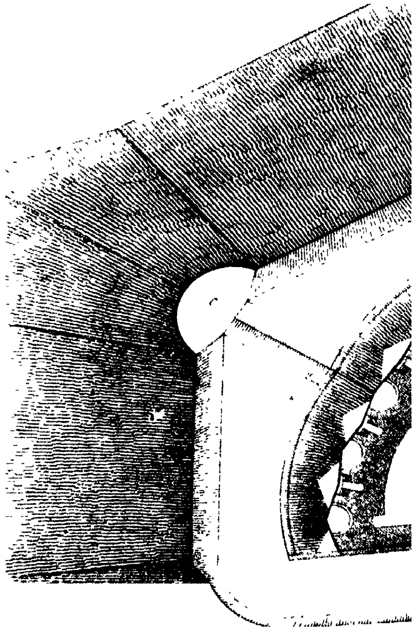


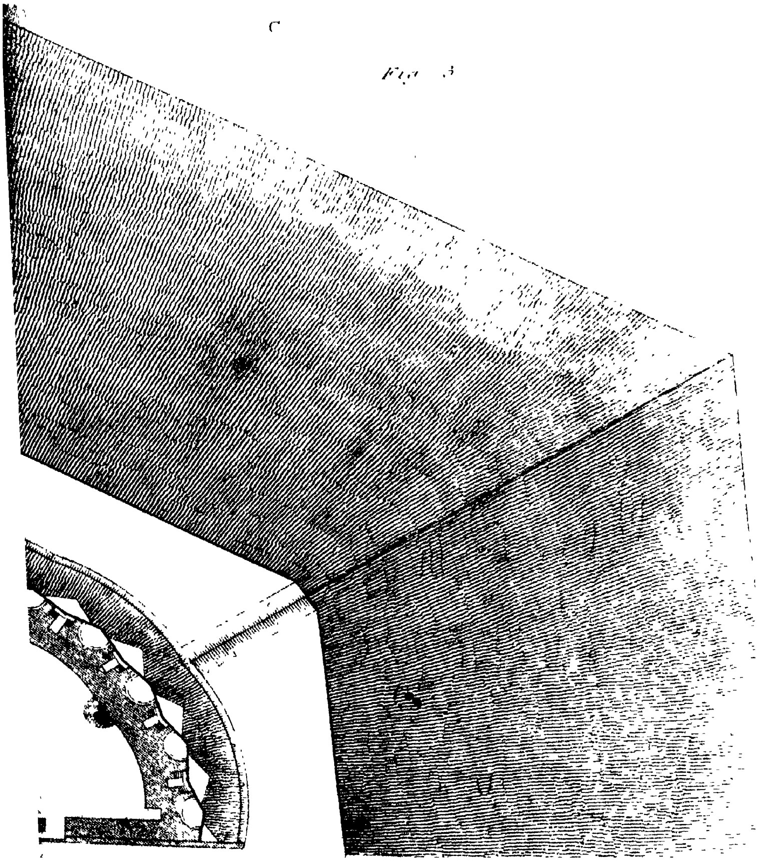
Fig 2
Section on A B of Fig 1



a *Staircases*
b *Lodging Traverses*
c *Drops*

AST DEFENCES.

Fig. 3

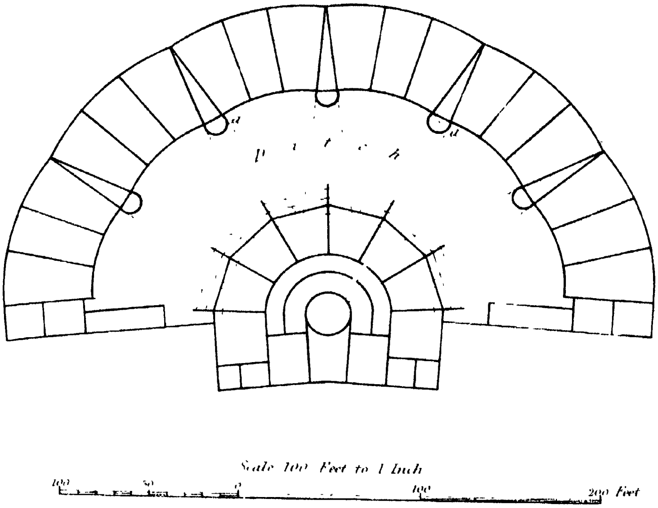


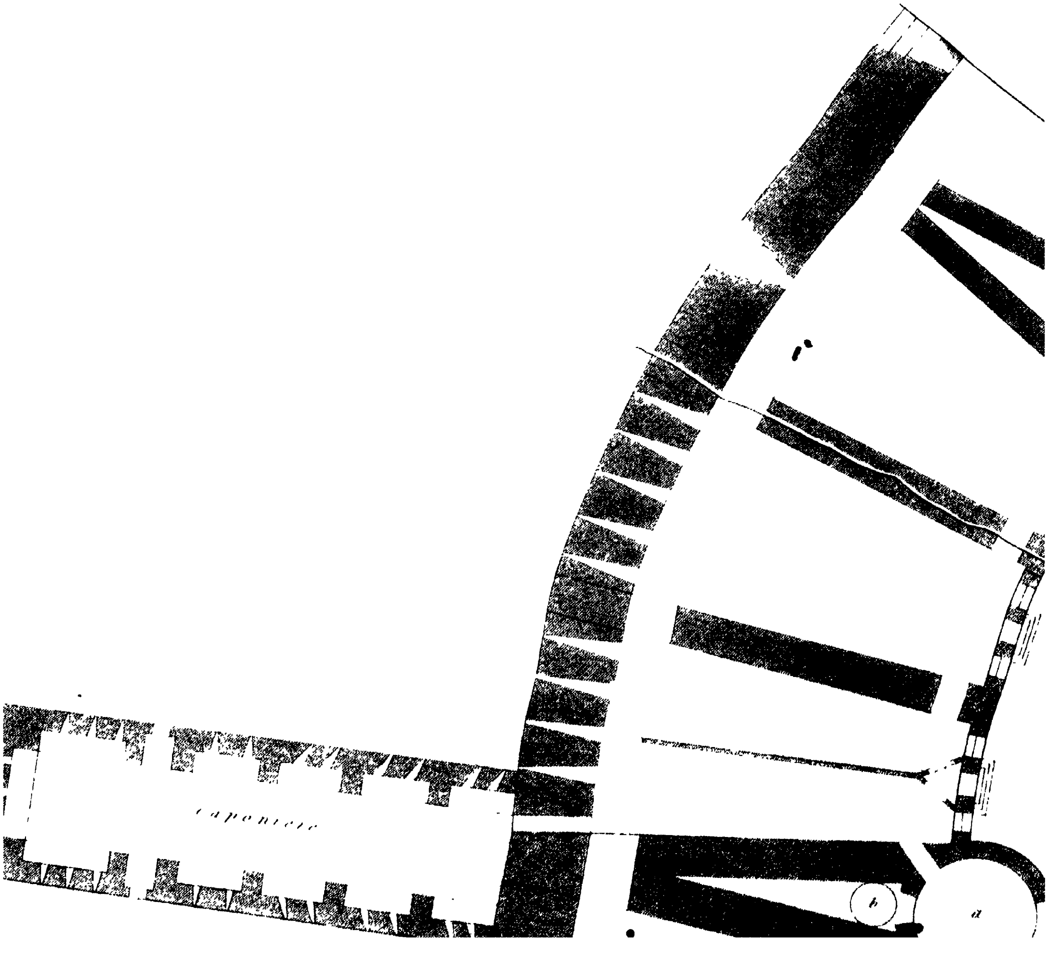
EXAMPLES

being a

Fig. 6.

Skeleton Plan





AST DEFENCES

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Fig 8
Machicoulis in Plan

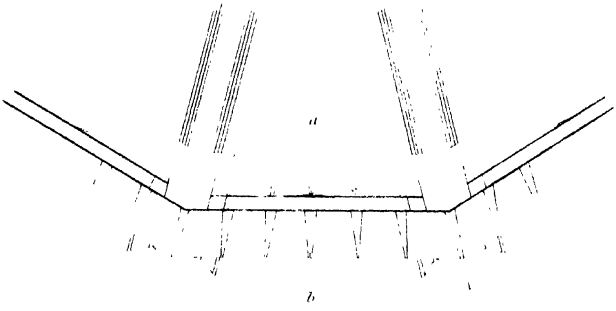


Fig 11
Construction of the
Revetments

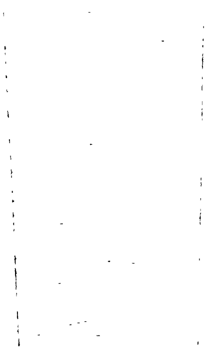


Fig 9
Elevation of the Machicoulis

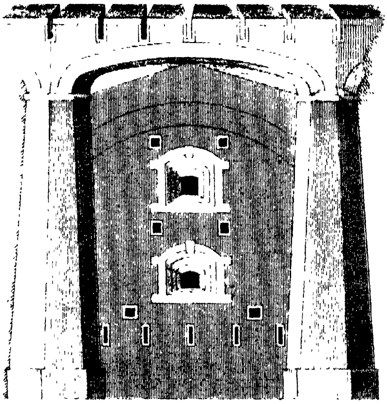
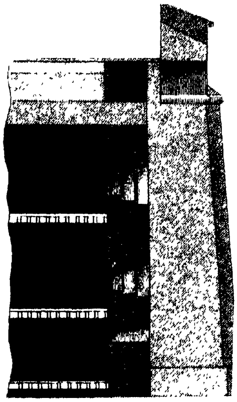
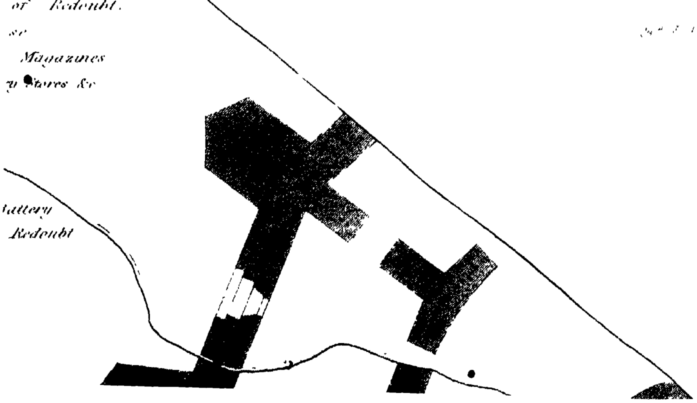


Fig 10
Section of Machicoulis
through a b
(Fig 8)



Scale 20 Feet to 1 Inch

g 12
of Battery and
of Redoubt.
se
Magazines
y Stores &c



assez connus, sur l'emplacement des batteries de côte. Les boulets ricochent sur l'eau mieux que sur terre, et tous les ricochets, sous 2 ou 3 degrés, fonte perdre peu de force aux gros boulets. Ceux de 24, sous 4 degrés, conservent encore plus de force qu'il ne faut pour percer le flanc d'un vaisseau, tel fort qu'il soit, à 300 toises et plus ; ainsi toute batterie qui, par son peu d'élévation, sera exposée à l'égoût des ricochets d'un vaisseau, recevra tous ses coups traînans qui lui feront encore beaucoup de mal ; et toute batterie qui sera assez élevée pour tirer à bonne portée sur un vaisseau, sous l'angle de 4 à 5 degrés, lui fera tout de mal possible, puisque les boulets traînans de la batterie iront tous au vaisseau ; mais ceux partant du vaisseau, qui est plus bas que la batterie, ne pourront ricocher assez haut pour monter jusqu'à elle, si elle a la hauteur supposée ci-dessous."

It will generally be found convenient to appropriate the upper part of such a building for a chapel, and the basement as a reception-ward, &c. (See Plates XI. and XII.)[1]

CENTRAL HALL, CORRIDORS, AND PRISON WINGS.

The central hall, and the corridors or passages which radiate out of it, and run through the prison wings, are open from the floor to the roof; and the cells being arranged on each side of the corridors, the doorway of every cell can be seen from nearly the same point. (See section, Plate XIII.)

CENTRAL HALL.

The central hall is used as the principal station of the officers engaged in carrying on the discipline of the prison. A gallery, which is a continuation of that on which the cells open, runs round it about 10 feet above the floor, affording access to the chapel and all the wings, and a circular staircase is placed in a convenient situation, communicating from the ground floor to both the galleries above.

PRISON WINGS, OR CELL BUILDINGS.

The prison wings, as before explained, radiate from the central hall, and the cells open into the corridor: these may be ranged on two or three stories; the lower range of cells being on the level of the floor of the corridors and hall; the upper range opening upon galleries attached to the wall, which are continued round the central hall.

THE BOUNDARY WALL.

The boundary wall should be of sufficient height to preclude all chance of escape, unless with the aid of some external means, which, by other precautions, ought to be rendered unattainable. For this purpose it should be from 18 to 20 feet high above the ground, and the foundations should be of such a depth, according to circumstances, as to prevent their being undermined in the course of a single night. The height also should be in some measure determined by that of surrounding objects, so that, as far as possible, the prison

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[1] The prison cells being spacious and well ventilated, it is scarcely deemed to be necessary to build an infirmary, excepting in very large prisons.

yards may not be seen into. The boundary wall should present an even, smooth surface on both sides; and if buttresses become necessary from its height or extent, they should be at least 3 feet broad, or the angles should be rounded off, to prevent their being made use of in climbing. The coping at the top should be smooth, and of a semicircular form, and should not project beyond the face of the wall; or the top of the wall may be finished in open brick-work. There should be a clear space of from 15 to 25 feet on the outside of the boundary, that no erection may be made against it, and that the exterior may be open to inspection; and in like manner the prison wings, generally speaking, should not be connected with it, but a clear space should be preserved round the interior.

It is desirable to have only one gateway in this external boundary, and this should open into an enclosed court-yard. The gate being retired a little will be of advantage in affording the means of defending it through loopholes made in the side walls, should attempts be made to force it during riots, or popular excitement.

GOVERNOR AND CHAPLAIN'S HOUSES.

In all large gaols it will be necessary to provide suitable residences for the governor and chaplain. It is desirable, when circumstances admit of it, that their houses should be placed contiguous to the entrance, but on the outside of the boundary wall, in order that the domestic arrangements of these officers may not interfere with the discipline, nor their own convenience be curtailed by the prison rules.

OFFICERS' HOUSES.

It will generally be desirable to provide accommodation contiguous to the prison for all the officers employed in carrying on the discipline; and, for this purpose, in large prisons, detached houses may be advantageously placed at the angles of the boundary wall, as shown in Plate X. By this arrangement the interior would be better watched, and an additional security against escapes would be obtained; and, if necessary, external violence during popular tumults might be more effectually resisted by means of loopholes commanding a view of and flanking the outside of the wall.

These general principles, and the ventilation and warming of the cells, will apply equally to any description of prison, and are convenient for any system of discipline.

DISCIPLINE.

Before entering into the consideration of further details, it will be of obvious importance to obtain an insight into the nature of the discipline which it may be in contemplation to enforce, in order that corresponding arrangements may be made.

This opens a very wide field of inquiry, and it is one that has at various periods engaged the attention of many eminent and enlightened men throughout the civilized world.

It may, however, be sufficient for our present purpose very briefly to allude to the subject, and leaving the arguments to take care of themselves, to arrive at the conclusion that the individual separation of one prisoner from another is the only basis on which any sound system of prison discipline can be formed.

Among other advantages, it prevents the possibility of contamination; it is a severe punishment to be alone, and it affords the well-disposed prisoner the opportunity of reflecting on his past life, and its consequences, and of forming some rational resolutions for the future.

The philanthropist Howard, the Duke of Richmond, and others of their day, entertained very sound views on the subject, and maintained that the separation of prisoners was essential to their punishment or reformation.

The Americans, when looking out for a good system of discipline, adopted the same principle, and have carried it out to some extent. It was most ably brought under the notice of the Government of this country in 1837 and 1838, by Mr. Crawford and Mr. Whitworth Russell, the Inspectors of Prisons for the Home District, in their second and third Reports to Parliament; and since the year 1842, when Pentonville Prison was first occupied, the system, from being better understood, has rapidly gained ground in public estimation.

M.M. De Beaumont and De Toqueville, in France, and Dr. Julius, in Prussia, have also successfully advocated the same principle, and it appears likely to be extensively adopted in those countries, and all over Europe.

The considerations which are urged in support of different systems are more or less interesting, but as they are beside our present inquiry, a very brief outline of the discipline of each will be sufficient to give a general idea of what they are.

Three systems only present themselves for consideration:

1st. An associated system in operation in some prisons of this country and elsewhere, based upon a *Classification* of prisoners:

2nd. The *Silent System*, in which prisoners are associated for labour or exercise during the day, and sleep in single cells at night.

3rd. The *Separate System*, in which each individual prisoner is confined in a cell, which becomes his workshop by day and his bed-room by night, and is thus effectually prevented from holding communication with or even being seen so as to be recognized by a fellow prisoner.

When public attention was called to the defective construction, and demoralizing, neglected discipline of the prisons of this country, some twenty or thirty years ago, it was most unfortunate for all the interests concerned, that a step was made in the wrong direction. It was considered that if prisoners could be *classified*, it would effect every thing that could be desired in the way of punishment and reformation.

Parliament was appealed to when this mania was at its height, and, in 1823, the wisdom of our ancestors was set aside by the repeal of many complicated Acts extending from the time of Edward the Third to that period. Statutes against " rogues, vagabonds, sturdy beggars, and other lewd persons," were abrogated or consolidated, great efforts were made, and vast sums of money were expended, in the erection of prisons calculated to facilitate the *classification* of prisoners. The best specimens of construction for this discipline were on a radiating principle. A central tower was supposed to contain an Argus, and from four to six or eight small detached blocks of cells radiated from it; the intervals between the buildings formed the yards for the different classes. (See Plate XIV.) These were exposed to an inspection from the centre that would, when exercised, detect riotous or disorderly conduct, but was not intended to check the recognized right of each class to amuse themselves as they pleased. Each of these detached blocks contained a certain number of small cells, generally about 8 feet long by 5 feet broad; and there was a day-room or rooms in each, where the prisoners of the class could sit over the fire and while away time by instructing each other in the mysteries of their respective avocations. In fact, had it been an object to make provision for compulsory education in crime, no better mode could have been devised.

If each class respectively had been composed of assault and battery men, or burglars, or sturdy beggars, they could only have acquired in association increased proficiency in fighting, picking locks, or imposing on the tender mercies of mankind. But no sooner was the discipline brought into operation, than this difficult condition had to be dealt with. The burglar was sent to prison for trying his hand at begging, a professed sheep-stealer for doing a little business as a thimble-rig man, and a London thief for showing fight at a country fair. These men, in the scales of justice, would be of equal weight with the simple clown who might have been detected in his first petty offence, and it may be conceived that a few weeks' association of the guilty with the comparatively innocent would not result in the reformation of the former, but in the permanent contamination of the latter. It will be at once apparent that such is the diversity of crime and character, that there is no possible standard by which any classification can take place which shall effectually prevent such a result.

In a valuable work on the prison discipline of the United States, written by M.M. De Beaumont and De Toqueville, and quoted in a recent publication by the present King of Sweden, then Prince Oscar, it is said, "L'impossibilité d'opérer une classification positive des criminels a été prouvée avec une certitude si mathematique que l'on doit la prendre pour point de départ dans toute la réforme des prisons."

Eminent men who have made the theory of prison discipline their study, and others who have had practical experience in the government of prisons, unite in exposing the fallacy of any discipline founded on a classification of prisoners: we may therefore safely quit the subject, and proceed to examine the claims of the *Silent System.*

If the members of each class of prisoners, instead of being left, as they are in most prisons, to unrestricted social intercourse, were obliged to sit side by side on a bench, and were compelled to work under the immediate superintendence of an officer, whose duty it would be to punish any man, who, by word of mouth, look, or sign, attempted to communicate with his fellow prisoner, we should have the *silent system* in operation.

This system contemplates each man having a separate sleeping cell, but that he shall be associated with others during the day for labour or exercise, under a rule of silence. And as minute classification is not so absolutely necessary as before, the usual practice is to assemble such classes as can be properly brought together, in order to economize superintendence.

The silent system of discipline has its advocates, but the arguments in support of the advantages of association, however strictly regulated it may be, leave so much obvious evil untouched, that there can be no question as to its being wrong in theory, and if so, it will be difficult to prove it right in practice.

We will therefore dismiss the silent system with faint praise, and advert to the details of the separate system.

As already explained, each prisoner under this system is confined by day and by night alone in a cell, and measures are taken for preventing his holding any communication whatever with a fellow prisoner.

It may be said, this is *solitary* confinement with a vengeance; and so it is in one sense, but when the administration of the discipline of separate and solitary confinement respectively is examined, it will be found that there is a very wide difference between them.

A prisoner in *solitary* confinement may be placed in any kind of cell; in many instances they are shamefully deficient in size, and even in those requisites necessary to the preservation of health. He is locked up and fed, generally speaking, on bread and water, and no further trouble is taken about him. This severe discipline cannot legally be enforced for more than one month at a time, nor for more than three months in one year.

In the year 1839, an Act passed (2nd and 3rd Vict. cap. 56), in which there was a permissive clause to render it legal to adopt the separate confinement of prisoners for any length of time to which the sentence extended, but it was saddled with these conditions: " Provided always, that no cell shall be used for the separate confinement of any prisoner, which is not of such a size, and lighted, warmed and ventilated, and fitted up in such a manner, as may be required by a due regard to health, and furnished with the means of enabling the prisoner to communicate at any time with an officer of the prison."

It was also provided that no cell should be used for such confinement until its fitness should have been certified to the Secretary of State by an Inspector of Prisons; that a prisoner should have the means of taking air and exercise when required; that he should be furnished with the means of moral and religious instruction, with books, and also with labour or employment.

It will be obvious from this explanation that there is an essential difference between *Solitary* and *Separate* confinement, and that there is but little real affinity between them.

This will be more apparent when it is considered, that in depriving a prisoner of the contaminating influences arising from being associated with his fellow prisoners, all the good influences which can be brought to bear upon his character are substituted for them; and that scarcely an hour in the day will pass without his seeing one or other of the prison officers, and that he is required to have constant employment or labour.

I have been led to enter upon an explanation of discipline at greater length than I fear will be considered consistent with the immediate object of this Paper, which is to communicate information on the construction of prisons. But when I look to the important situations held by officers of the corps, and the influence they may exercise in the colonies, it is desirable that every officer who may be in authority or who may be consulted upon a plan for a prison, should have some knowledge of the different systems of discipline, and be able to form an opinion on their relative merits, so as to adopt that which is sound in principle and best suited to the circumstances.

This is of the greater consequence as the subject is not generally understood; and where there are any preconceived notions, there is generally much prejudice and misapprehension to be overcome. Classification has had possession of the public mind for so many years, that innovations are looked upon with great suspicion; and as in any movement, whether in the moral or the physical world, there is a *vis inertiæ* to be overcome, it will generally be found that elderly gentlemen who sit in easy chairs, with their minds made up on any point, have their fair share of it.

But with reference to prison discipline we are evidently on the eve of reform. The subject is under anxious consideration from one end of Europe to the other; and there appears every reason to believe that the separate system of discipline will, by its own merits, eventually bear down all opposition; or, at least, that the principle of separation will be recognized as the basis upon which all discipline will be founded: hence the necessity of endeavouring to frame plans, which, whilst they may be applicable for any system of discipline, shall be proper and convenient for the *Separate System*, for which it will be borne in mind that certain conditions are prescribed by Act of Parliament.[2]

We will therefore proceed to consider the details of construction which are more immediately applicable to the *Separate System.*

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[2] 2nd and 3rd Vict. cap. 56, sec. 4.

DETAILS.

1st. The separate system, as before stated, demands that each individual prisoner shall be separately confined by day and by night in a cell, which shall be light, thoroughly ventilated and warmed, and of sufficient size to admit of his being employed a portion of the time in manual labour.

2nd. That the construction of these cells shall preclude all communication between one prisoner and another; the prisoner, however, to have the means in his own power of apprising an officer of his wish to see him in case of illness or other emergency.

3rd. That there should be the means not only of general inspection and superintendence, but that each prisoner should be subject to unobserved inspection.

4th. In order that the integrity of the system may not be broken in upon by the stated assembly of the prisoners for divine worship or instruction, it is essential that the chapel should be fitted with separate sittings or stalls; and that it may not become necessary to associate prisoners when taking exercise in the open air, separate yards, in the proportion of one for every four or five prisoners, should be provided for the purpose.

By referring to the plans it will be found that the above objects are all specially provided for.

5th. It will tend greatly to the convenience of administering any kind of discipline, and save much additional trouble to officers, if the cells be fitted up with the means for washing, and with other conveniences, so as to render it unnecessary for a prisoner to quit his cell until ordered to do so. (See Plate XV.)

CELLS.

The size of cells being a matter of primary importance, much consideration has been devoted to the subject, and the result has been that a cell 13 feet long by 7 broad, and about 9 feet high,[3] is considered sufficiently large for prisoners undergoing long periods of separate confinement.[4] Cells of this size

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[3] This size is about 3 or 4 feet longer than is necessary for an ordinary sleeping-cell, but the cost of the difference in a new prison cannot in general amount to more than from 3½ to 4 per cent. on the outlay.

[4] The discipline of separate confinement originated in England, and the proper size of cells was fixed by the Act of Parliament in the year 1778 (19th Geo. III. cap. 74), which enjoined that they

admit of the introduction of small machines for the employment of prisoners, give space for exercise, are wide enough to sling a hammock, and allow an active ventilation to be maintained without subjecting the occupant to a draught that would be prejudicial to his health.[5]

The division walls between the cells should not be less than from 14 to 18 inches in thickness, whether built of stone or brick. The ceilings may be a *half-brick arch, grouted in cement.*[6] *The spandrils being filled with concrete, will be ready to receive a floor of asphalte or plaster on the surface, or a floor of 3-inch Yorkshire stone may be placed over the arch. The external walls should be two bricks and a half thick, or 2 feet of stone; and as they are rendered hollow by the number of ventilating flues in them, it may be a necessary precaution to lay in near the outer surface a single course of hoop iron every 6 inches. The internal walls, next the corridor or passage, should be two bricks thick, or 18 inches of stone: the flues to be worked in these walls for ventilation will be more particularly described.*

WINDOWS AND DOORS.

The detail of the windows is given in Plate XV., and they should be glazed with fluted glass. It is desirable, as affording additional means of ventilation, that one pane should be glazed double, as shown in Plate XIII. fig. 8.

In prisons where the cells open into a spacious corridor, one door is sufficient for all purposes. The details are shown in Plate XV.

EXERCISING YARDS.

The means of affording the prisoners exercise in the open air, without compromising individual separation or entailing a disproportionate number of officers to superintend them, will be observed in Plate X. The yards radiate from a central point, round which there is placed a passage or room, having an inspection into each yard: they have an open railing on the out-

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should not exceed 12 feet in length by 8 feet in breadth, and 11 feet in height; nor be less than 10 feet in length, 7 feet in breadth, and 9 feet in height.

[5] M. de Chatel, who presides over the Department of the Interior at Paris, recommended, in a circular issued in 1841, that cells for separate confinement should be 4 metres long, 2·25 metres broad, and 3 metres high, which is rather larger.

[6] In the upper cells, as a measure of security, the arch should be in two courses, turned separately with a layer of hoop iron at 4-inch intervals between the courses.

side, in order to allow a free circulation of air; and a small roof is attached to the division walls, to afford shelter when necessary.

CHAPEL.

The chapel, as already stated, should be fitted up with separate stalls or sittings. The details will be observed in Plate XII.

This arrangement will be found of advantage, especially in extensive prisons, in affording facility for conveying religious or other instruction during the week-days. The chaplain would by these means be enabled to communicate with the prisoners in classes, without infringing the principle of separation, and thus to devote a longer period to a proportion of them every day than he would have it in his power to do if his intercourse with each individual were limited to visiting the cells.

The sides of each stall, and the doors which form the continuation of those sides, and shut up the general passage to each row, radiate upon the pulpit, so that each prisoner can see and be seen by the chaplain.

The rows of seats should rise in a regular series, one above another. The second row may be 1 foot above the first; the third 1 foot and ½ an inch above the second; the fourth 1 foot 1 inch above the third, and so on: the back of each row being made of such a height as to intercept communication when the prisoners are standing up, but not so high as to conceal them when sitting down. About 4 feet 6 inches has been found to be the proper height for securing this object for male adult prisoners. The seats designed for females and juveniles should be rather lower.

A double passage is made down the centre, or one on each side of the chapel, opening into and communicating with the gallery or galleries surrounding the central hall, and thus affording two or four points of access to it.

A staircase leads up from the gallery to a point which is on a convenient level for entering the higher row of seats, from whence a succession of steps, arranged in pairs, communicate downwards with each row in front.

VENTILATING AND WARMING THE CELLS.

The proper ventilation, and the means of warming the cells, when necessary, are objects of primary importance to the health of the prisoners, and demand the most serious consideration; for it should be borne in mind that the windows in the cells being fixtures, and the doors being effectually closed to prevent communication, the only mode of introducing the requisite supply of fresh air, and of abstracting what is impure, must be by artificial means.

The difficulty of applying ordinary modes of ventilation by opening windows or such means arises from their being destructive of discipline, in favouring the transmission of sound; and this has been one great difficulty to contend with in the principle which has been adopted.

Before, however, we enter upon the somewhat complicated details of effecting this object in a large prison, it will render what follows more plain to show the application of the principle which is in operation at Pentonville in its simplest form.

To do this we must descend into a well-ordered coal-pit.

It is generally known that coal lies in slightly inclined beds or strata of different thicknesses, and that in working it numerous galleries are made. If it be considered that these galleries are frequently from 500 to 1000 feet below the surface, and liable to be filled with noxious and inflammable gases, the absolute necessity of preserving an active ventilation will be at once apparent; in fact, it would be impracticable to work in them without it.

In the smallest colliery there are always two pits or vertical shafts from the surface: one is sunk to the lowest level of the coal bed, and is made use of for raising the water; and the other, higher up the level, is for raising the coal. These two shafts may also be made available for ventilating: it is, however, more convenient, and is usual in large collieries, to have two shafts specially for the purpose, one called the *Upcast Shaft*, for extracting the foul air, and the other the *Downcast Shaft*, for supplying fresh air in its place.

When pits are very deep, one shaft, divided into two compartments by an air-tight partition, will answer the same purpose.

It will be seen on referring to the plan and section, figs. 1 and 2, Plate XVIII., that the air which enters the galleries and passes along them from the *Downcast Shaft* A, finds its exit again to the surface by the *Upcast Shaft* B. This movement is effected and maintained in action by means of a fire made at the bottom of the *Upcast Shaft*, which rarefies the column of air within the shaft, causing it to rise with a proportionate velocity: the partial vacuum thus created is immediately filled by the colder and heavier foul air from the galleries, and this again is replaced by fresh air from the surface through the *Downcast Shaft*, which completes the circulation.

The velocity of the current through the galleries will chiefly be regulated by the difference of temperature existing in the two shafts; and such is the extreme mobility of air and its tendency to regain its equilibrium, that the movement originated in the *Upcast Shaft* by an accession of only a few degrees of temperature above that of the external atmosphere, will, under proper arrangement, exert an influence throughout the whole system of galleries in connexion with it, however extensive and complicated they may be.

The mode in which the current between the two shafts is made to circulate to the places where the works are carried on, or wherever it may be required, is very simple.

In getting coal, the galleries are usually worked in pairs parallel to each other, about 6 feet apart, and at every 5 or 6 yards these galleries are united by a short transverse cut, the object of which is to allow of both the galleries being ventilated.

In the plan, fig. 2, Plate XVIII., it will be seen that the fresh air passes from the shaft A along one gallery, then through the short transverse cut into the other, and from thence proceeds down another gallery to the *Upcast Shaft* B. Old workings or galleries not made use of, such as are represented at C and D, are stopped up either wholly or partially by doors or walls, otherwise the current would take the shortest course to the upcast shaft, and leave the workmen at the extremity of the galleries without any supply.

The extent to which a sytem of ventilation on this principle can be applied, will scarcely be credited by any one unacquainted with the coal fields in the north of England: it may be sufficient to say, that many of the air courses connected with the same shaft are 9 or 10 miles in length.

The plan, figs. 3 and 4, will show a series of galleries so ventilated from two shafts, that the work of cutting away the blocks of coal, or pillars, which are situated between the galleries can safely be proceeded with in any portion of the area.

It will be observed that the air first passes from the downcast shaft along the main galleries from *a* to *b*, where a portion of the current is diverted from its course to ventilate a distinct set of galleries. (See fig. 3.)

In order to direct the current to the points *m*, *m*, where the work is supposed to be in progress, the side galleries are closed by doors or walls *s*, *s*, *o*, *o*; and when it is required that the current shall enter the short portions of the gallery in which the miners are engaged, a boarded partition is fixed, round which the air passes. (See fig. 2.)

The arrows indicate the course of the current, which may easily be traced in figures 3 and 4, through the different galleries, to the *Upcast Shaft.*

In like manner the direction of the current will be observed through the larger system of galleries shown in fig. 4; the traps *p*, *q*, *r*, *s*, being fixed to guide the circulation from the first main gallery *c*, through the successive channels *e f*, *g h*, &c., until it finally issues by the main foul air gallery *k*, *k*, *k*, to the *Upcast Shaft.*

The mode in which the foul air is made to traverse the gallery through which the fresh air passes to the whole mine will be observed in figs. 5, 6, and 7.

The quantity of air required in different mines varies with circumstances, but the velocity of the current along the main galleries may conveniently be maintained at from 6 to 8 or 10 feet in a second.

As these galleries, however, are under ordinary circumstances made use of either as a communication from one part of the works to another, or for drawing the coal to the shaft, it would be inconvenient to the workmen to have a very strong current of air passing along them; hence there is a practical limit to their being made use of for both purposes.

This brief explanation of the subject will perhaps have served to show that the simple principle on which coal mines are ventilated, may be readily applied above ground in barracks, casemates, or galleries, by substituting a large chimney for the *Upcast Shaft*, and allowing the ingress of fresh air to supply the place of the foul air whenever it may require to be drawn off.

Reverting to the ventilation of a prison, the objects to be attained may be thus stated.

1st. The regular supply of a sufficient quantity of fresh air, and, when necessary, of temperated air, into each cell, without subjecting the occupier to any inconvenience from the draught.

2nd. The withdrawal of a like quantity of foul air.

3rd. That no additional facilities of communication between prisoners in adjoining cells should be afforded by the means made use of, and, therefore, that the transmission of sound should be carefully guarded against.

In the first consideration of the means by which these objects could be secured, Messrs. Haden, Engineers, of Trowbridge, were consulted, and afforded valuable assistance in perfecting the details of the system adopted at Pentonville Prison.

It will be observed, by referring to Plate XIII., that an apparatus is placed in the basement story, consisting of a case or boiler, connected with a proportion of pipes, adapted for the circulation of hot water; and in connexion with it there is a large cold-air flue open to the outer air. The fresh air introduced through this flue is brought in contact with, and passes over, the boiler and the pipes, and may therefore be warmed or left at its natural temperature, as may be desired. The air thus brought from without passes right and left along the flue which runs horizontally under the floor of the corridor (figs. 3 and 7), from whence a communication is established by lateral small flues separately with each cell, both on the lower and upper floors.

The means by which this is effected will be noticed in fig. 7, where A, B, C, are the fresh-air flues passing into the middle of the corridor wall; from thence they will be observed passing up the wall of the corridor, and terminating in a grating close under the arched ceiling of the cells, on each of the three floors.

A current of air is thus introduced from the outside into each cell of the three stories; and it may be warmed, or otherwise, as already mentioned. The object of making the point of entry at the top of the cell instead of at the bottom, and diffusing it through a grating on an extended surface, is, that no unpleasant draught may be experienced by the occupier of the cell, which, in a confined situation, would be the case were it brought in at the level of the floor; and that he may not have any inducement to frustrate the intention of ventilation by stopping it up.

The means of extracting a corresponding quantity of foul air is as follows: A grating is placed close to the floor of each cell, on the side next the outer wall, and diagonally opposite to where the fresh air is introduced. This grating covers a flue, which passes up the outer wall (figs. 1, 3, and 6,) and communicates with a main foul-air flue placed in the roof. The main foul-air flue terminates in a ventilating shaft, rising above the top of the building. The small flues (D, E, F) forming the communication between the grating near the floor of all the cells, and the main flue in the roof, will be noticed in figure 1.

By this arrangement the total lengths of each pair of flues respectively made use of for introducing fresh air into the cells, and extracting foul air from them, are rendered nearly equal on all the stories. This promotes uniformity of action; and the advantage due to the *ascending* principle, and to difference both of temperature and altitude, is also secured. Another provision of some *importance should be adverted to. Fresh air should be taken into the main flues, communicating with all the cells in the respective wings or divisions from the side which happens to be exposed to the wind. The force or pressure produced by a very moderate breeze, combined with the other arrangements and circumstances which are favourable for ventilation, will generally cause a sufficient current to pass through the cells without any fire being lighted in the extracting shaft for ensuring it. The operation of the system will by these means at all times be improved, and a considerable saving of fuel will be effected.*

It will be borne in mind that the same flues are made use of for ventilating the cells both winter and summer; the only difference between the proceedings to be adopted is, that during the summer, when air is introduced into the cells at its natural temperature, a fire is lighted, when necessary, in the ventilating shaft (Plate XV. fig. 1); and during winter, when the temperature of the air must be raised, a fire is lighted in the heating apparatus below, the smoke and disposable heat from which, being discharged into the shaft, answers the same purpose.

By means of the system of flues which has been thus briefly described, a communication is established, first, from the outer air, through the warming apparatus, to the top of each cell; and then from the floor of each cell upwards, through the extracting flues and ventilating shaft, into the outer air again.

WARMING.

As ventilation involves the introduction of fresh air whenever it may be required, it is obvious that in order to do so without inconvenience, during the winter months, it will be necessary to warm it.

There are various ways of effecting this, but it may be taken for granted, that in all cases where the cheerful blaze of an English fire is superseded by the use of warm air, it is essential to comfort as well as health, that the radiating surface from which the heat is obtained, should be at a very moderate temperature. The great defect of the whole genus of metal stoves and cockles deriving their heat directly from the fire, is the difficulty of regulating the temperature of the surfaces within certain limits. This inconvenience, however, is obviated by making use of *water* or *steam* as a medium of heating. On comparing the two for this purpose it will be apparent that the circulation of water in metal pipes is to be preferred to steam, chiefly from its affording the means of heating the surfaces to any degree under that of the boiling point, whilst to maintain steam at all, they must be kept at a uniform high temperature.

There are many varieties in the form of a hot-water apparatus, as it is called, but they all act upon the simple principle, that particles of water, when heated and rendered specifically lighter, rise to the surface. If, therefore, an apparatus be disposed so that the heated water may flow through a pipe fixed at the top of the boiler, and as it gradually becomes cooler by imparting its warmth elsewhere, may return by another pipe to the bottom of the boiler, the circulation will be complete.

The motive power which maintains the current is the difference of weight of the columns of water in the *flow* and *return pipes*, which causes an unequal pressure on the points where those pipes are inserted into the boiler, and induces the circulation.

An apparatus consists of the boiler and pipes, or other metal surfaces for radiating heat, a small feed cistern for supplying the boiler, a tube for letting out any air or steam that may accumulate in the pipes, a thermometer for regulating the heat, and a cock for emptying the whole.

The feed cistern should be placed a few feet above the highest point to which the pipes are carried, and the tube for discharging air or steam should be fixed at the highest point of the pipes, and rise some feet above the feed cistern.

The apparatus shown in the plan combines every requisite that can be desired for the purpose of warming.

1st. There is a large proportionate area of radiating surface deriving its temperature from the circulation of hot water, producing the effect required in the coldest weather, when that surface is maintained at an average temperature of about 100° to 120°, but under ordinary circumstances not exceeding from 80° to 100°.

2nd. A provision is made for increasing the area of surface in the main flues, in proportion as its temperature is lowered by an increased distance from the boiler, thus maintaining an equality of temperature in the cells furthest removed from the central point.

3rd. The means of reducing the quantity of radiating surface in the main flues to meet the effects of a sudden rise in the temperature of the external atmosphere.

4th. It is simple in its construction, extremely economical in the consumption of fuel, and very durable from the fire not being in immediate contact with the boiler.

A series of experiments have been carried on at the request of the Commissioners for the Government of Pentonville Prison, by the principal Medical Officer of the establishment, the results of which are satisfactory in establishing the following important facts:

1st. That from 30 to 45 cubic feet of pure fresh air is made to pass into every cell in a minute, and that this abundant ventilation goes on with extraordinary regularity.

2nd. That this current of ventilation, and a temperature of from 52° to 60° of heat, can be uniformly maintained in the cells during the coldest weather, at an expense of less than ¼*d.* per cell for twenty-four hours, and the summer ventilation by means of a fire lighted in the extracting shaft has been kept up at less than half the expense.[7]

The following Tables, extracted from the Second Report of the Commissioners, show the remarkable equality of temperature maintained in the cells at Pentonville Prison, and the adjusting power of the apparatus in retaining that equality, independent of the sudden changes in the external atmosphere.

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[7] In the coldest weather of the winter 1842-3, the quantity of fuel consumed at Pentonville Prison was from 2 cwt. to 2½ cwt. for each apparatus in twenty-four hours, by which sixty-six cells, and the adjacent corridors, were warmed and ventilated; but in 1843-4, in consequence of the flues being quite dry, the consumption of fuel was only one-half the above quantity, and the cost of warming and ventilating each cell amounted to less than one farthing for twenty-four hours; the price of Merthyr coal, in each case, being 25*s.* 6*d.* per ton. Previous to the opening of the prison 5 cwt. of coal was required to maintain the same conditions. The greater part of this quantity was expended in the vaporization of water, and consequently had no effect on the cells. Hence the necessity of not trusting to any results concerning temperature in connexion with the consumption of fuel or the power of an apparatus, until all the flues and the building are perfectly dry.

No. I.—PENTONVILLE PRISON.

Table of recorded Temperatures for the month of February, 1814.

Date.	External Temperature.		Internal Temperature.	
	Maximum.	Minimum.	Maximum.	Minimum.
1 Feb. 1844	39°	28°	59°	56°
2 ,, ,,	36	28	59	54
3 ,, ,,	34	28	56	51
4 ,, ,,	36	27	55	51
5 ,, ,,	36	28	55	51
6 ,, ,,	35	25	55	50
7 ,, ,,	40	29	54	50
8 ,, ,,	42	32	54	51
9 ,, ,,	41	31	55	51
10 ,, ,,	40	32	55	51
11 ,, ,,	39	31	55	51
12 ,, ,,	36	30	55	50
13 ,, ,,	35	24	54	50
14 ,, ,,	31	24	53	49
15 ,, ,,	39	28	53	49
16 ,, ,,	45	32	53	50
17 ,, ,,	46	34	54	50
18 ,, ,,	47	37	55	50
19 ,, ,,	46	40	56	51
20 ,, ,,	47	30	57	52
21 ,, ,,	38	28	55	52
22 ,, ,,	37	31	55	51
23 ,, ,,	35	25	55	50
24 ,, ,,	49	28	54	50
25 ,, ,,	43	34	54	51
26 ,, ,,	49	39	55	51
27 ,, ,,	44	27	56	51
28 ,, ,,	38	29	54	51
29 ,, ,,	46	33	55	51

G. Owen Rees,
Principal Medical Officer.

No. II.

Date.	Minimum temperature of external air.	Minimum temperature of the cells.
January 1, 1844	33°	60°
,, 2 ,,	31	60
,, 3 ,,	22	57
,, 4 ,,	23	57
,, 5 ,,	42	57
,, 6 ,,	46	58
,, 7 ,,	39	60

COLONIAL PRISONS.

In hot or cold climates some difference in construction, to meet the particular circumstances, will be found necessary, although it may be equally advantageous to preserve that principle of discipline which involves the individual separation of prisoners.

In the West Indies, for example, it will be desirable that the outer walls should not be exposed to the sun, and that advantage should be taken of the prevailing winds for ventilating the cells and keeping them cool. In such cases it may be advantageous in large prisons to place the cells back to back, and let them open outwards on galleries, care being taken to build the wings at right angles with the prevailing winds: the ventilation may then be effected as shown in Plate XIX.; the flues serving alternately for the admission of fresh air, and the exit of vitiated air, according to the change in the direction of the wind.

In Canada, where extreme cold has to be provided for, a building in which the external walls are filled with flues, and having the windows of small proportionate area, will require less artificial heat than ordinary dwellings: the same construction and the same principle of warming and ventilating adopted at Pentonville will therefore be applicable.

It would, however, be necessary to increase the area of the surfaces for radiating heat in the main flues, and to warm the corridors by stoves when necessary, so as to assist in keeping the cells at an equal temperature. The main flues should also be cased with non-conducting materials, or otherwise protected, so as to prevent the radiation of heat where it was not required.

With these precautions there is little doubt that any desired temperature might be maintained in the cells during the coldest weather of a Canadian winter, and that it would not be materially affected by the sudden changes that occasionally take place in that climate.

BARRACK CELLS AND POLICE STATIONS.

The same principle of construction which is found to be advantageous in large prisons may conveniently be applied on a very limited scale for barrack cells, &c. The committee appointed to report on the subject of military imprisonment, and the different questions connected with it, have recommended that cells in the proportion of two for every one hundred men should be established in each barrack; in which sentences of confinement by order of the commanding officer, and limited periods of solitary confinement by sentence of a court-martial, should be carried into effect. The proposed construction and detail of such cells is shown in Plate XVI., but there will be many situations where, from difficulties in the size and shape of the ground, or other circumstances, they cannot be executed as laid down; the principle, however, may apply.

In such cases it will be important to preserve the size of the cells, the means of inspection, and of ventilation and warming. With reference to the latter point, if fresh air be freely admitted into the corridor or passage, and warmed when required by an Arnott's stove, and if the extracting flues be connected with a vertical air shaft in which there is a smoke flue from some fire generally in use, the arrangements for ventilation and warming will be very economically and effectually provided for. When the number of cells is very limited, the trouble and expense of keeping a fire lighted during the summer months specially for ventilation should be avoided, and with this view it is desirable to provide an opening from the cell directly into the external atmosphere, to be made use of whenever the weather will permit. Means must be adopted for preventing such an opening affording facilities of communication between prisoners in adjoining cells. A very simple method would be to introduce the air into a cell in the same manner as into a magazine, the internal grating being covered with a slide, or a square of the window may be glazed double, leaving an opening of 1 inch, as shown in Plate XIII. By such simple method an accidental ventilation will go on, under most circumstances, that will be found sufficient for keeping the cells in a wholesome state at all times of the year when it is not necessary to warm the air.

In Canada, however, as there is not in barrack cells the mass of material to retain heat which is found in larger prisons, greater precaution against cold would be necessary: it is suggested that the external walls of barrack cells and police stations should be built hollow, that the internal walls be lined with boards, and that a double sash be provided for use during the winter months; that a large stove or stoves should be placed in the passage or corridor, and a stove pipe carried transversely through the cells at the springing of the arch; and that, in order to impart the warmth of the passage to the cells, an active ventilation should be kept up by means of the extracting shaft and smoke flue from the stoves.

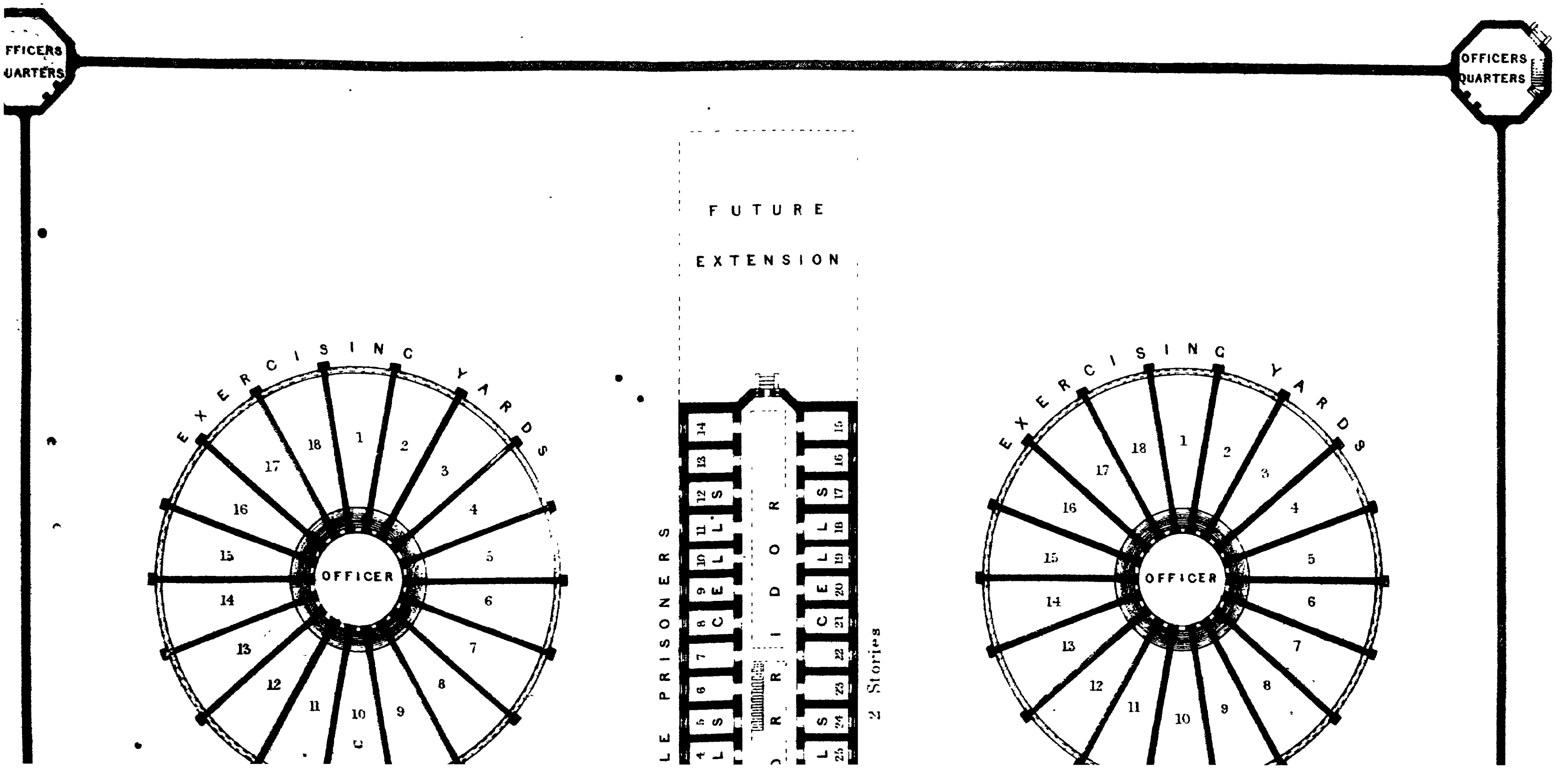
In like manner, in hot climates, special provision should be made for protecting the walls, doors, and ceilings from the effects of the sun's rays, and for promoting ventilation.

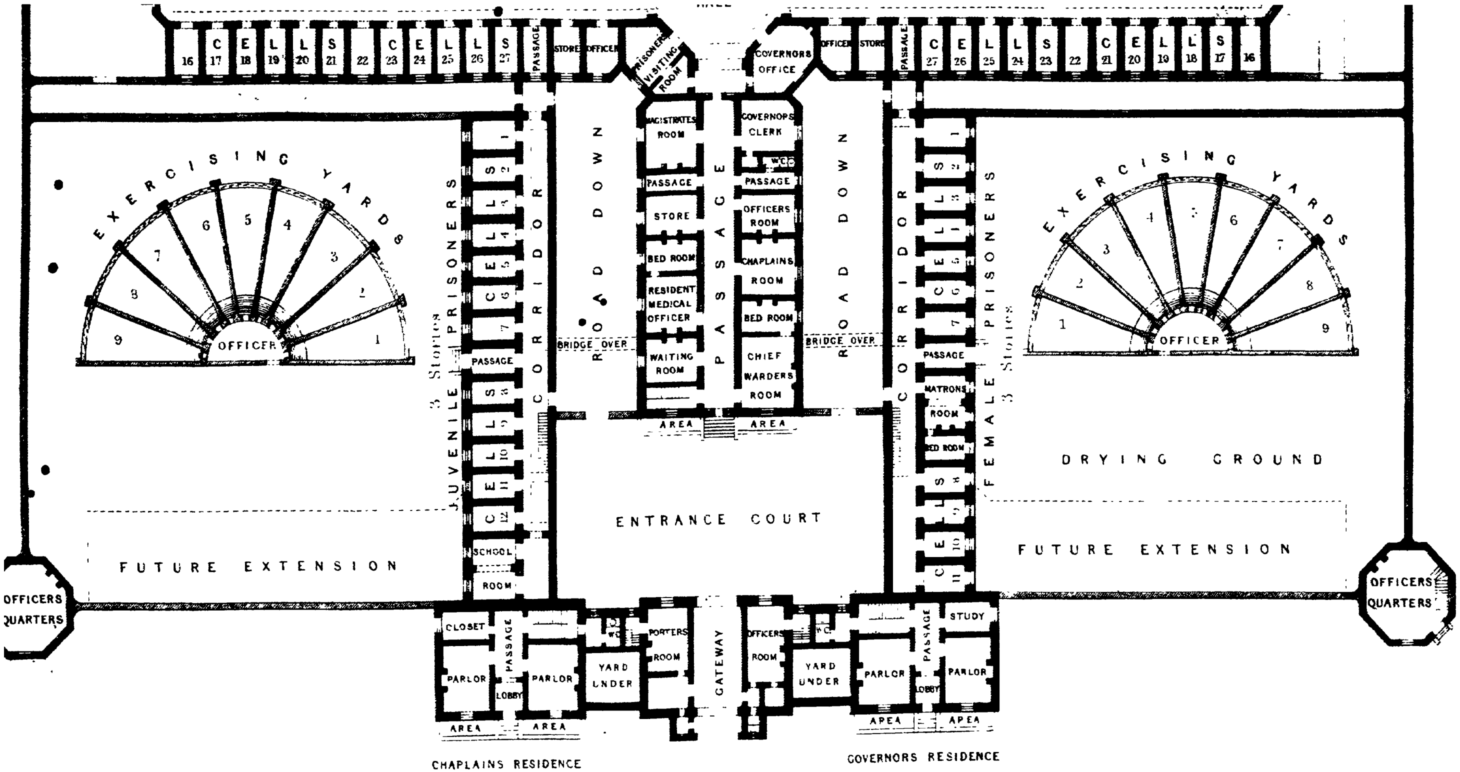
It is stated at the commencement of this Paper, that the system adopted for ventilating and warming prisons was equally applicable to barracks, casemates, &c.; and it is scarcely necessary to add, that an object which cannot fail to have a beneficial influence on the health of the troops is deserving of serious consideration. A few practical suggestions on this head will form the subject of a separate Paper, in the hope it may appear that the adoption of a regular principle of warming and ventilating barrack rooms, &c., will not only add to the comfort of the men, but will prove a measure of economy in diminishing the consumption of fuel.

J. Jebb,
Major, Royal Engineers,
Surveyor-General of Prisons.

DESIGN SHEWING THE GENERAL ARRANGEMENT OF A PRISON.

ACCOMMODATION	
MALES	170
FEMALES	40
JUVENILES	40
TOTAL	250





GROUND PLAN.

SCALE OF FEET.

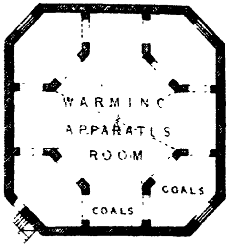
50 40 30 20 10 0 50 100 150 200 250

J. Jebb
Major Rl Engrs

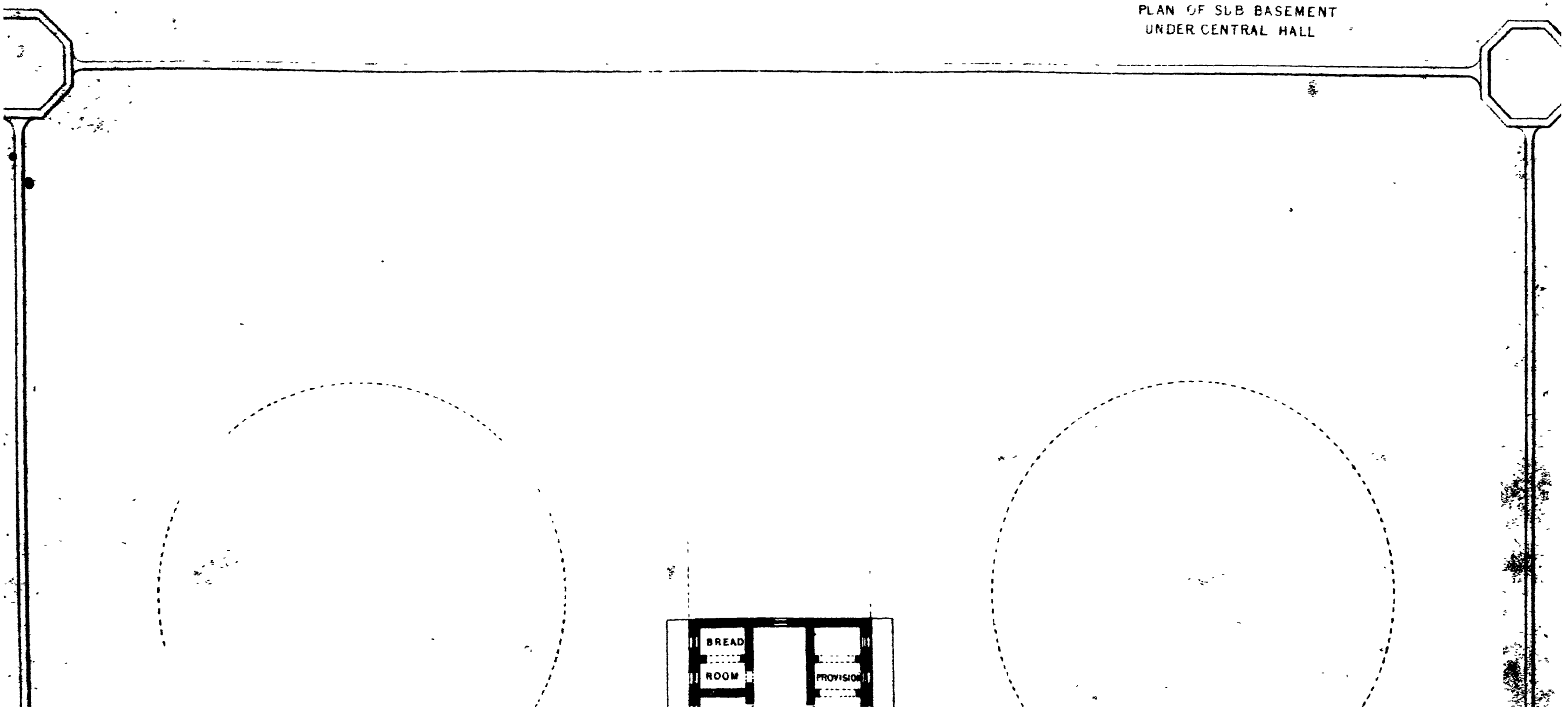
B.R.Davies fau

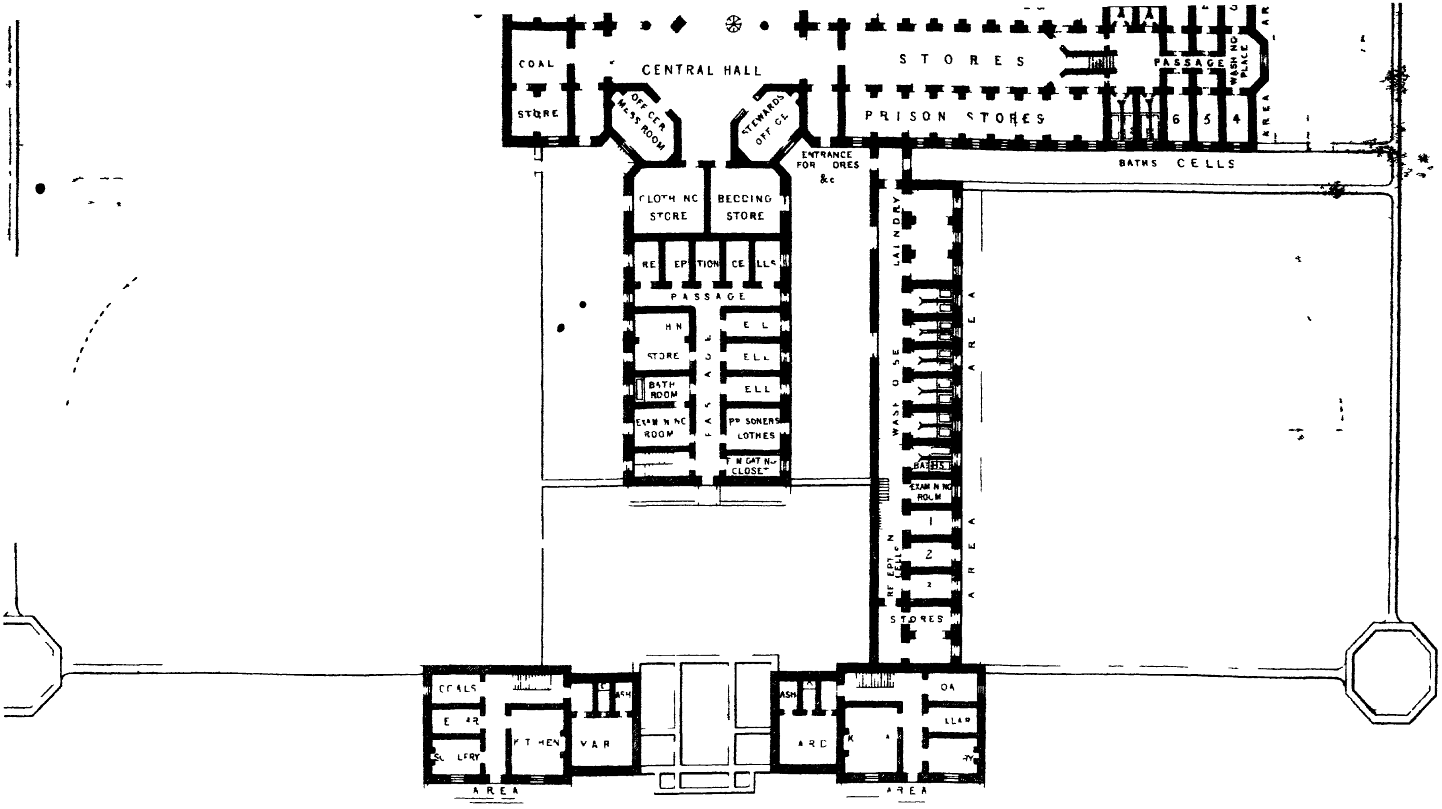
London John Weale Architectural Library 59 High Holborn 1844

DESIGN SHEWING THE GENERAL ARRANGEMENT OF A PRISON.



PLAN OF SUB BASEMENT
UNDER CENTRAL HALL





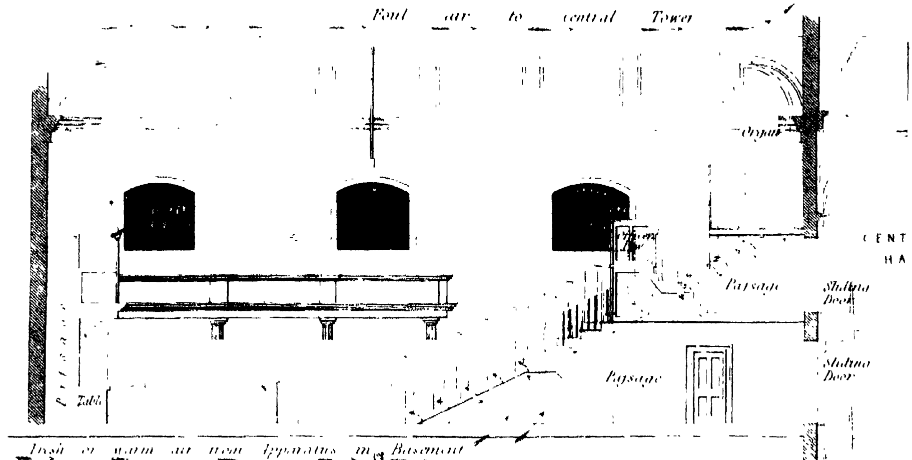
BASEMENT PLAN

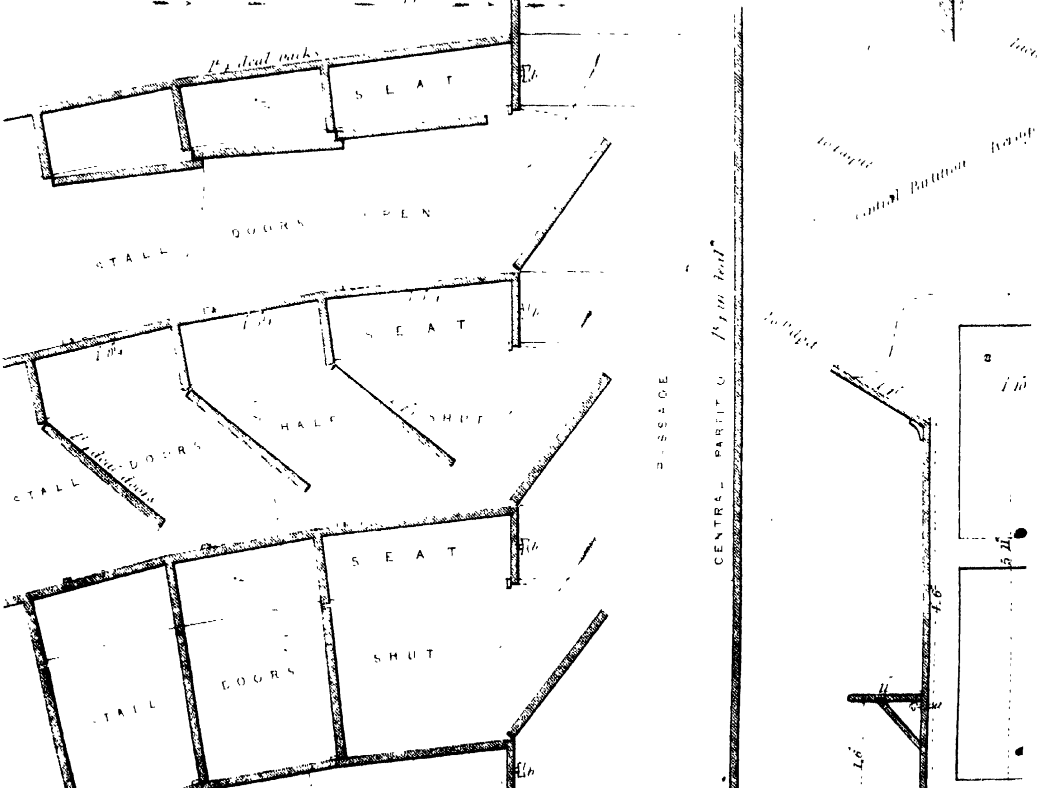
SCALE OF FEET

J. Jebb
Major Rl Engs

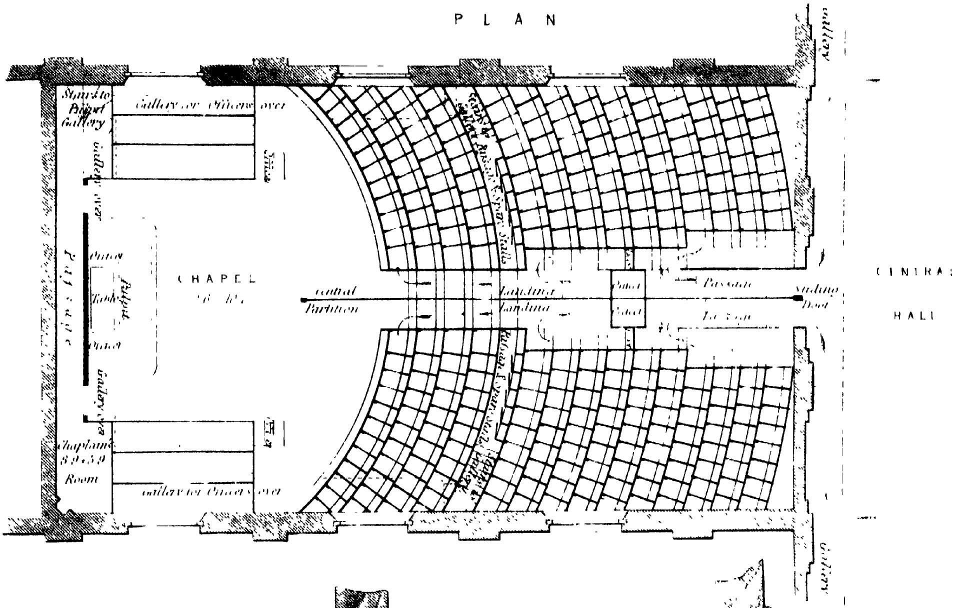
CHAPEL AT

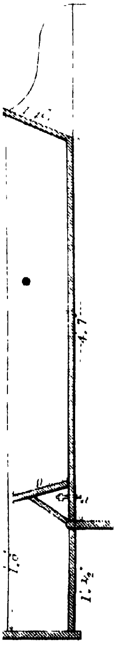
LONGITUDINAL SECTION

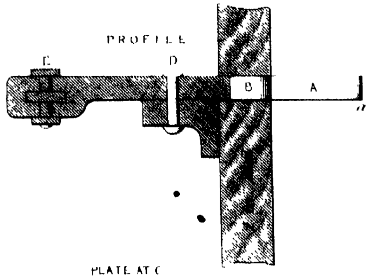




E PRISON.


PLAN




PROFILE

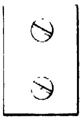
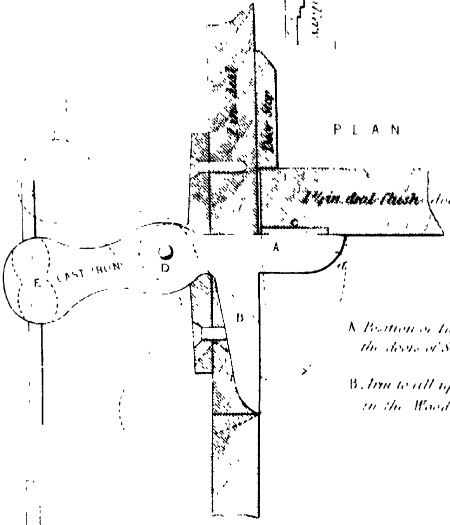
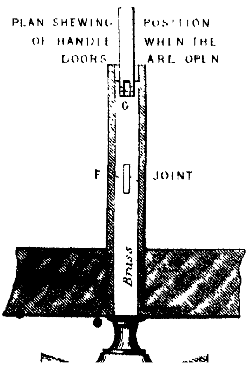


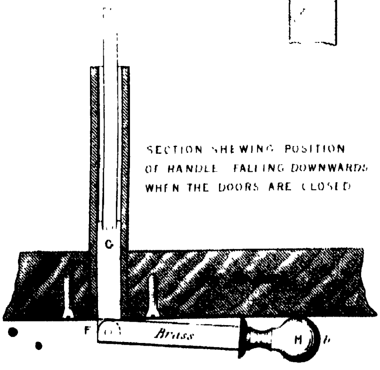
PLATE AT C


PLAN

A Position of fastenings when the doors of Seats are closed

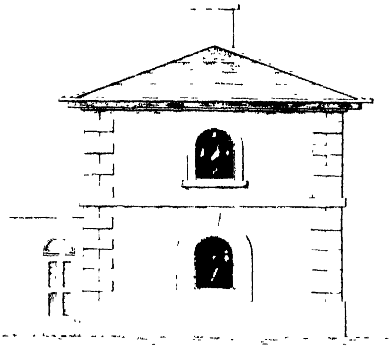
B Iron to fill up the opening in the Wood work


PLAN SHEWING POSITION OF HANDLE WHEN THE DOORS ARE OPEN

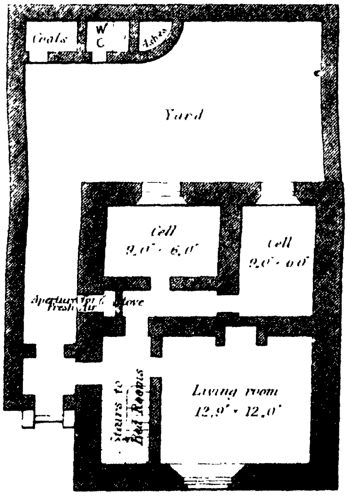

SECTION SHEWING POSITION OF HANDLE FALLING DOWNWARDS WHEN THE DOORS ARE CLOSED

DESIGN FOR A POLICE STATION

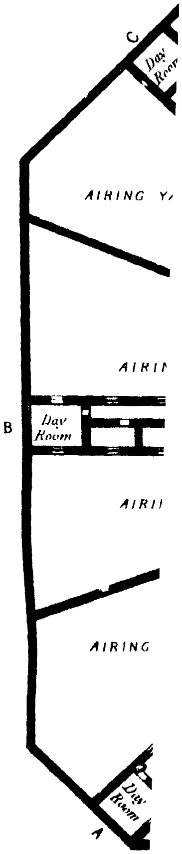
containing 2 cells and accommodation for a Constable.



ELEVATION



GROUND PLAN

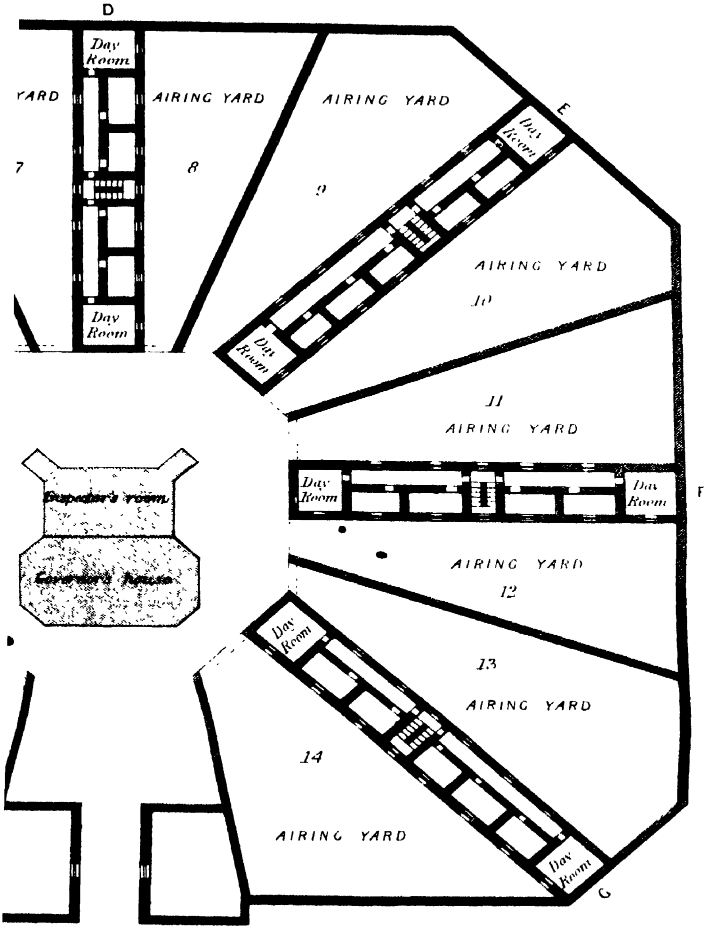


Scal

OF A PRISON

lesigned for the

ICATION OF PRISONERS.



REFFRENCE.

Buildings containing Sleeping Cells

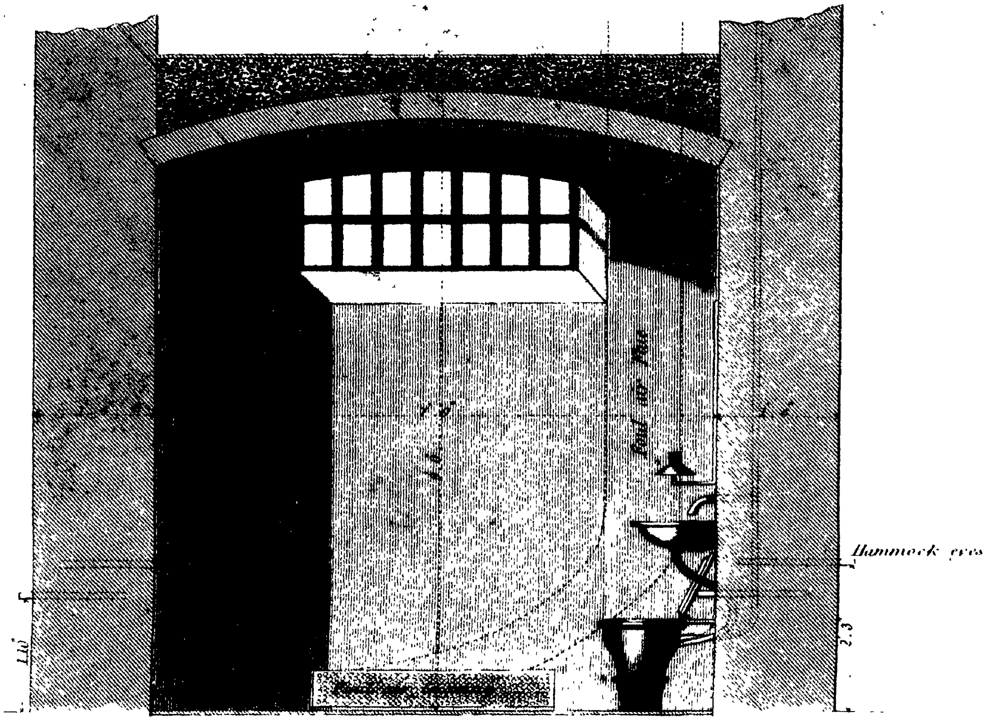
or association by day.

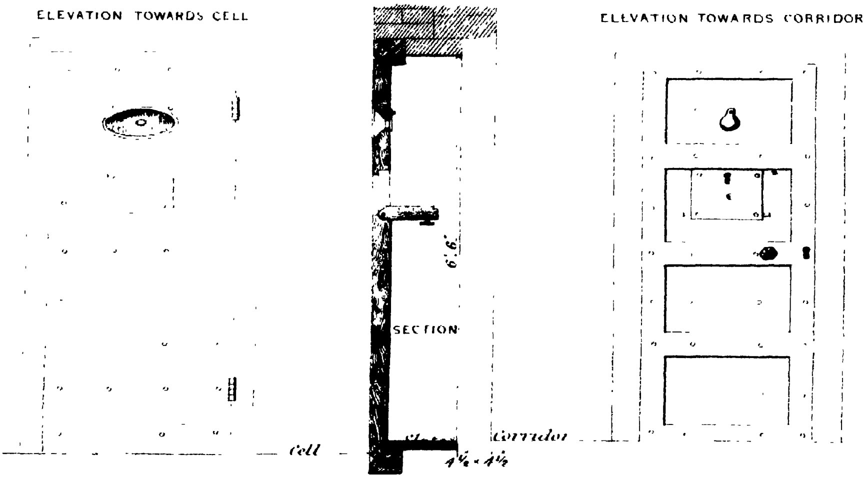
100 *150* *200 Feet*

J. Jebb
Major R.l Eng.rs

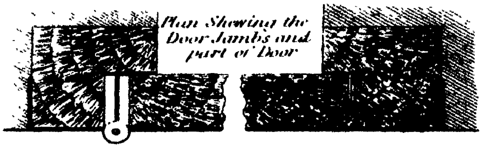
B.R. Davies Sculp

TRANSVERSE SECTION



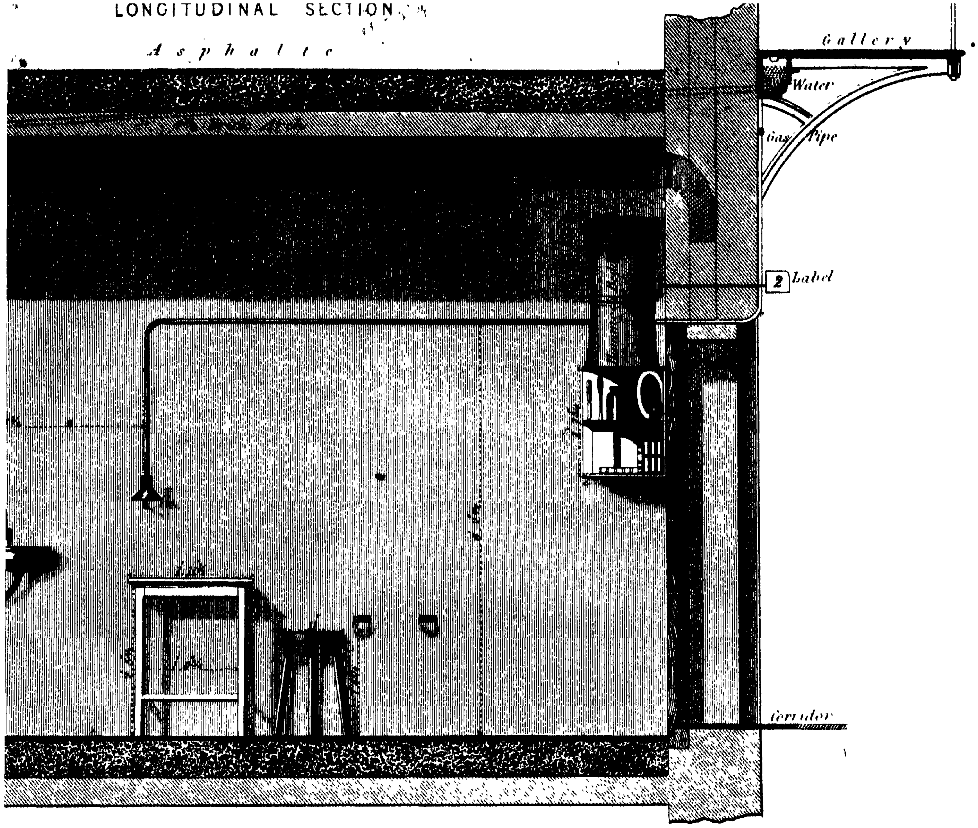


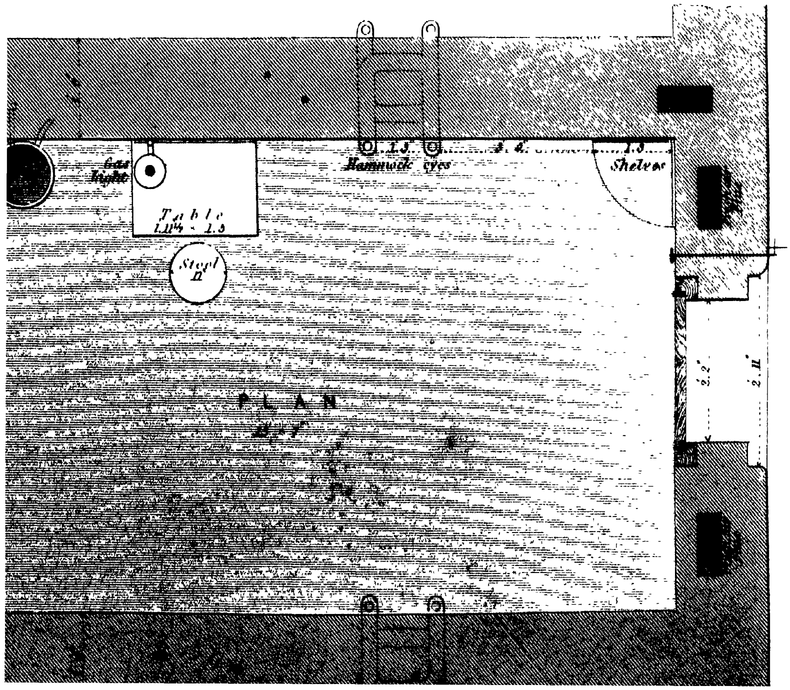
CELL DOORS


Plan Showing the Door Jambs and part of Door

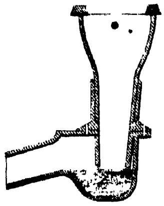
Corridor

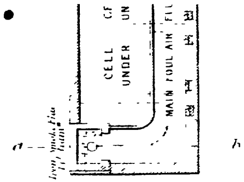
LONGITUDINAL SECTION



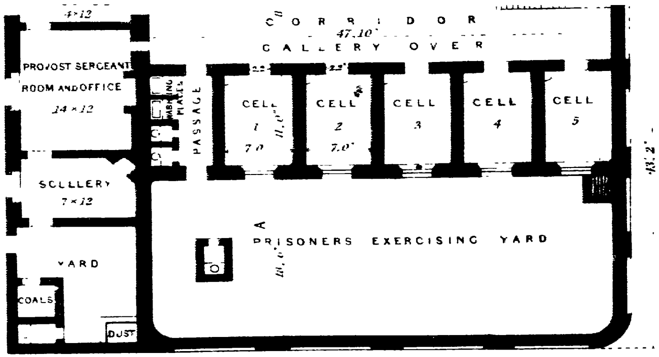


DETAILS OF SOIL PAN, TRAP, BASIN &c



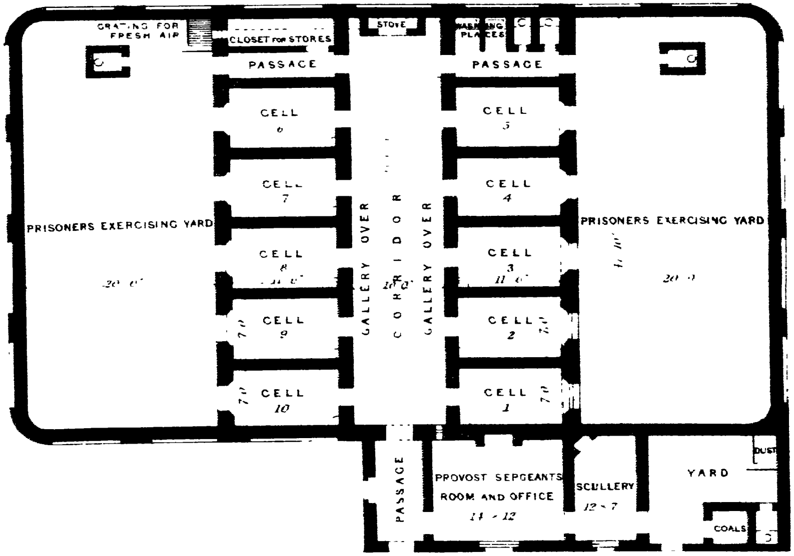


PLAN OF THE MAIN
FOUL AIR FLUE IN THE ROOF

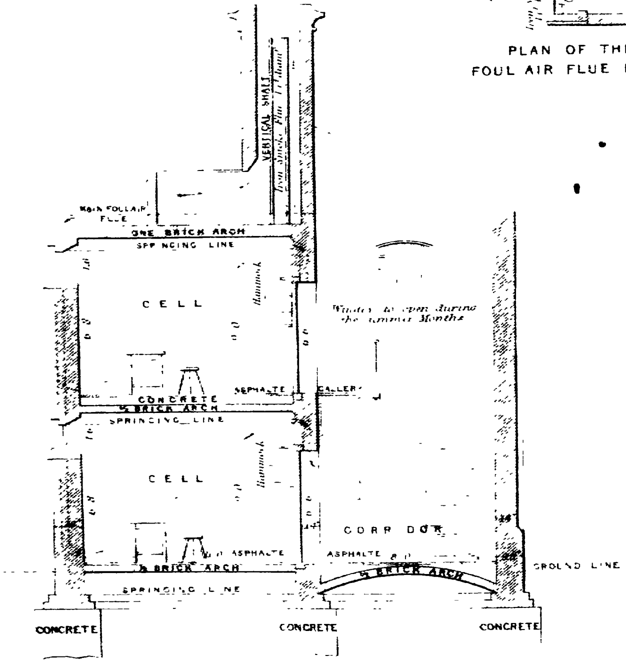


GROUND PLAN

FIG 2

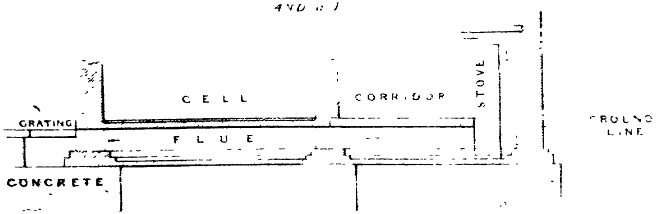


GROUND PLAN



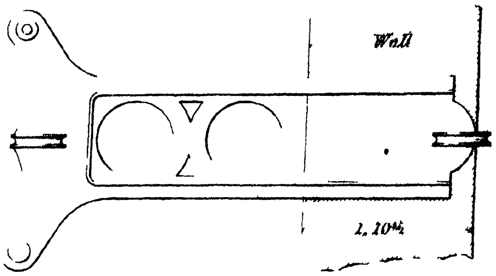
TRANSVERSE SECTION ON THE LINE A B

AND a b



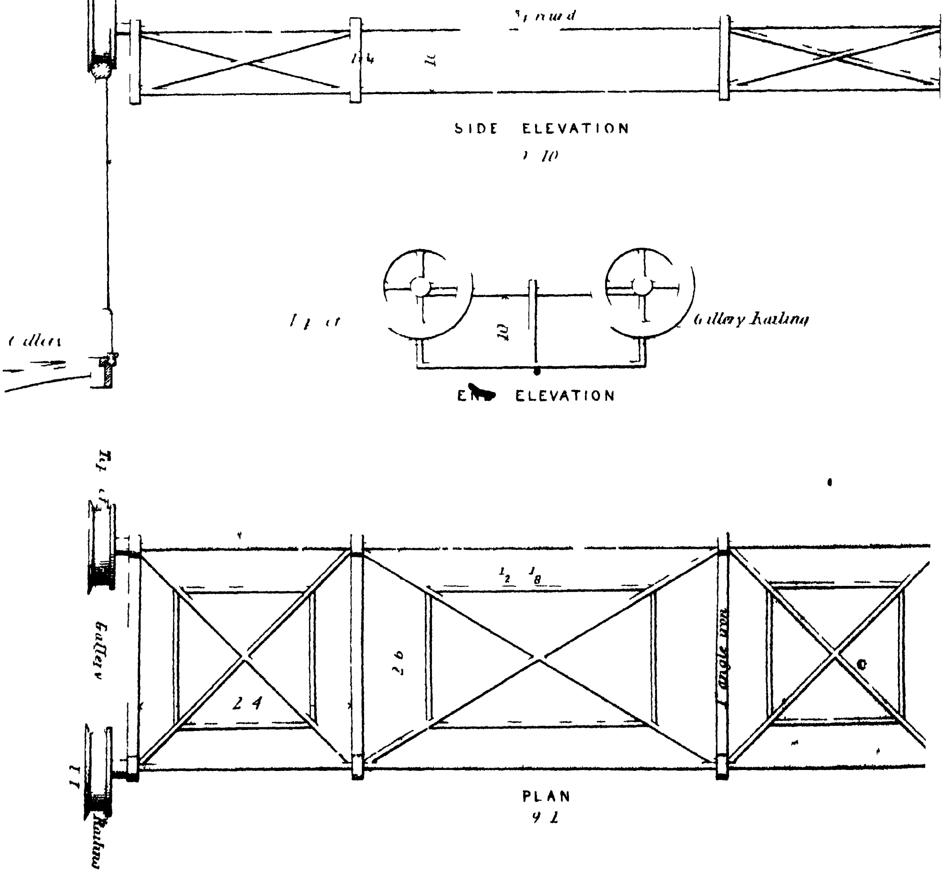
Scale ½ Inch =

PLAN OF BRACKET AT A



LIGHT IRON CARRIAGE

TO RUN ON GALLERY RAILING FOR DELIVERY OF DIET &c



SIDE ELEVATION

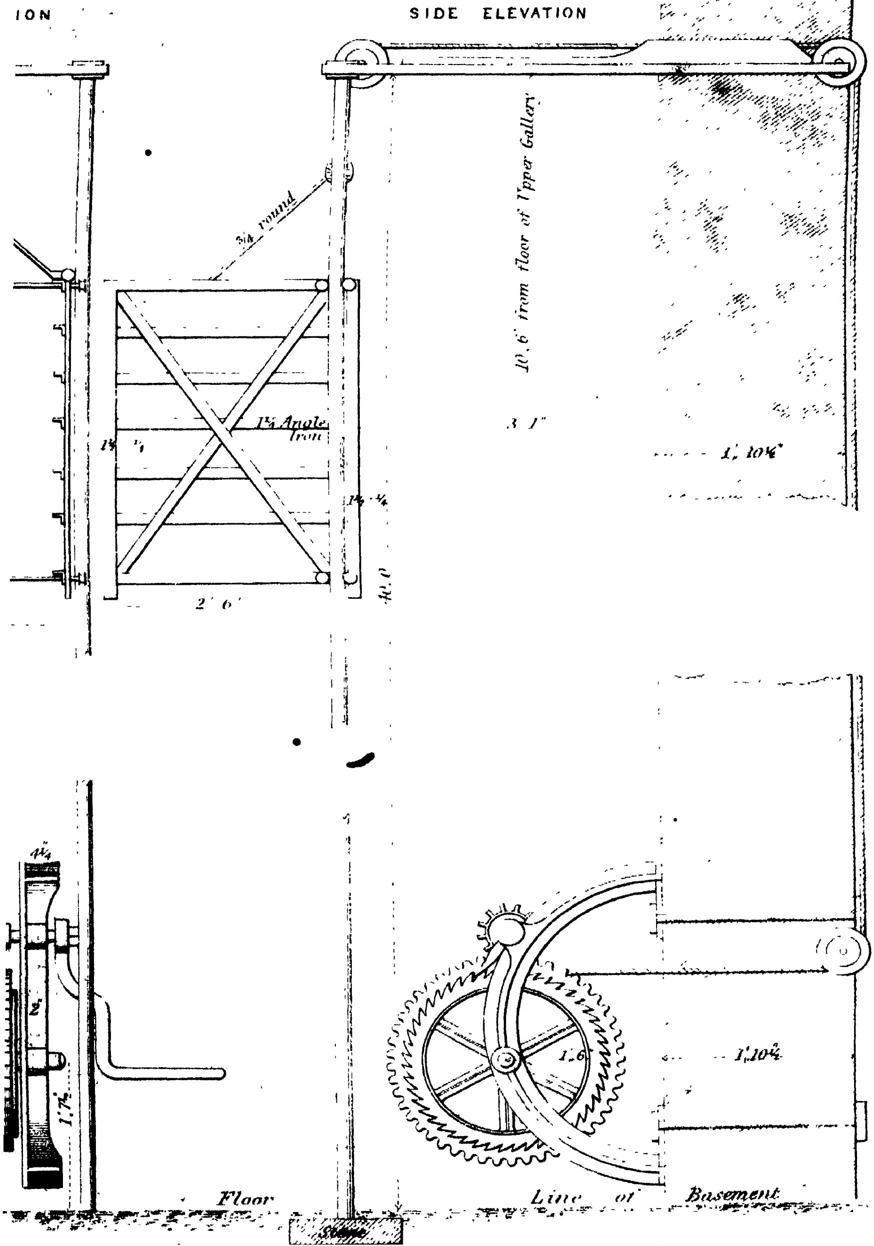
END ELEVATION

PLAN

Plate XVII

MACHINE

ING DIET &c FROM BASEMENT TO GALLERIES.



J. Jebb
Major R. Engrs

PLAN AND SECTION

SHEWING THE PRINCIPLE ON WHICH THE VENTILATION OF A COAL PIT IS EEFFCTED.

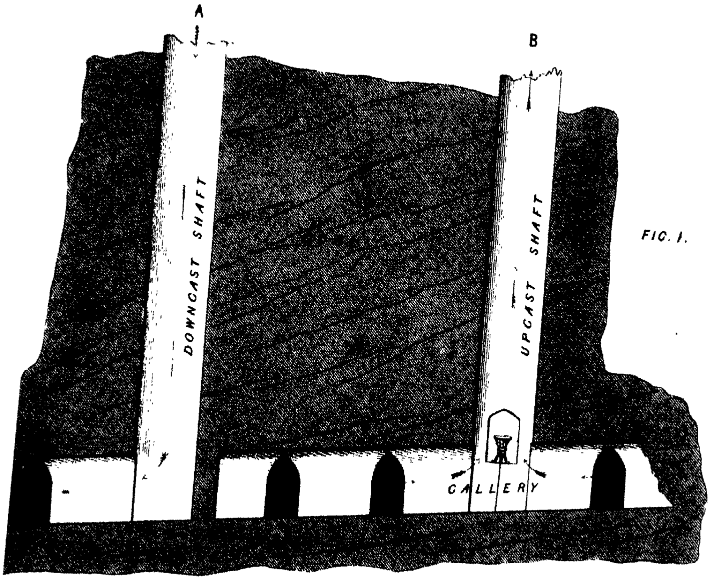


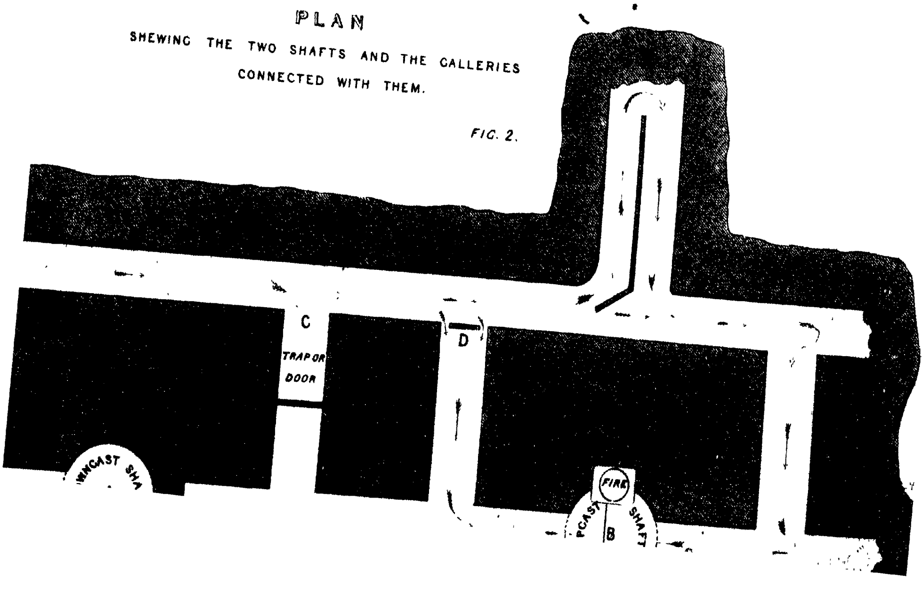
FIG. 1.

SECTION

PLAN

SHEWING THE TWO SHAFTS AND THE GALLERIES CONNECTED WITH THEM.

FIG. 2.

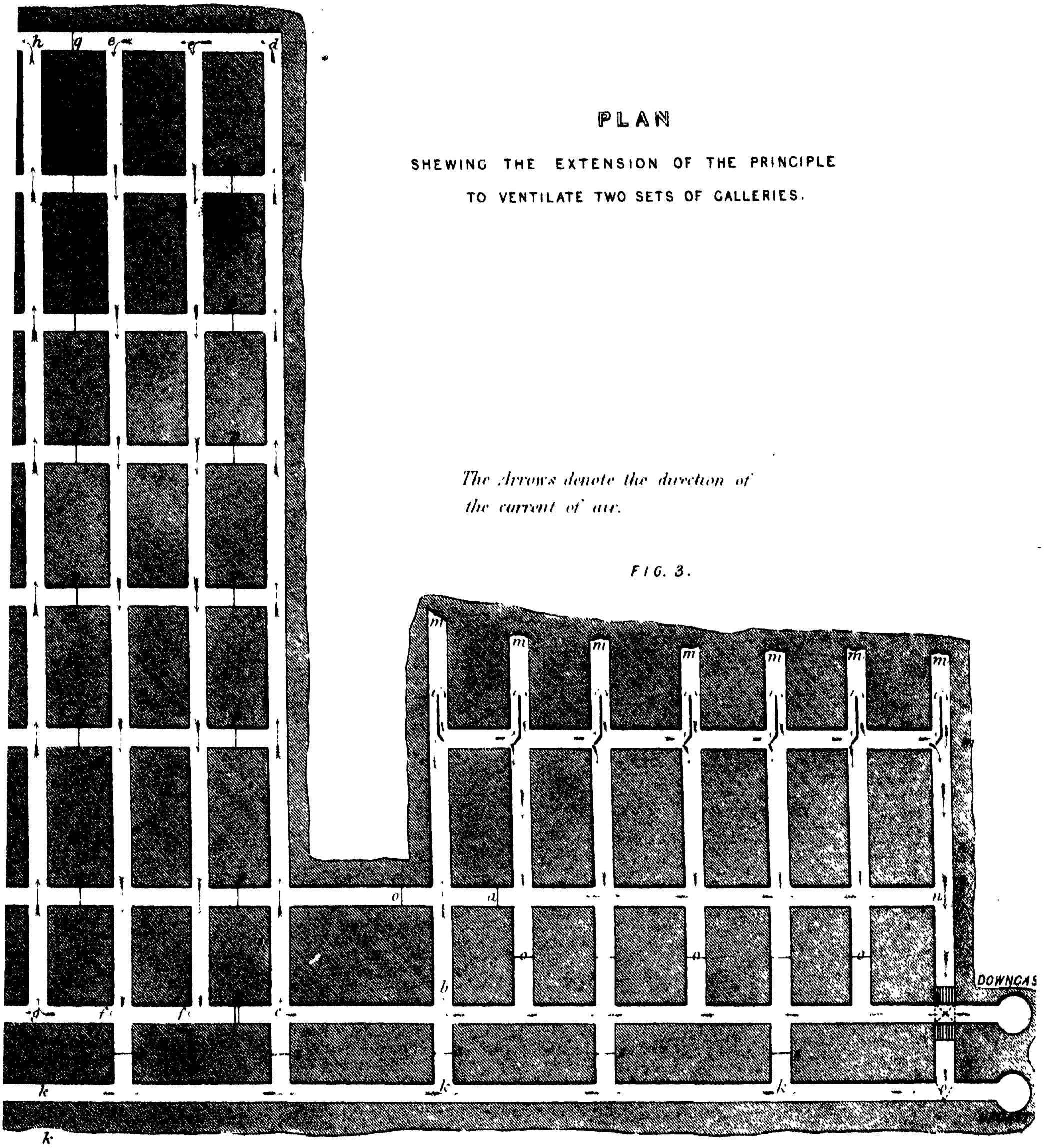


PLAN

SHEWING THE EXTENSION OF THE PRINCIPLE
TO VENTILATE TWO SETS OF GALLERIES.

The Arrows denote the direction of the current of air.

FIG. 3.



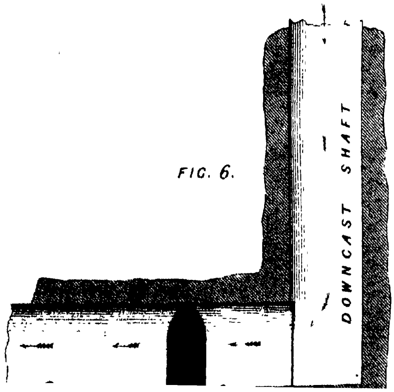
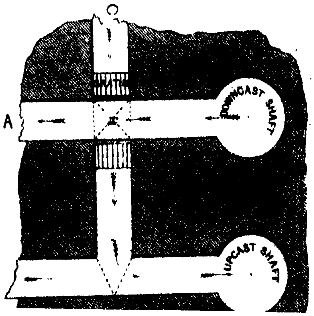


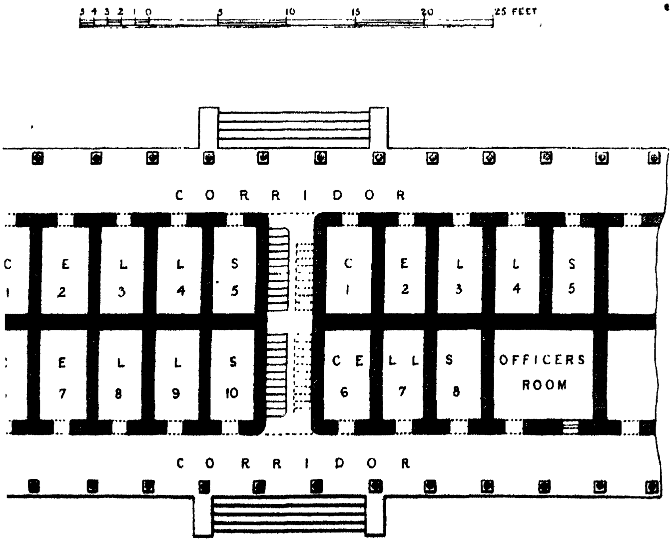
FIG. 6.

FIG. 7.



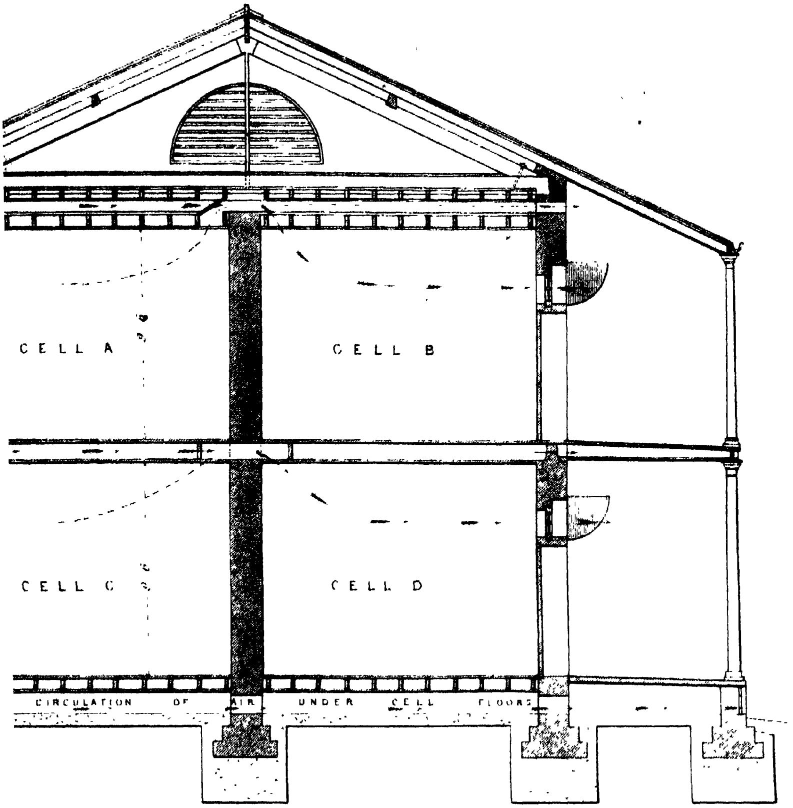
PLAN SHEWING A PRINCIPLE OF C

ELEVATION.

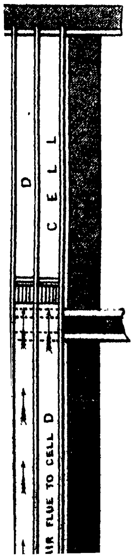


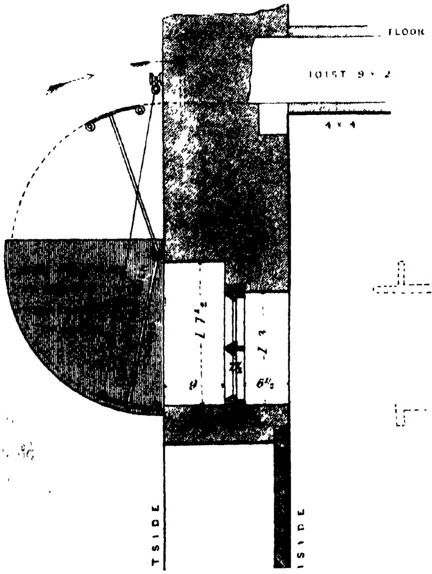
GROUND PLAN.

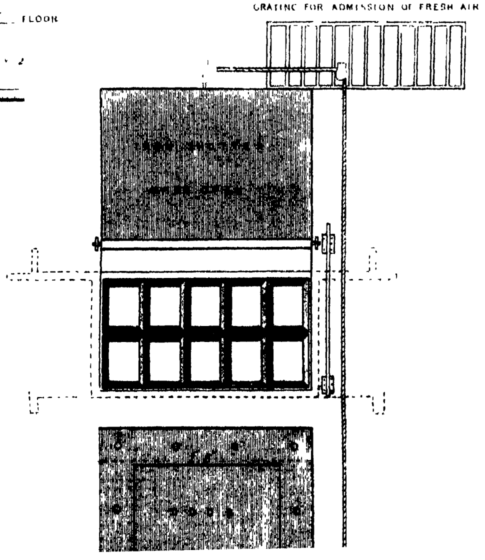
DAPTED FOR A HOT CLIMATE.



TRANSVERSE SECTION.







III.—*On the Conducting Power of Water as applied to Submarine Explosions by Voltaic Electricity, with Details of Apparatus. By Lieut.* HUTCHINSON, *R. E.*

THE power of water for completing an electric circuit has long been established as a principle by the experiments of Dr. Watson in 1748 with respect to electricity of friction, and more recently in 1803 with voltaic electricity by those of Erman, Basse, and Aldini. The experiments of the latter, an Italian philosopher, were conducted on the sea-shore, near Calais, and were perfectly successful in showing that a voltaic circuit of which a single wire forms one portion may be completed by a considerable extent of water forming the other portion: in these experiments, Aldini, however, employed a compound battery of 80 cells, which produced a current of very great intensity.

The interesting experiments of Steinheil, Wheatstone, Bain, &c., carried on from 1838 to 1841, have since shown that this power of battery may be very much reduced, and in some cases altogether dispensed with, by the simple expedient of attaching a certain surface of metal to each extremity of a single wire immersed in water, when, on the application of a battery of small power, an electric current will be transmitted, of an intensity nearly equal to what would be given by the usual mode of a double wire; or without any battery at all, a current would be established, by means of the metallic plates alone, considerably weaker, but still possessing sufficient energy to cause deflection of a magnetic needle or of a wire coil, which may be applied for the purposes of telegraphic communication, the object principally kept in view in the prosecution of these experiments. This principle of metallic plates is also noticed by Professor Daniell, in his 'Introduction to Chemical Philosophy,' where, in speaking of the effect of immersing a positive and negative plate in acidulated water, and bringing their upper extremities in contact to produce voltaic action, he states, "contact between the two plates need not take place at all, provided a communication be established between them by means of any other metal; a very fine wire is sufficient for the purpose, and will be efficient even *in lengths which may be measured in miles.*" Mr. Snow Harris has also very ingeniously applied the conducting power of water in his experiments on lightning conductors, though he is not understood to have adopted the principle of the metallic plates in his various applications of the electrical power.

My attention has also been for some time led to the same subject in carrying on some experiments in June and July last, by Major-General Pasley's order, on the relative power of different lengths of wire conductors in use over the wreck of the *Royal George*, for transmitting the electric fluid.

These conductors consist of two stout copper wires, fixed on each side of a 1½-inch rope; the wires are carefully insulated and covered with tape, yarn, and a water-proof composition; the rope is saturated with the same composition, being immersed in it while boiling, and yarn is then bound over the whole, with a second coat of the composition over it. The apparatus used for these experiments was the voltameter, consisting of a glass vessel with inverted tubes; two pieces of platinum wire were fixed into the sides of the vessel, and bent at right angles to enter the tubes: on connecting the two ends of the conducting wires at one extremity, placing a voltaic battery at the other, and the voltameter within the circuit, the water in it was rapidly decomposed; gas was emitted and passed into the tubes, which, being graduated with a scale divided to eighths of inches, showed the relative power of each length of wire-conductor by the quantity of gas delivered in a certain time. I was, however, surprised to find that decomposition of water ensued even when the ends of the wires furthest from the battery were disconnected; and it soon became evident that as these wires had been frequently used in firing charges at a depth of 13 fathoms under water, a certain degree of moisture must have been forced in by the great pressure at that depth through the exterior coating, notwithstanding the precautions used to make it and the wires water-proof; and thus the electric fluid must have been led from one wire to the other, causing action in the voltameter, which became still more apparent on applying the voltameter and battery to a length of wire-conductor which had never been under water, as unless the ends of the wires were connected, there was no gas emitted. This was another convincing proof of the conducting power of water, though at that time it in some measure frustrated the object of our first experiments, which were intended to have been made with wires perfectly dry and independent of any conduction by moisture; but prosecuting the subject still further, I have since been enabled to apply this power most usefully in firing charges which are daily required over the wreck.

The method of doing this will now be stated.

Pursuing the experiments which had already been made, I found that metallic surface was necessary at each extremity of a single wire, to ensure the transmission by water of an electric current sufficiently powerful for the ignition of fine platinum wire. The experiments conducted at Spithead on this particular subject were commenced on a small scale by firing bursting charges from a wooden trough about 4 feet long, filled with water; the length of water-conductor was gradually increased, until a circuit of 1000 feet was completed, one-half formed by the single wire, the other by the water at the surface of the sea; the metallic communication was established by zinc plates at one extremity, and either sheet-tin or copper at the other, and it was found that certainty in firing could not be ensured with much less than about 3 superficial feet of surface of the former or positive metal; but in respect to the negative metal, it did not appear that extent of surface was of so much consequence.

In the case of submarine explosions, it would be necessary to have one metal present at the bottom of the sea, and the other at the top, the water forming the conductor between them; and as the greater part of the charges used at Spithead are common oil-cans of tin (a good conducting metal and negative to zinc), varying from two to five gallons, it occurred to me to make the charge itself at the bottom serve as the means of establishing electrical communication with the zinc plates at the surface.

Before lowering the charge to the bottom, the single wire is connected to one of the priming or short wires inserted in the bursting tube, and the other priming wire is turned down on the tin and connected with it. The charge is then taken down by a diver, who places it, and after he has come up, the zinc plates are immersed, of which I had three, 10″ × 7″, connected by wooden pins let into the sides, and by copper wire passed through a hole made in the top of each plate. The end of the single wire above water, and that of the short length attached to the zinc plates, are led to a voltaic battery, which, for firing charges in 13 fathoms, should not consist of less than 10 sets of plates of a moderate size (10″ × 7″ or 10″ × 8″), and we used both copper and cast iron as the negative metal in our batteries, either of which answered perfectly well. On forming contact at the battery, the intercepted portion of the circuit from the zinc plates at the top to the tin can at the bottom of the sea is completed by the depth of 80 feet of water between them, which serves as the conductor; the electric current is thus passed through the piece of fine platinum wire fixed across the priming wires of the bursting charge, which also forms a part of the circuit, and is instantaneously ignited.

This simple application of so beautiful a principle has now been in operation at Spithead, with the approval of Major-General Pasley, for about three months, and it may be considered as certain and secure; and I consider it superior to the system of the double wires in several respects, but chiefly because the latter are liable occasionally to be brought improperly in contact in spite of all precautions. Nearly one-half of the metallic conductor is by this means saved; and the single wire, with its water-proof coatings, not being more than $\frac{3}{8}$ inch in diameter, may be conveniently coiled on a common log reel, and held in the hand while being passed over the side of a vessel when used on a wreck; whereas with the double wire a large drum is absolutely necessary, in order that it may be coiled flat and free from kinks.

Several of our medium-sized charges of 260 ℔s. used at Spithead were contained in wrought iron cylindrical vessels, the surfaces of which were usually painted or lacquered, and in firing them by this method we found that it was only necessary to brighten about 3 square inches of metallic surface for contact with the wire, leaving the rest covered and insulated from the water.

In the case of charges contained in wooden casks, it would be necessary to attach a sheet of tin or other conducting metal to the surface of the cask, to which the second priming wire would be connected.

It should be remarked, that in lieu of a solid conducting wire $\frac{1}{5}$ or $\frac{1}{6}$ inch in diameter, a more convenient form for blasting will be that of a wire rope, composed of three or four finer wires twisted together; it will thus be much more flexible and less liable to break, and the junctions of the several lengths of wire may be very securely united by splicing as in a hempen rope: with the solid wire these joints are always difficult to form in a secure manner, and a fracture is more liable to occur at a joint than at any other part.

The twisted copper wire rope which we used during the present season at Spithead was composed of three strands $\frac{1}{10}$ inch diameter, or No. 14 gauge: 30 ℔s. weight of this size, or 1000 feet in length, made 300 feet in length of the conducting wire when completed nearly $\frac{1}{5}$ inch thick.

The water-proof coating put on over the single wire to insulate it from water was composed as follows: the wire was carefully coated with the excellent water-proof composition (first proposed by Serjeant-Major Jones, in 1839, and since invariably used in all the experiments of the corps at Chatham, and in the operations at Spithead), consisting of 8 parts of pitch, 1 of bees'-wax, and 1 of tallow, over which was bound a layer of coarse tape covered with a coat of composition, then another layer of tape and coat of composition; the whole was then bound round with fine-spun yarn, which was lastly covered by a coat of the same composition: the conductor, when thus completed, did not occupy a space of more than $\frac{3}{8}$ inch in diameter. The tape used was called "Patent Manchester Filleting," in pieces of 18 yards, three of which were sufficient for a length of 40 feet. A conductor 200 feet in length may be thus completed in three days by two men accustomed to the work.

The battery of 10 sets of plates, already noticed as possessing adequate power for firing submarine charges at Spithead with the single wire, will be found very convenient for general blasting operations; and if considerable power be required, two, three, or any number of them may be connected as a combined battery. On commencing the operations this year at Spithead, we required powerful batteries for simultaneous explosions, and by Major-General Pasley's direction we constructed two, one similar to those used at Dover, in the demolition of the Round-down Cliff, composed of 20 sets of plates of copper and zinc; the other consisting of the same number of sets of cast iron and zinc, which were afterwards cut in halves, making 4 of 10 sets of plates each. The cast iron battery was similar to one which had been for some time in operation at the Egyptian Hall, Piccadilly, for the illustration of electro-magnetic experiments, exhibited by Mr. Robert Davidson,[1] and which had attracted the Major-General's attention as possessing great power, durability, and constancy of action. The substitution of iron for copper as the negative metal, somewhat reduces the cost of a battery, which is an object when working on a large scale, and this probably led to its adoption by Mr. Davidson and others, who have used it combined with zinc for blasting purposes in Scotland: in other respects, copper, as the better conducting metal, would be supposed to possess the superiority. The dimensions of the plates for our large iron battery were (as

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[1] It should be remarked that the plates used in Mr. Davidson's battery in London were of wrought iron, but he recommended cast iron, having found that material answer best in his experiments at Edinburgh. We afterwards tried wrought against cast iron by the voltameter, and found the latter rather more powerful.

before stated) 10″ × 7″, which had been found a convenient size at Dover: there were 20 sets of plates, each consisting of one of zinc between two of cast iron, making 20 of the former and 40 of the latter metal; each plate slid in a groove cut into the frame of the battery so that it might be easily withdrawn for cleaning: this arrangement differed from the Dover batteries, where the double copper plate surrounded the zinc as a single rectangular case; but in cast iron, separate plates are more convenient and much lighter. The connexions of this battery were formed by strips or bands of sheet copper (32 oz. to the foot), ½ inch wide; and as each zinc plate of one cell had to be united to two iron plates of the adjoining cell, there was a double row of connexions on each of the positive, and a single one on each of the negative plates, united in sequence by binding screws from cell to cell, as shown in the accompanying drawing, which represents a 10-plate battery of similar Plate construction, with handles and an apparatus of cog wheels and racks, suggested by Corporal Harris, for raising it out of, and lowering into, the trough; for as it is important, from the destruction to the zinc plates by the acid, to keep the battery in action as short a time as possible, this affords a convenient mode of raising the plates, and suspending them immediately above the trough: the acidulated water will thus drip from them into its proper cell, and none will be lost.[2]

A very excellent composition, similar to sealing-wax, which we used in covering the inside of the troughs of the batteries, was composed of the following materials:

Spirits of wine	½ gallon.
Vermilion	¼ ℔.
Shell lac	½ ℔.
Gum sandarach	2 oz.

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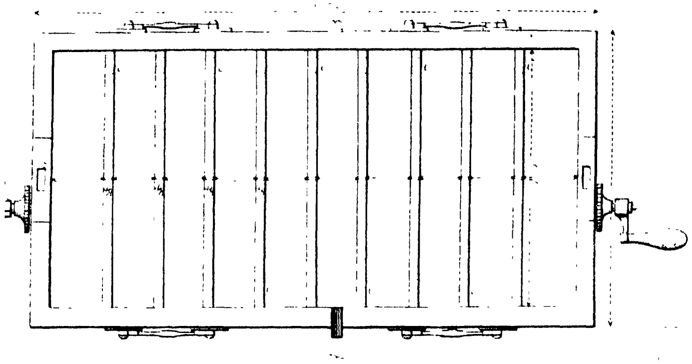
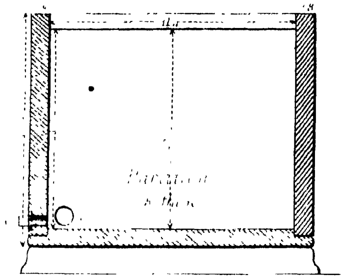
[2] One battery only of this description was made by Corporal Harris and Private John Skelton, Royal Sappers and Miners, (while employed during the last summer at Spithead,) by Major-General Pasley's permission, for the Non-commissioned Officers' model-room at Woolwich. Our other batteries were all of the simpler form (preferred by the General), with handles for lifting in and out of the troughs, which for common purposes would be preferable, as being less complex.

Captain James, who has lately constructed a voltaic apparatus at Athlone, for some mining operations, informed me that he counterbalanced his battery by weights over pulleys attached to the frame, by which arrangement one person alone could work it.

Plan of Bench



Section on AB



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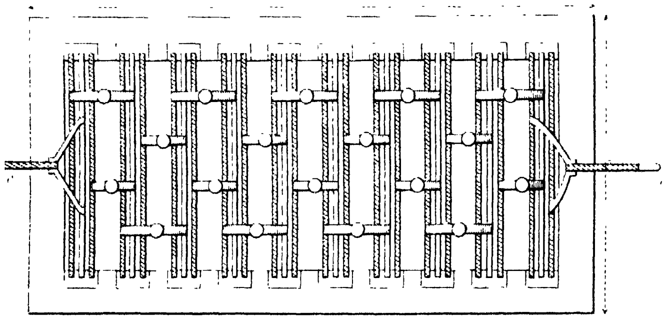

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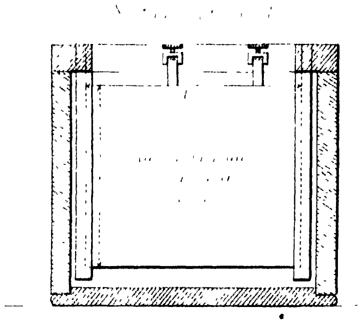
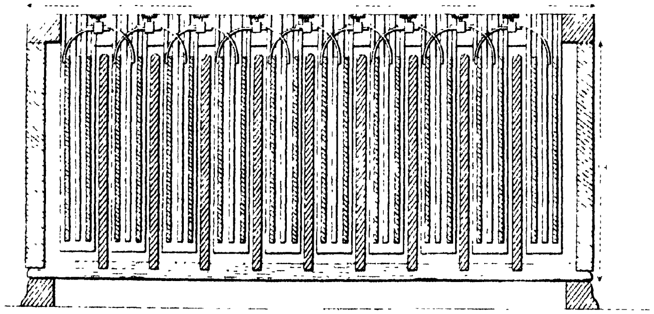
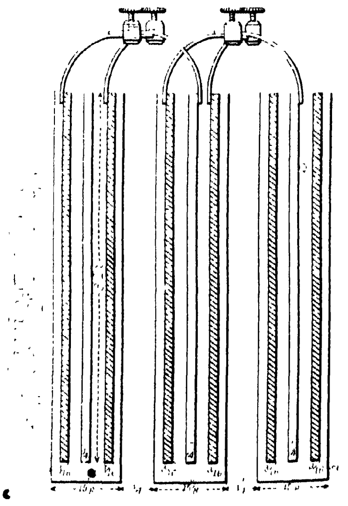


Longitudinal section shewing
the cells connected

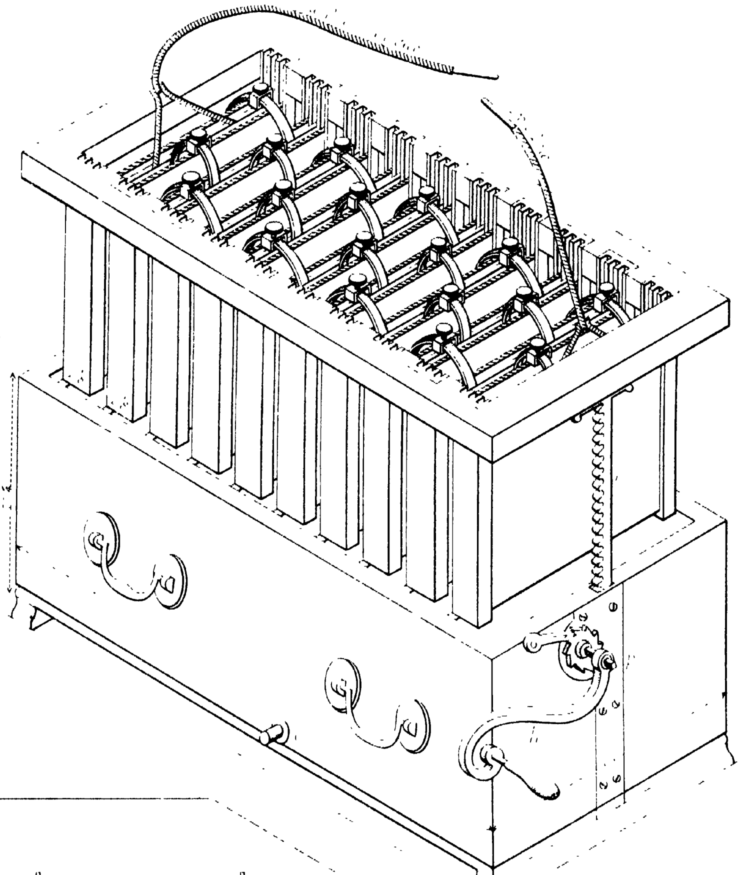




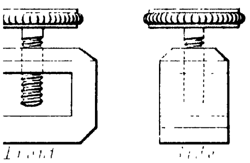
[illegible] figures are on a Scale ⅛ in [illegible]
[illegible] on a Scale ¼ [illegible] Feet

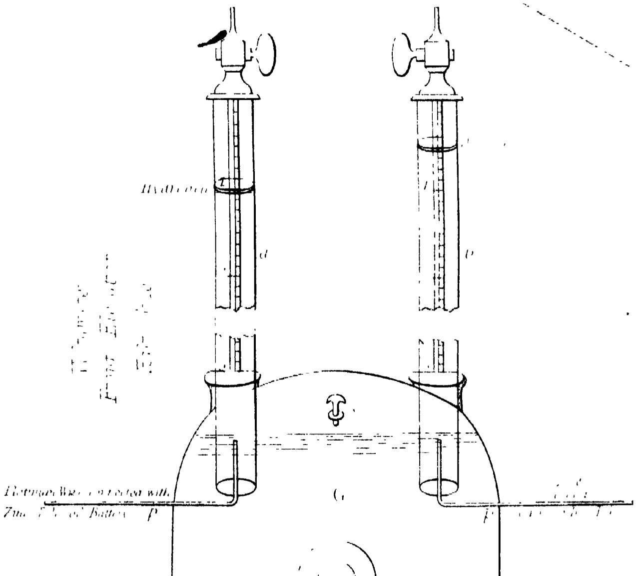
V

Isometrical View
of the Battery
raised above its Trough
Scale ⅛ In = 1 Foot



Connecting Screw
Full Size





[illegible]
Front Elevation
[illegible]

[illegible]

[illegible]

The shell lac and gum sandarach should be pounded and put into a bottle with the spirits of wine, and dissolved by a gentle heat, after which the vermilion is added, which gives consistency and colour to the compound. This quantity will be sufficient for covering with two coats the troughs of two batteries of ten cells, containing about 23 superficial feet each.

The power of our different batteries and conducting wires was tested by the voltameter or decomposing apparatus, which affords a very accurate mode of measuring the quantity of electricity passing in a voltaic circuit. The form of voltameter used for these experiments is represented in the drawing annexed. Plate XX.

a and *b* are two straight glass tubes, ¼ inch interior diameter, closed at the upper extremities, and graduated with a scale of inches and eighths; these are fitted into the top of the glass vessel G, by the two necks left on it to receive them; they project downwards about 1½ inch below its upper surface.—*p p* are two platinum wires, about 3 inches long, securely fixed and sealed into the sides of the glass vessel; one-half of each wire is bent outwards horizontally, the other half projects upwards into the tubes.

The vessel is filled with acidulated water by the neck in front, which is then closed by a stopper; the tubes are filled by inverting them with the vessel downwards: on passing an electric current through the liquid, by the platinum wires, the water is rapidly decomposed, and its component gases are evolved; hydrogen passes into the tube whose wire is in contact with the zinc or negative pole of the battery, and oxygen into the other, the gases forming in the proportion of two volumes of hydrogen to one of oxygen: as the tubes become filled with their respective gases, the water is displaced from them more or less rapidly, according to the strength of the current, and we are thus enabled to measure the electrical force or intensity by the quantity of gas delivered in a certain time: while the current is passing, the small stopper *s*, on the top of the glass vessel, must be withdrawn, to allow the compressed air, which would be formed by the expulsion of water from the tubes, to escape by the orifice.[3]

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[3] A simpler sort of voltameter is generally used, in which the two gases are collected in one and the same glass tube, and which would have answered equally well for testing the comparative power of different batteries.

Record of Experiments made with the Voltameter.

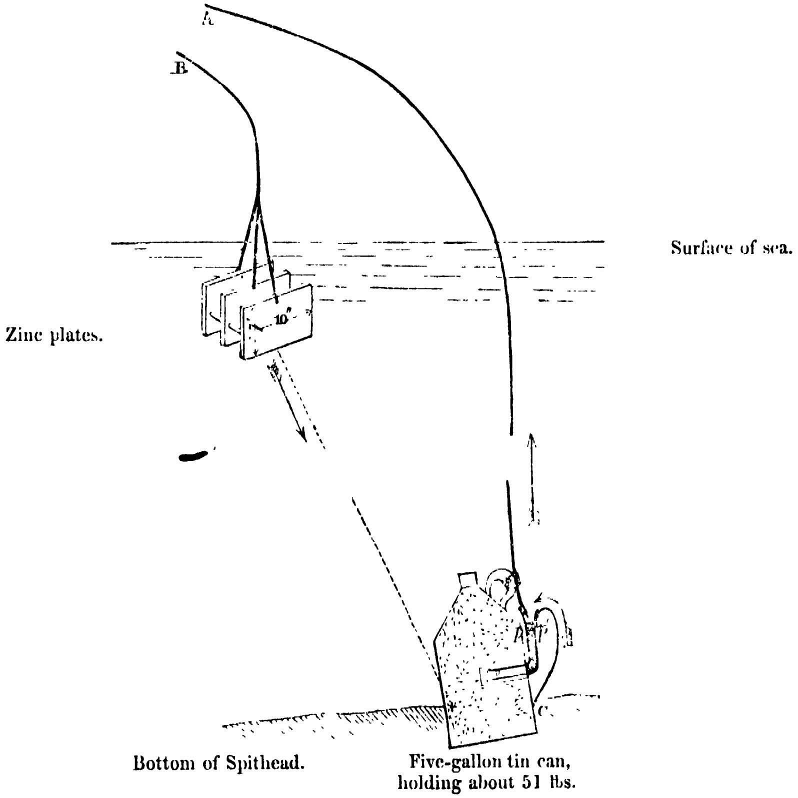
Date of Experiment.	Description of battery.	Length of conducting wire, or situation of voltameter.	No. of inches and parts lowered in		Time of making contact with voltameter.	Remarks.
			Hydrogen tube.	Oxygen tube.		
1843.			in.	in.	Seconds.	
5th August	20-plate iron	Applied at the battery	5	$2\frac{7}{16}$	30	These experiments were for trying the relative power of the batteries without length of conducting wire.
,,	Do.	Do.	$3\frac{1}{2}$	$1\frac{3}{4}$	20	
,,	Do.	Do.	$2\frac{3}{8}$	$1\frac{1}{4}$	18	
,,	Do.	Do.	$2\frac{1}{4}$	$1\frac{1}{8}$	15	
,,	20-plate copper	Do.	4	$2\frac{1}{4}$	30	
12th Aug.	10-plate iron	Do.	2	1	30	
12th Sept.	Daniell's 6-cylinders	Single, 200 feet in conjunction with water.	$2\frac{3}{4}$	$1\frac{3}{8}$	Minutes. $1\frac{1}{2}$	The metal at bottom was a tin can, and at the surface of the sea three zinc plates, 10″ × 7″, length of water-conductor 80 feet.
,,	Do.	Double, 200 feet	$3\frac{1}{8}$	$1\frac{3}{4}$	Do.	The ends of the double wire, at the bottom of the sea, were connected and made water-tight.
7th Oct.	Daniell's 8-cylinders	Double conductor, 100 feet	$2\frac{1}{4}$	$1\frac{1}{8}$	Seconds. 30	These experiments were made with conducting wires perfectly dry and independent of conduction by moisture.
	Do.	Do. 200 do.	$2\frac{1}{16}$	$1\frac{1}{16}$	30	
	Do.	Do. 300 do.	2	$\frac{7}{8}$	30	
	Do.	Do. 400 do.	$1\frac{3}{4}+\frac{1}{16}$	$\frac{3}{4}+\frac{1}{16}$	30	
	Do.	Do. 500 do.	$1\frac{3}{4}$	$\frac{7}{8}$	30	

These experiments show, 1st, That the cast iron and zinc battery is more powerful than the copper, in the proportion of 5 : 4, and that for short periods it gains power by immersion in the exciting solution. 2nd, That the circuit of the single wire, in conjunction with water, is weaker than that of the double metallic wire of the same length, in the proportion of $2\frac{3}{4}$ to $3\frac{1}{8}$, or as 22 : 25, too trifling a difference to affect the ignition of platinum wire, as a surplus power of battery would always be used. 3rd, The experiments made on the 7th of October, with different lengths of conducting wires, are noticed to show the very gradual diminution of power (as indicated by the voltameter), which was found to take place in the transmission of the electric fluid through wires from 100 to 500 feet in length. From the perusal of a well-established law on this subject, "That the resistance to electrical transmission through a metallic wire, has been found to increase with the length of the wire; that is to say, that the resistance to the transmission of the charge will be twice as great when the length of the conductor is doubled, or three times as great when the length is trebled,—a law observable from one hundred up to one thousand feet in length,"—I had anticipated that a much more sensible difference of power would have been shown by the voltameter, in proportion to the length of the wire, or distance from the battery.

These experiments were made with great care, and frequently repeated under the most favourable circumstances.

G. R. HUTCHINSON,
Lieutenant, Royal Engineers.

Sketch showing the mode of firing charges by a single wire, making the sea or other depth of water complete the circuit.



The ends of wires A and B are led to the poles of a voltaic battery in a boat or lighter.

Wire A goes to the negative or zinc pole.

Do. B ,, positive or iron pole.

p p'. Priming wires of bursting charge.

C. Point of contact of priming wire *p'*, with surface of tin. The wire should be attached to the can by a piece of rope yarn passed round it.

IV.—*A Description, with Memoranda, of the Bridge across the Kat River, at Fort Beaufort, Cape of Good Hope. By Captain* WALPOLE, *R. E.*

late XXI.

THE stone bridge at Fort Beaufort, designed by Colonel Lewis, of the Royal Engineers, is a plain and simple structure, consisting of a centre arch 60 feet span with a rise of 13 feet, and two flood arches 14 feet wide. The piers of the main arch are 16 feet thick, and the two abutments are each 25½ feet; the bridge is 20 feet wide, and exclusive of the wings, 171 feet long, and from the offset to the level of the road-way 46½ feet high. The parapet walls are 1 foot 8 inches thick, leaving a road-way 16 feet 8 inches broad.

The stone of which it is built is a hard sandstone.

The quoins and tail bonds, which are cut and dressed, are for the most part very massive, and the rest of the face-work is large rubble-work in courses more or less regular; the backing consists of large and small stones well grouted.

The voussoirs of the main arch are all of one uniform depth, 3 feet, and a little more than 12 inches at the intrados; and the spandrils of the main arch are filled with solid masonry to within a foot of the string-course.

The coping stones, 6 inches deep, partly parallel and weathered, were secured together with ⅝-inch iron dowels, which, before insertion, were thickly coated over with white lead and oil.

The foundations of the right abutment and pier were formed with very little trouble; but the laying in the foundations of the left abutment and pier proved tedious and operose, as the rock was 10 or 12 feet below the bed of the river.

It is apprehended it will be necessary, sooner or later, to effect some kind of protection to the foundations of the wing-walls of the left bank, river floods having washed away much of the bank, which on that side is altogether alluvial. The centre for the main arch, also the design of Colonel Lewis, was made of bastard yellow-wood, the wood most commonly used, but possessing very indifferent qualities, being remarkable for shrinking, splitting, and twisting. For a description of the construction of the centre, and the scantlings of its parts, see figs. 1 and 2.

Plate XXII.

All the heads and feet of the different uprights were not only mortised and tenoned, but were housed and draw-bored. Fig. 3 is descriptive of the scarfings of the ribs, which were connected with bolts and nuts.

The wedges, about 4 feet long, were iron-wood, cut to the proportion of eight to one.

The straining pieces between the trestles were so placed as to serve as bearings for the floor for the workmen when striking the wedges.

The footings for the trestles were formed of large slabs of stone laid in excavations about 5 feet wide, 6 feet deep, and upwards of 20 feet long. These footings (as was supposed) proved of sufficient stability without going down to the rock, the bed of the river being composed of gravel and shingle.

Three days after the key stones were set the centre was struck. Fig. 1 represents the state of the piers at the time.

The lowering the centre, which was very gradually performed, took about six hours, a part of an afternoon and part of a morning, one day (a Sunday) intervening.

When the operation of striking the wedges was commenced, many of the wedges yielded with very few blows, whilst others were moved with considerable labour, which rendered it necessary to introduce soap between the faces and backs of the wedges. This showed it was an *oversight*, during the progress of laying the arch stones, not to try occasionally whether the wedges were all sustaining an equal proportion of the weight.

After about ten courses of arch stones of both haunches had been set (see Note), it was observed the centre at the small segments of the arch stood away from the intrados about 1⅛ inch (see fig. 4), and that the voussoirs *a*, *b*, *c*, and *d*, had each settled about half an inch, the joints also opening a little. This circumstance was attributed partly to shrinkage of the wood, for it was squared, framed, and fixed before it had time to dry thoroughly, and partly to the joints of the frame-work yielding to a lateral pressure: precaution was then taken to load the vertex of the centre, and the sheeting at XX was wedged back to the intrados.

Though this was an occurrence which tended to cause some alarm, it was in the end of little consequence, for a mason in a few hours' work dressed off the *small projections of the arch stones, and left the curve of the arch with no visible defect.*

It is to be remarked, the arch stone below the one marked (*a*) did not move, but rested at an angle of 44°. Previous to dropping the key stones into their places, the joints were besmeared with white lead and oil; this was done to facilitate any movement that might be required to adjust the positions of the stones, and to lessen the friction when driving them home.

Amongst the stone cutters there were some indifferent workmen, and it sometimes occurred the arch stones were not so truly shaped as was desirable, and the bedding was often very unequal. Notwithstanding, it was with satisfaction ascertained, when the centre had been lowered, that the settlement of the crown did not exceed 1¼ inch.

It was most fortunate no rising of the river, whilst the centering was in position, was ever of sufficient magnitude to cause any damage of importance; for a flood has occurred since the completion of the bridge, which would have done great destruction to the work in any advanced state short of ⅓rd of each of the semi-arches being laid.

The river on the morning of the 27th January, 1844, rose twice as high as it had ever been seen before. The head water at the bridge on the day stated was only *four feet* from the crown of the main arch; the back water was about 5 feet 6 inches; the bridge became an immense obstruction to the river, reducing the water-way to about one-half. By a rough experiment after the water had fallen a little, the current was found to run 20 feet in 4½ seconds, or about three miles per hour, under the main arch.

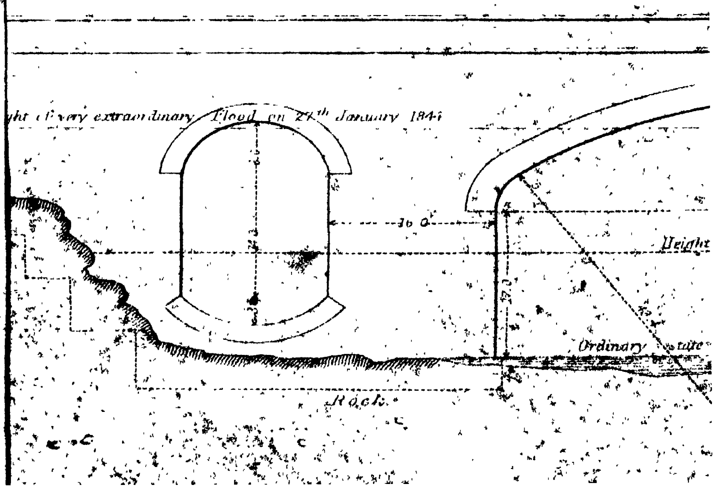
This flood has well tried the equilibrium of the arch and the stability of the work, and not a doubt can exist of "Victoria Bridge," rock-like, resisting hereafter the mightiest torrents that may descend from the Kat berg.

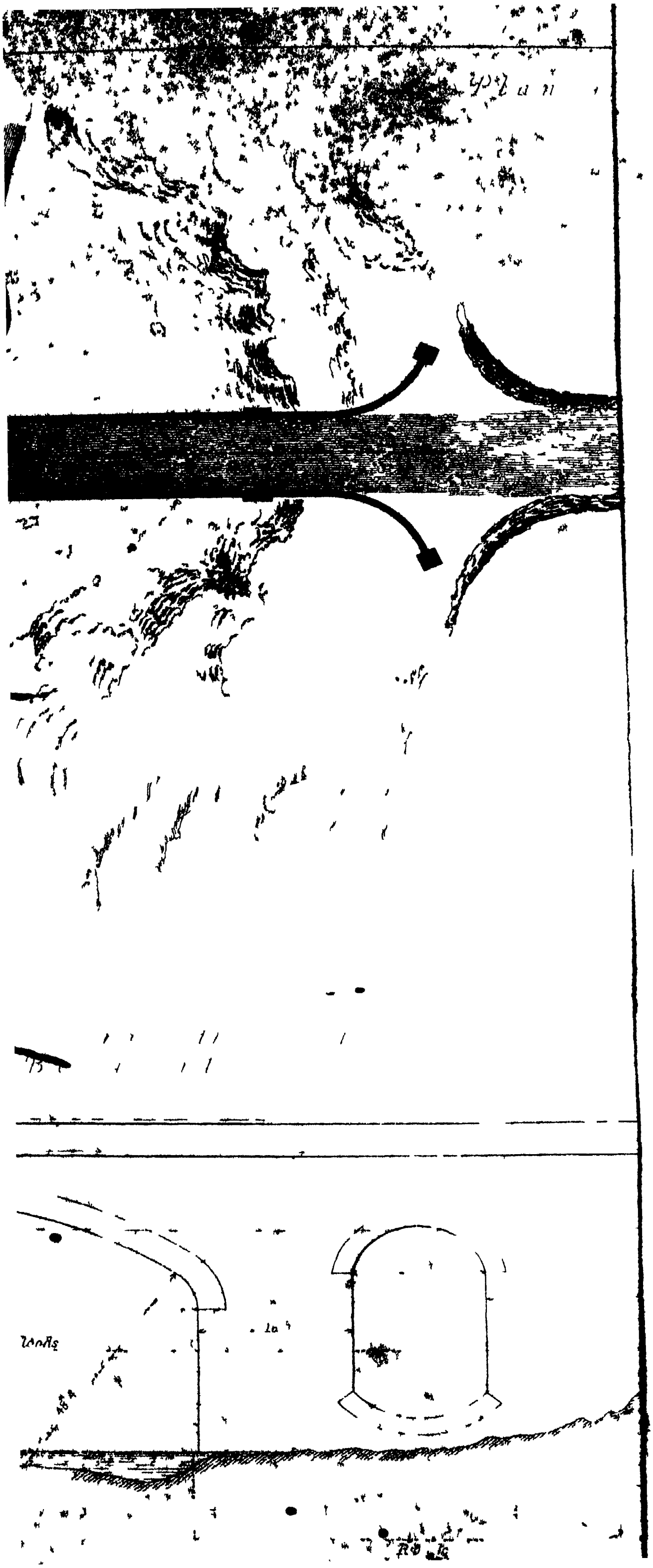
The bridge was commenced in July, 1840, and was completed on the 5th December, 1843. It would have been finished much sooner but for the want of workmen at different times, and for six months an insufficiency of funds.' The cost of the work amounted to £4970. 9*s*. 7*d*.

J. Walpole,
Captain, Royal Engineers.

Fort Beaufort, 1st Feb. 1844.

Elevation


ght of very extraordinary Flood on 27th January 1844
16 0
Height
17 0
Ordinary state
Rock


Rock

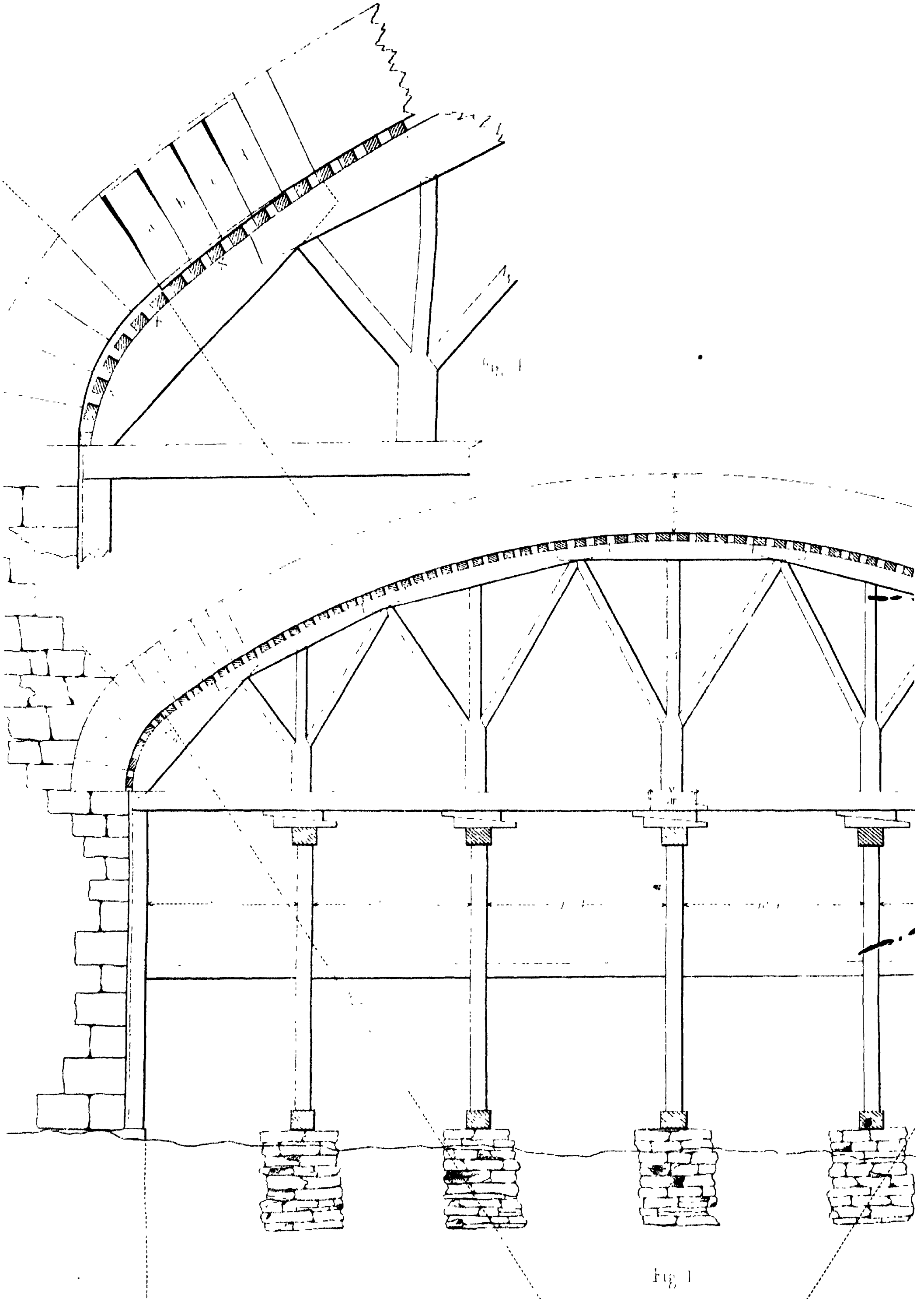
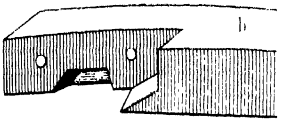
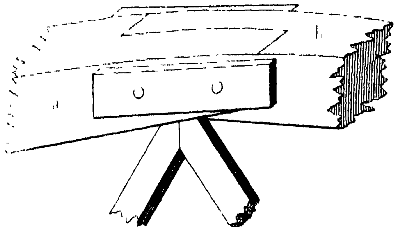


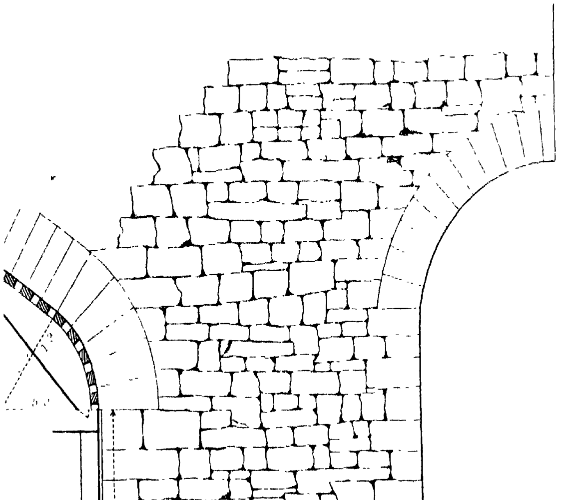
Fig. 1

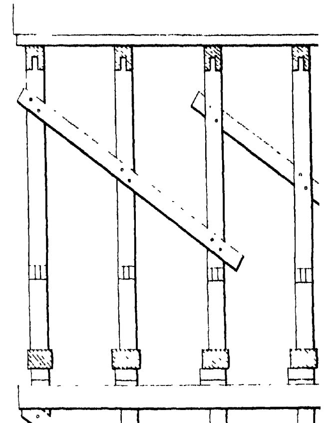
Scale

8 feet to 1 inch


b


b
a





Note.—Rumours having reached the ears of His Excellency that something had gone wrong with the bridge, the following Report was written in consequence:

Report for the information of Major Wortham, Commanding Royal Engineer, eastern frontier, bearing upon the subject of some slight defects that were visible in the main arch of the bridge at Fort Beaufort prior to its being keyed.

1. The joints of three of the first courses of the large segment of the main arch had at both haunches opened previous to the keying; the openings at the back of the joints at one haunch were about $\frac{1}{2}$ an inch, those at the other haunch much less; these courses had also settled about $\frac{1}{2}$ an inch.

2. When these defects occurred too many courses of arch stones had been laid to render it advisable to have them removed for the purpose of adjusting the positions of the stones which had dropped.

3. These defects are chiefly to be attributed to the shrinking of the timber composing the centre, and to a certain extent to the compression of the joints of the frame-work; they are, however, defects of such slight importance that a mason in the course of a few hours will render them unobservable. Considering the unfavourable circumstances under which this arch was constructed, these defects are as small as could have been expected. When the timber was procured for the centre it became necessary to frame it and put it up before it was dry; a shrinkage was consequently going on whilst the arch stones were being placed upon it, and at this moment, when it was so essentially necessary to continue the arch with all dispatch, operations were curtailed from the want of funds, and the expedition with which this portion of the work should have progressed was not practicable for many months.

Throwing an arch of 60 feet span was a novel undertaking to all employed; and when it is considered the crown on striking the centre has only descended about $1\frac{1}{4}$ inch, without any derangement of the curve or flushing at the joints, such results were gratifying to those interested about this structure.

J. Walpole,
Captain, Royal Engineers.

Fort Beaufort, 10th July, 1843.

V.—*Addition to 'Notes on Acre,' &c. By Lieut.-Colonel* ALDERSON, *R. E.*

THE Plan and Sketch of Jerusalem, with the following Note, were intended to have been introduced into the Paper on Acre in the 6th volume, but there was not time for it. It is now therefore inserted as a portion of that Paper, as it is considered any Notes on Syria or Palestine would be incomplete without some notice being taken of the Holy City.

Jerusalem.—Although the Holy City is not on the coast, nor perhaps on the direct line which an invading army would take to make itself master of Syria, its possession must ever be regarded as one of great importance in the accomplishment of that object, exercising, as it necessarily must do, great influence in the subjection of the country to a foreign power.

Jerusalem contains between 11 and 12,000 inhabitants, and is situated about ten leagues east of Jaffa: for the first three leagues the road lies across the plains of Sharon to Ramla, the ancient Arimathea, thence for about three more over undulating ground, when you enter the mountainous district in which Jerusalem is situated.

It is surrounded by a high and strong cut stone wall, built on the solid rock, loopholed throughout, and varying from 25 to 60 feet in height; it is seen to its base, having no ditch.

On the west front is the citadel called David's Castle, forming part of the town walls, and surrounded by a dry ditch.

This work, though placed in a re-entering angle, is of considerable importance to the defence of Jerusalem: it has artillery mounted on it, and would require heavy artillery to breach it.

The walls too, of the city, are sufficiently strong to require something more than field artillery to effect a breach in them; whilst their position, surrounded on every side by mountains, and difficult of approach for heavy artillery, gives to the fortifications which surround the Holy City an importance which their first appearance would not seem to justify.

The trace is however very defective, and on the north and south sides may be closely approached under cover, whilst on the east it is commanded within 500 yards by the Mount of Olives, and there is little flanking defence on this extended front. Still the valleys of the Kedron and Jehoshaphat on this front, of Ben Hinnom on the south, and of Gihon on the south-west, which unite below the pools of Siloam, and isolate the city, add considerably to its means of defence. The Church of the Ascension on the Mount of Olives might be made available as a strong advanced work, and outworks in front of the Damascus gate on the north, St. Stephen's on the east, and Zion on the south, would afford considerable addition to the defences, particularly the latter, as, from the nature of the hill of

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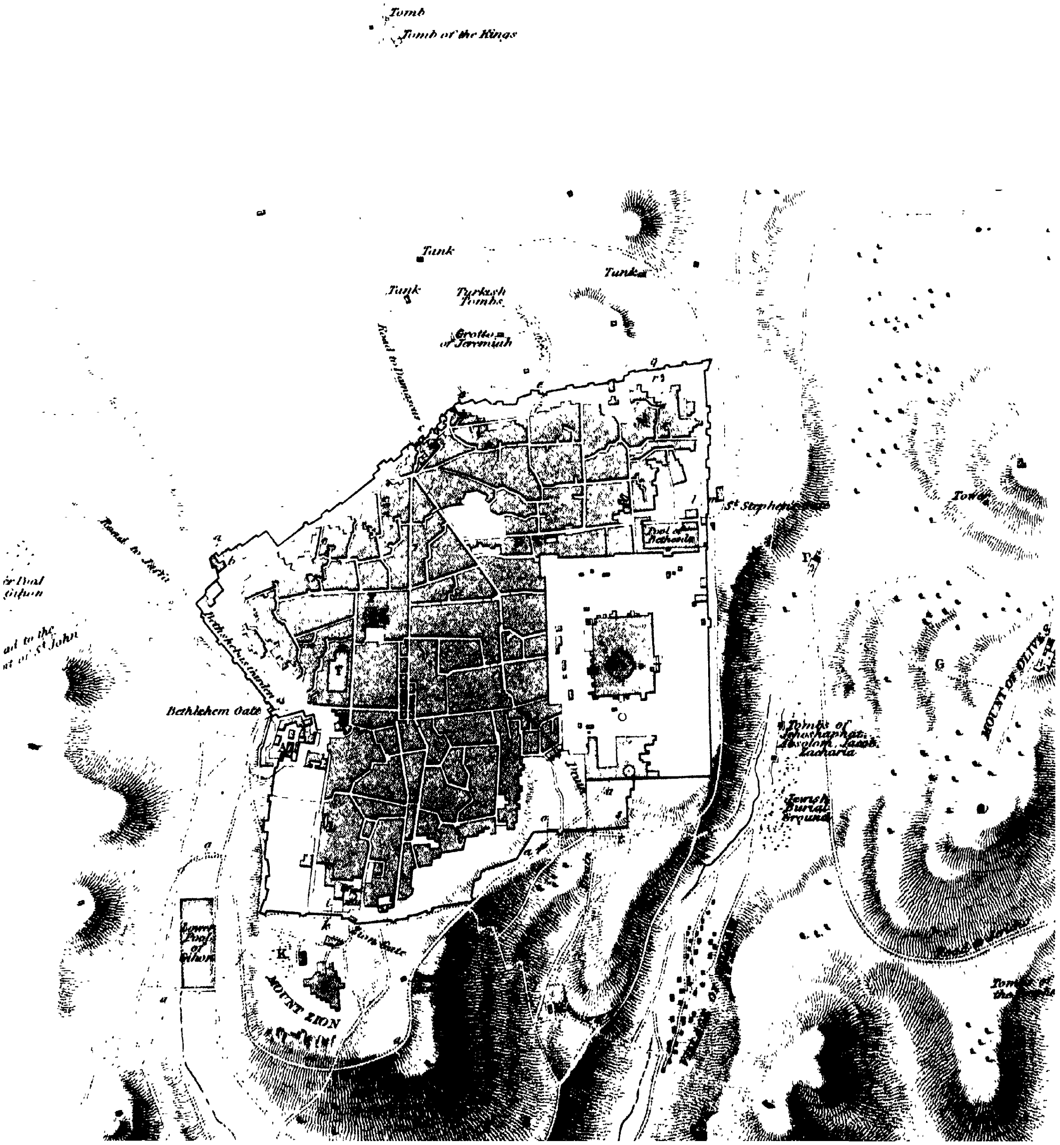
Plan of the Town and Environs of JERUSALEM.



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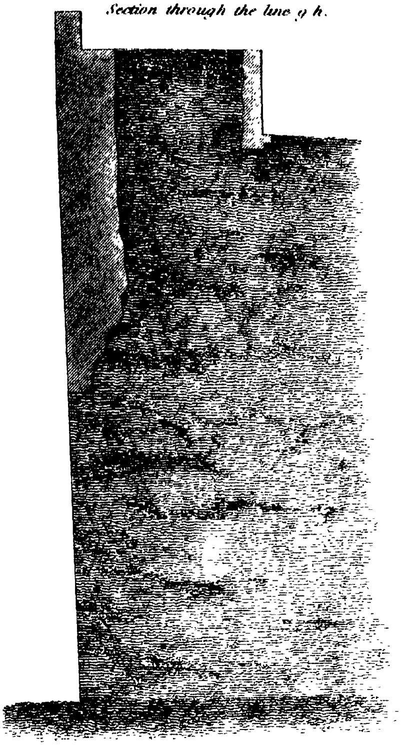

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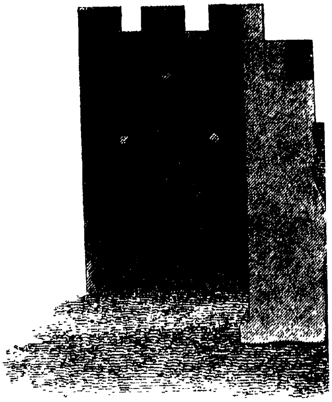

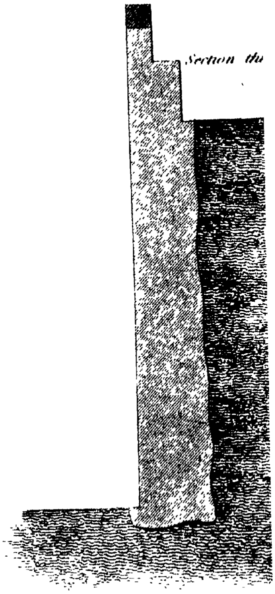

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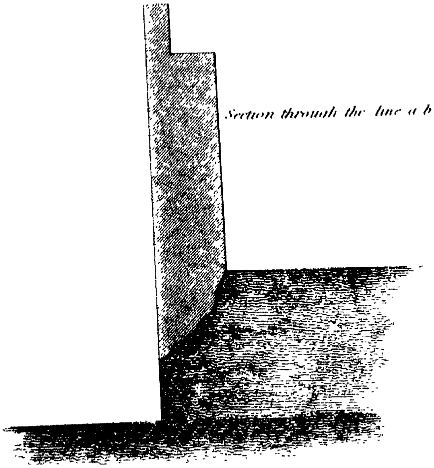

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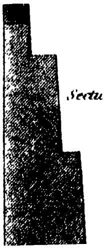
ences.

of Solomon's Temple.
w Residence of the Mutsellim.

Empress Helena.
posed to be the spot where
les the Lord's Prayer.
our Saviour was betrayed.
ed.

ch Herod's Palace stood.
hurch now building.



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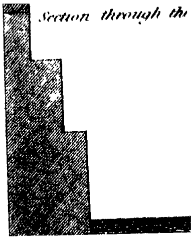


Section through th

Mount Zion, the walls are approachable within pistol-shot unseen. Here, however, from the situation of the citadel and the Armenian Convent, a protracted resistance might be made, were even a breach in the outer walls effected.

A free communication round the walls generally is much required.

Jerusalem is supplied with water by means of an aqueduct from the pools of Solomon, about three leagues distant on the road to Hebron, passing round Bethlehem. This might be cut off; but were the pool of Bethesda and other tanks in the city cleaned out, as well as the pool of Lower Gihon, just outside the walls, a good supply of water might be obtained.

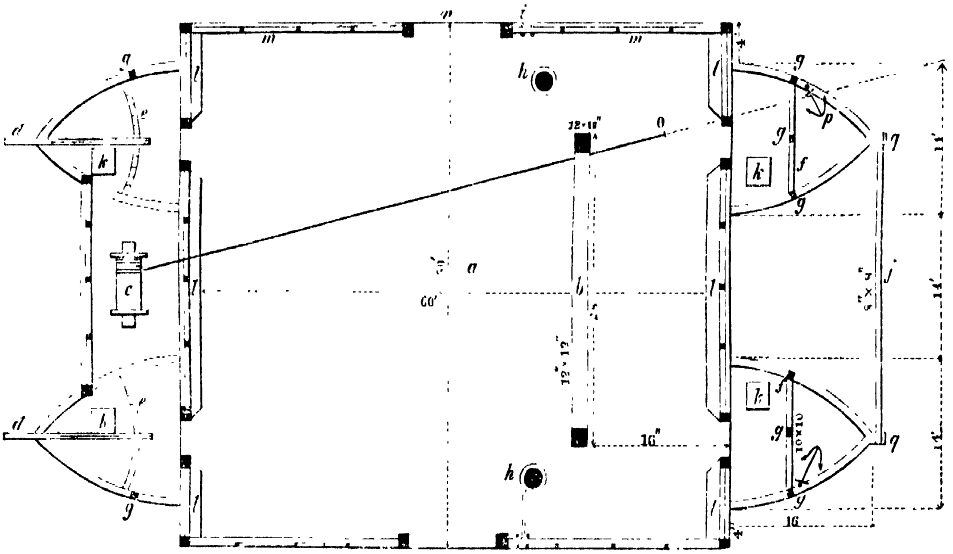
In addition to the strong interest which Jerusalem possesses in itself, it is important as a base for operations from the southern frontier, *viâ* Hebron and Bethlehem, forming the left of the position of which Jaffa is the right.

The ground between Hebron and the Dead Sea being almost impracticable for an invading army, from the numerous gullies and water-courses running into that sea, it would necessarily oblige them to come nearly up to Bethlehem (only two leagues distant from Jerusalem) before they could get to the plains of Jericho and the Jordan, and then pass on to Damascus.

The city is large, and affords within its walls considerable accommodation for troops, as well as for the formation of a dépôt for stores and provisions.

R. C. ALDERSON.

VI.—*Notes on Swing or Flying Bridges.* *By Captain* NELSON, *R. E.*



Swing Bridge on the Rhine, at Bonn.

SUCH bridges, as well as those of boats, are frequently used on the Rhine, a river on which permanent structures would be objectionable in certain military points of view, as well as in those of a mercantile nature, as impeding the great timber rafts which are constantly floated down from the upper Rhine as long as the river remains free from ice.

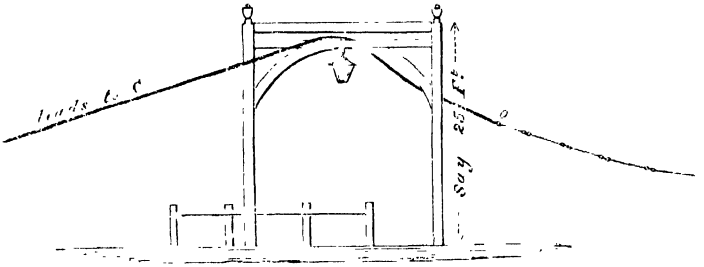
In this description of swing bridge, the necessary obliquity to the stream is given by the rudder. The above figure shows the bridge in plan as it swings from side to side at the lower end of a mooring chain, somewhat less than 500 yards long, the upper end being well fixed and anchored in the centre of the stream, and the intermediate length supported on boats.

The wharfs which receive the bridge on its arrival are moveable, and so arranged by floating them on boats like those of the bridge, that they can be adjusted to any state of the waters; there is a difference of 30 feet between the extreme levels, at Bonn.

References.

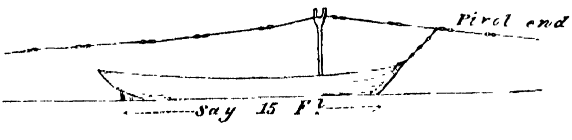
a The platform, say 3″ pine planking on rafters 8″ × 8″ and 4 feet apart, lying across the boats; ends projecting 4 feet beyond the outer sides. The boats are very strong, decked, and nearly flat-bottomed; they bear the platform as it rests upon the deck, about 5 feet above the water.

b The horse on which the mooring rides and traverses; the traversing beam is under, and parallel to, the top beam, thus,



c From the adjusting windlass *c* to *o*, the mooring is a 9″ hawser; but from *o* to the pivot, a chain composed of bar links 2 feet long, and connecting rings; both links and rings of about ¾″ square bar iron.

The length of the mooring depends on the width and velocity of the stream; but it is not customary to make it less than the breadth of the river. At Bonn, between the bridge and pivot, it rest on 9 boats, 50 or 60 yards apart.



d d Rudders.

e e Battens nailed to the deck, to which the steersman stays that tiller at which he does *not* stand, by means of a sort of boat-hook.

f f Cross beams, a few inches above the deck, which with the heads *g*,

g g Serve for belaying, &c.

h h Windlasses to check the bridge when it arrives at the wharf, as well as to bring it up square alongside of this last; a 6″ rope is used for this. The checking is also assisted by letting fall a drag-board, which hangs ready across the bows, at *g g*, as soon as the bridge comes within a few yards of the side.

i i Wooden rollers, set vertically in the framing of the railing.

j Connecting beam.

k k Hatches.

l Seats for passengers.

m m Railing.

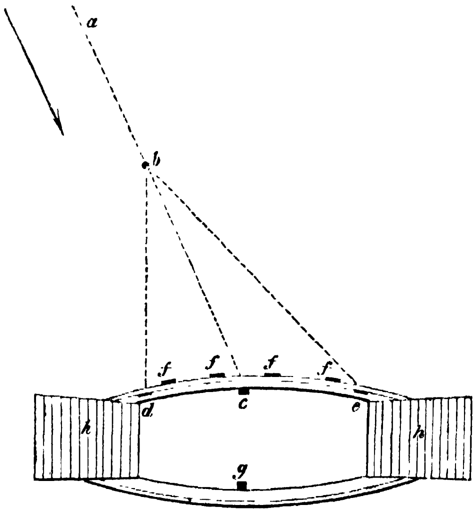
n n Entrances.

o Point of junction of cable and chain in the mooring.

p p Anchors in case of accident: a row-boat is likewise attached to the bridge.

In the winter, should there be much drift ice, these bridges become useless; their place is then supplied with common ferry-boats.

The preceding account is that of one of the largest bridges: the following refers to one of the smaller class, at Linz, also on the Rhine.



It consists of only a single boat about 12 feet wide, and perhaps 30 feet long. The oblique direction in this sort of swing-bridge is given by the chain *d b e*. *a b c* is the mooring.—*d b e*, a small chain passing through a block at *b*, and wound up at *d* or *e*, according to the side to which the boat is moving. To assist the conversion of the direct force of the stream into the necessary oblique one, 4 small lee-boards are slung at the sides at *f f f f*.—*c g* is a horse as in the preceding, but the mooring is fixed only to the post *c*.—*h h*, gang-boards let up and down like a drawbridge, from the horse.

The mooring is supported on boats, as before. When the bridge comes within a few feet of the bank, it is punted home to the wharf.

N.B.—*b* is in the last boat supporting the mooring.

R. J. NELSON,
Captain, Royal Egineers.

Dublin, Feb. 9, 1844.

VII.—*Memoranda on Transition*[1] *Lime and Limestone as obtained from different Quarries at Plymouth. By Captain* NELSON, *R. E.*

THE following notices are a part only of a body of like information which is desirable with regard to not only the remaining descriptions of the principal calciferous rocks (such as the cement septaria, chalk, Kentish rag, Purbeck, Portland, and Bath stones, dolomites, lias, and mountain limestone), but to granite, greenstone, syenite, and the numerous porphyries, slates, and sandstones chiefly used as rubble or ashlar in building.

In addition to the above, every hint is valuable which can be given on the *general management* of quarries, with reference to the selection of site, the point of opening, draining, mode of working, and other items of consideration which have so serious an influence, not only on the economy, but actual produce of a quarry, and probably, therefore, on the whole dependent system of works to be supplied.

The series of questions on which Quarry No. 1 was examined is herewith submitted for improvement. It is to be hoped that officers who have the opportunity will not fail to enrich our projected 'Aide-Mémoire' on these subjects.

R. J. NELSON,
Dublin, Feb. 9, 1844. Captain, Royal Engineers.

FIRST QUARRY.

The works at which these Notes were made consist of quarries chiefly for raising limestone in blocks of from ¼ cwt. to 1 cwt., either to be burned on the

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[1] This term, though nearly obsolete, is still retained, as geologists have not as yet decided on the place of the Plymouth limestone in the series of English rocks. It is a fine-grained, hard limestone, abounding in zoophytic and other organic remains; colour varies from light to dark grey; takes a high polish as a marble; and very generally gives a pure lime,—too pure for a water-cement.

The prevalent opinion is, that it belongs to the great coal formation.

spot, or to be shipped for different places in the neighbourhood where no lime is to be found. The excavation is carried on with reference to the future projects of the proprietor for docks and building ground; the stone is likewise wrought for curb-stones and paving slabs, but will not rise in masses large enough for wharf ashlar.

The burning establishment is a block of four kilns; to these, the stone is brought from below in tip-carts on railroads, by a 16 horse-power steam engine, up an inclined plane.

N. B. Throughout these Memoranda, the ton is by weight. In inquiries of this kind the word 'load' must be carefully scrutinized as to its local meaning.

1. Quantity raised per man per day?	Speaking generally under the circumstances of this quarry, 5 tons per day, shipped at about 200 yards from the rock. The workman is expected also to load and unload the cart, as well as to keep his quarry clean by removing the rubbish 50 yards.
2. Wages (1839)?	May earn 15*s.* per week on piece-work. The system here, is, for a ganger to contract at 8*s.* per load of 16 tons, put into cart only; he has to pay his labourers about 15*s.* per week, as above. The proprietor carts to quay, unloads, and ships.
3. Depth of jumper holes put down per day?	16 feet in four 4-feet holes is a good day's work.
4. Is the rate of pay increased at unusual depths, or is assistance given?	For the first 5 feet, 2*d.* per foot; after that two men are allowed.
5. Powder used per ton of stone?—Who finds it?—Price of powder?	4 ℔s. for the 16-ton load.[2] The ganger finds powder,—buying it of the proprietor at 6*d.* per pound.
6. Best proportion to fill of a hole?	About $\frac{1}{4}$th.
7. What saving is effected by tamping, allowing for the per contra of time lost?	Not observed with sufficient accuracy.
8. What kinds of tamping have been tried, other than the common?	Water tamping, and inclined to think well of it; the charge is enclosed in an oil-paper cartridge, into the neck of which a Bickford's fuze is fixed.

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[2] Taking the ton at 14 cubic feet, 16 tons = about $8\frac{1}{3}$ cubic yards.

9. What is done with spallings not shipped off?	Spallings, not less than a man's fist, are collected for the kiln; under this, they are wheeled off as rubbish for made ground.

XIII. 10. Machinery, tools, &c.?

	First cost.	Wear and tear.	Fuel and working, &c., per day.	Time of lasting.
Steam engine complete .	about £300	..	Man . . . . 2s. 6d. 8 cwt. culm 6s. 8d. 1 „ coal 1s. 2d. 10s. 4d.	
House	„ £70	..	..	
Tip-cart	„ £12	3 cwt. iron, 6 pr. of wheels.	..	With repairs, 9 years.
Moveable quarry crane .	„ £30	..	..	
Railroad, per yard[3] . .	..	..	..	
Quarry cart[4]	£15	3 cwt. iron.	..	With repairs, 9 years.
1 horse	£30	..	Wear of cart . . 1s. Man . . . . . . 2s. Horse . . . . . . 3s. 6s.	
Navigator barrow[5] . .	10s. 6d.	..	..	3–5 months, according to the work, without repairs.
Shovel	3s. 9d.	..	..	6–9 months, according to the work.
Plank, 2½ yw pine, ft. sup.[6]	4½d.	..	..	6 months.
Jumpers per lb. . . .	5d.	..	..	

Blanks are left above where the information was unattainable or unsatisfactory.

11. Who finds?—Who repairs?	The proprietor finds all machinery, tools, &c.: the ganger finds steeling and sharpening for jumpers, but the proprietor pays for lengthening.

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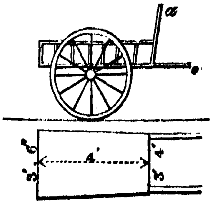
[3] Wrought iron rail 3″ × 1″, which is too narrow, as it cuts the wheels too rapidly; these are on edge, on wooden stools; cast iron would be constantly broken by the fall of the stones when blasting.

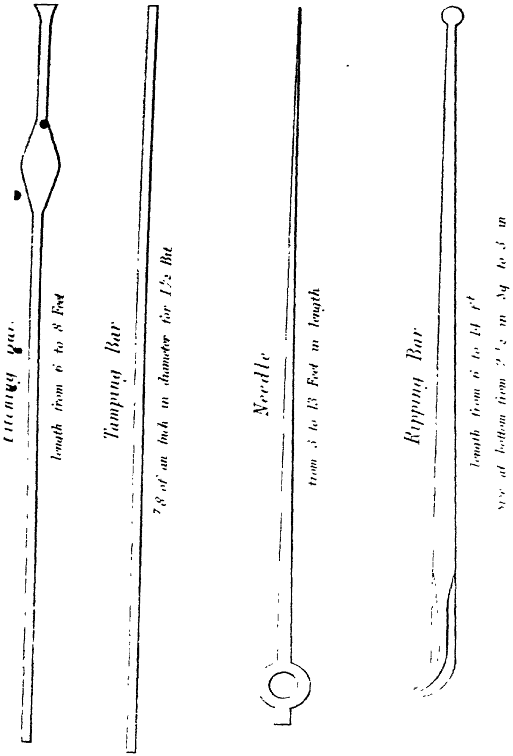
[4] Short quarry carts, very stout, and lined with 2½″ × ⅛ flat iron; they carry from 1½ to 1¾ ton. This compact build is better suited to violent work than larger, lighter, and less expensive carts, which may be had for £10 or £12, though likewise lined with iron bars.


a. high front.

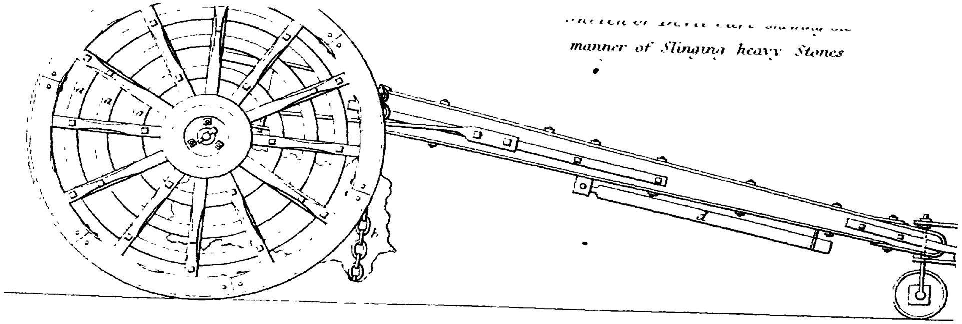
[5] Common pattern, with wooden wheel. In the quarry, where they are used all day, and where they are loaded and worked quietly, all is wooden; but at the wharf, where the work is shorter and sharper, a plate iron body on a wooden carriage is used: the last, if of iron, though more economical, would be too heavy for the quarrymen. Iron wheels are considered as too destructive to the planks.

[6] In the quarry, generally about 25′ × 14″ × 2½″, hooped and bolted; they are longer, broader, and thicker at the wharf.

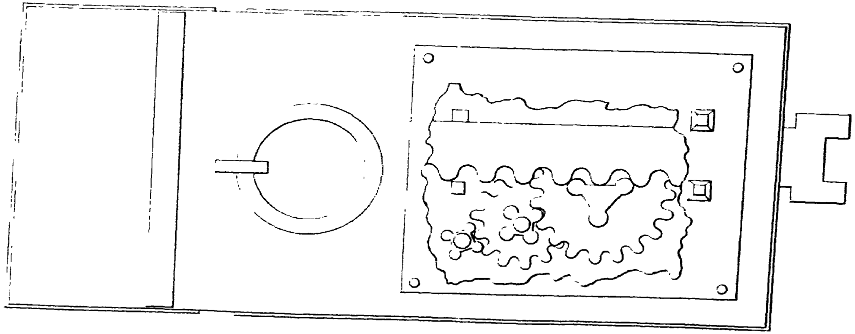
Tools used in Quarrying



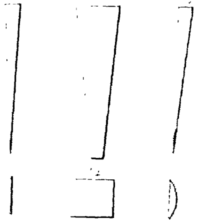
Sketch of Devil Cart shewing the manner of Slinging heavy Stones

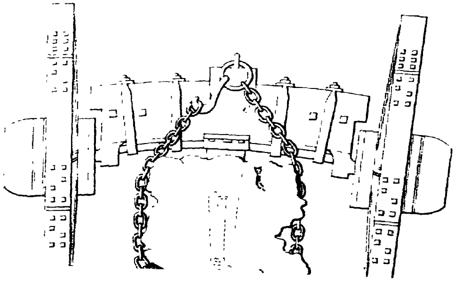


Quarry Screw-jack

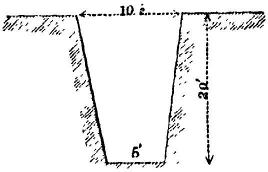


Feather and tears





a a a Iron bands ¾ of an inch thick.
The cart is provided with a pole 10 ft in length used as a means [illegible] the stone being lifted [illegible]

12. The duty of a horse and cart?	80 tons per day from quarry to wharf, 300 yards full; do. back empty.
13. Fuel used in burning?	Swansea culm (Anthracite), coal being in general too sulphurous to allow the burner to work.
14. Mode of filling kiln?	Two bundles of reeds; 10 cwt. or 12 cwt. chips, larger above; thus far filling up about 4 feet deep; then 3 cwt. rather large culm, 2 courses of stone, say 6″ thick together;[7] 2 cwt. culm, 7″ stone; $1\frac{1}{2}$ cwt. culm, 8″ stone; $1\frac{1}{2}$ cwt. culm, 9″ stone; and from thence, alternate with $1\frac{1}{2}$ cwt. culm and 9″ stone, until the kiln is filled.
15. Dimensions of kiln?	
16. Proportion of culm to lime obtained;—transition and lias?[8]	1 ton of culm should give from $3\frac{3}{4}$ to 4 tons transition lime. $1\frac{3}{4}$ ton of culm should give from $3\frac{3}{4}$ to 4 tons lias lime.
17. Time of burning one charge?	From $1\frac{1}{2}$ to 2 days, according to the wind.
18. Net produce of kiln per day?	From 32 to 33 tons, each 'ton' containing about 9 bushels.
19. Best lining for kiln?	On the whole, slate (local); fire-brick and Cornish granite have been tried, but are too expensive in proportion to their duration.
20. Prices of quarry and kiln produce?	Rubble limestone, shipped at 1*s*. $1\frac{1}{2}$*d*. per ton. Curb-stones 6″ thick; in the yard, 5*d*. per foot run. Paving flags, single wrought, in the yard, $4\frac{1}{2}$*d*. per superficial foot. Paving flags, double wrought, in the yard, 6*d*. per superficial foot. Lime at the kiln 7*s*. per ton. N.B. The lime is sold at the kiln at per double bushel.

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[7] When $\frac{1}{3}$rd filled, then fire over-night; next morning, if well drawn up, carry up the fire gradually.

[8] Brought from Aberthaw, for water-cement. Smeaton mixed one-half of this with the local lime in building the Eddystone Lighthouse.

SECOND QUARRY.

On another occasion I obtained the following notices in a neighbouring quarry, of like character with the preceding.

A jumper in 10 hours, net time, will put down 20 ft. with 1½″ bit.
„ „ 15 „ 2″ „

When using a 2½″ bit, he receives double after 12 feet depth; but not if he uses smaller tools.

The first set of tools is found by the proprietor: the difference of weight is paid for in returning them.

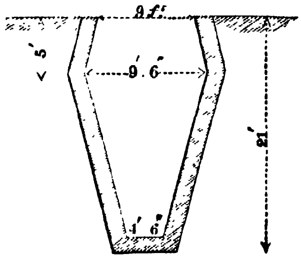
Barrows and planks are found by the proprietor; these barrows cost about 14*s.* complete.

The usual depths of the charge may vary from ⅓ to ½ that of the hole; and ½ lb. of powder should be allowed per cubic yard of solid rock.

A man will turn out and break up for rubble stone 4 'tons' or 56 cubic feet per day. If he has not to break up, then about 6 tons per day. When thus broken up into pieces of from ½ to ¾ cwt., and delivered at the kiln (close to the quarry), he will further break it up for burning at 1 load = 16 'tons' = 224 cubic feet per day.

The proportion of culm burned to quick lime yielded was 1 : 3; of slaked lime, 1 : 6.

In burning Aberthaw limestone, culm : quick lime : : 1 : 4, or culm : slaked lime : : 1 : 6 only.

A kiln 

gives from 90 to 100 bushels per day.

Wages at this time (1834) averaged 10*s.* 6*d.* per week for a jumper.

THIRD QUARRY.

The following Memoranda were obtained by Lieutenant Scott, R. E., from quarries in the same rock as the preceding; but as in these the stratification is very marked, and as there is but little disturbance from caverns, &c., the stone is raised in the largest blocks with heavy charges, so as to answer for breakwaters and wharf ashlar. Notwithstanding the pains taken by Lieutenant Scott, his original Notes give a good illustration of the vagueness, often amounting to contradiction, that characterises the replies of the 'practical men' to whom the detail conduct of such works is intrusted. The inquirer is so often baffled in this way, even on the closest questioning, that a report based on the information obtained at one spot alone, is likely to be but of little service. The following abstract, however, as checked by other information, seems trustworthy.

The largest block known to have been raised in these quarries weighed about 200 tons; and so variable are the effects of blasting in this, and most other places, that on one occasion upwards of 1000 tons were brought down by a charge of 100 ℔s. in a 30-feet hole. (See the last paragraph in this Paper.)

Labour.—20 feet of 1⅛″ to 1½″ bit in three or four different holes is a good day's work; but there is one man whose performance amounts to 30 feet per day, which is very unusual.

In deep holes, one man is employed for the first 6 feet; two for the next 10; and after 16 feet, three men, provided the hole is not more than 10° or 12° out of the perpendicular; if it be, even five or six men are put on in extreme cases after 15 feet. In such, it is usual to commence with a 2½″ bit, and end with about 1¾″; but the actual size of the hole is of course larger from the play of the jumper.

Charges.—In a 30-feet hole, about 25 ℔s. for the first charge (where the hole is about 2·3″ in diameter) is first tried as an experimental measure; this may or may not succeed, but will at all events probably disturb the beds beneath sufficiently to allow space for a repetition of the blast, perhaps three or four times over,[9] increasing somewhat every time before the final charge is introduced, as the block, if not well detached on all sides first, will be destroyed by the premature application of the full charge.

Should the tamping not be blown out, which does not always occur, there is no difficulty in thus repeating the explosions; but if it be destroyed, nothing can well be done until it is in some way or other replaced, even by putting down a new hole.

In the case of small blocks, not exceeding 15 tons, being dislodged by the first charge, the double screw-jack may render a second unnecessary.

One-half the depth of the hole, with the above-mentioned bits, seems to be the largest advisable charge that can be fired in the first instance without shattering the stone.

Well stratified as the rock in this quarry is, where the mass to be raised is not jammed at the sides, and where the beds dip to the front of the quarry, it is considered that ¼ ℔. of powder, per ton,[10] will dislodge the block sufficiently.

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[9] At Bermuda, in a soft calcareous rock where a cavity was readily produced, a third 'caving' was seldom necessary. In all these cases, where powder is poured in a second time, it is a prudent precaution (though but little attended to) to throw in a handful, to ascertain if any sparks remain. When accidents do occur from neglecting this, they are terrible indeed.

[10] A cubic foot weighs 160 ℔s.

VIII.—*Description of a Suspension Bridge erected over the Canal in the Regent's Park, upon Mr. Dredge's principle. By Captain* DENISON, *R. E.*

XIV. THIS bridge is one of several that have been erected by Mr. Dredge: the principle upon which they are constructed, as will be seen by the drawings, is, that the suspending chains should taper or diminish from the abutments to the centre; the rods also, by which the roadway or platform is suspended, are applied in an oblique direction. I have inserted the drawings and description of the bridge here, principally with the view of showing the effect produced upon it by the sliding forward of one of the piers, which, being built upon a bed of clay, was carried forward, the whole bank for a considerable distance having slid towards the canal.

The width of the canal, at the point where the bridge is thrown over it, is 47 feet; the span of the bridge, from the coping of one abutment to that of the opposite, is 67′ 10″. These abutments are 12 feet 2 inches wide on the face, and rise to a height of 18′ 6″ above the level of the water in the canal: they are built of brick faced with stone, and are 1′ 8″ thick; the wing walls, which run back for a distance of 34′ 10″ from the face of the abutment, are of 14-inch brick-work, stuccoed on the face: in addition to these wing walls there are two counterforts, extending back for a distance of 11 feet; these are also composed of 14-inch brick-work, and the space in rear of the abutment is thus divided in three spaces of 2′ 6″ in width, which spaces were filled up with clay well rammed: upon these counterforts, and upon the front and side walls, a 6-inch York landing is laid, which forms a support for the columns which carry the chains.

These columns, as shown in Plate XXV. fig. 1, are cast in a tapering form; they are 10 inches square at the base, and 7 inches at the height of 4′ 9″: upon the top of the column a square cap is placed, through which openings are made for the passage of the suspending chains, as shown in figs. 2 and 4. These columns are bolted down to the York landing by four bolts, well let into the stone, and run in with lead, and are 8′ 6″ apart from centre to centre.

The bridge is suspended from these columns by two equal and similar chains, each of which is composed of eleven links: the bars forming the links are 6½ feet long, and ⅝ths in diameter; the first link next to the column is composed of six bars, the next of five, and so on till the centre link is composed of but one bar: the plan of the chain is shown in fig. 6, Plate XXV.: the bolts connecting the links are of ⅞-iron; and the two short bars, shown at the outside of each connecting bolt, are intended to represent the suspension rods which sustain the roadway.

The retaining chains, which are carried to the rear, are each equal, and similar in every respect to one-half of the suspending chains; they taper in the same way, and the last or single link is fixed and bolted to a mooring stone sunk into the ground: the suspending rods attached to the links of the retaining chains are a little longer than those of the suspending chains, for the purpose of allowing them to descend below the surface of the ground, and reach the mooring stones, which are placed at some depth under ground, and have their planes at right angles to the direction of the suspending rods: these mooring stones are slabs of 5-inch York paving, 2′ 6″ square, and are all, except the last, built into the wing walls to the depth of 4½ inches.

The platform or roadway is formed of two longitudinal bars of wrought iron, 4 inches deep by ½ an inch thick, forming the sides or bearers; these are 8′ 6″ apart, and are let into grooves in the coping stones of the abutment to the length of 10 inches; on each of these bearers are fixed 25 shoes at equal distances of 2′ 9⅔″ apart, the first being 3 inches distant from the coping of the abutment: these shoes are cast with a groove in the inner side, to receive the ends of the transverse bearers, which are bars of wrought iron 3 inches deep by ½ an inch thick: in each of these transverse bearers sixteen holes are drilled, at 6½ inches distance from centre to centre, through which rods ⅝ths in diameter are passed from end to end of the bridge, forming the support of the planking of the roadway: the planking consists of ¾-inch boarding, and it is covered by a coat of asphalte about ⅝ths of an inch thick.

The suspending rods are fastened to the longitudinal bars on the sides of the roadway; two cast iron bosses are placed at the points where the suspending rods are to be fixed, one on each side of the longitudinal bar, and are bolted through it: the suspending rods pass through holes in these bosses, and are brought to a proper state of tension by nuts below.

The hand-rail is formed of wrought iron rods, supported by brackets, one of which is fixed to every alternate shoe, the upper part of which is cast out to receive it.

The bridge was completed in the summer of 1842, and as long as the weather remained dry no symptoms of failure were shown; but after the heavy rains in the autumn, the whole of the bank in rear of one abutment began gradually to slide forward, carrying with it the side walls and counterforts,—in fact, the whole of the abutment, with the exception of the York stone landing, forming the coping to which the pillars were bolted. All the mooring stones followed this movement, with the exception of the two at the ends [illegible] the suspending chains, which were placed beyond the point where the slip commenced. The whole distance to which the abutment was pushed forward amounted to 9 inches, and it is remarkable that the walls, notwithstanding this movement, hardly deviated sensibly from their perpendicularity.

It was stated that the side bearers were let 10 inches into the York landing at the top of the abutment; they therefore acted as struts to prevent the forward motion of this coping; and this, together with the retention of place of the extreme mooring stone, kept the columns in their original position, while the brick-work slipped from under them: the wing walls were of course fractured in different places during this movement forward, but the cracks were not of much importance.

Plate XXIV. shows the mode in which the abutment gave way, and the amount of the movement, as also the mode in which it has been attempted to guard against any future tendency to slip. A row of sheet piling has been driven a few feet in front of the abutment, and in rear of these three brick buttresses have been built against the foot of the abutment; from the ends of the piles two chains have been taken back, as land ties, and four piles driven at some distance behind the last mooring stone,—a stout beam connecting the piles together, forming one system, the whole of which must go before the abutment can move.

DREDGE'S S

Over

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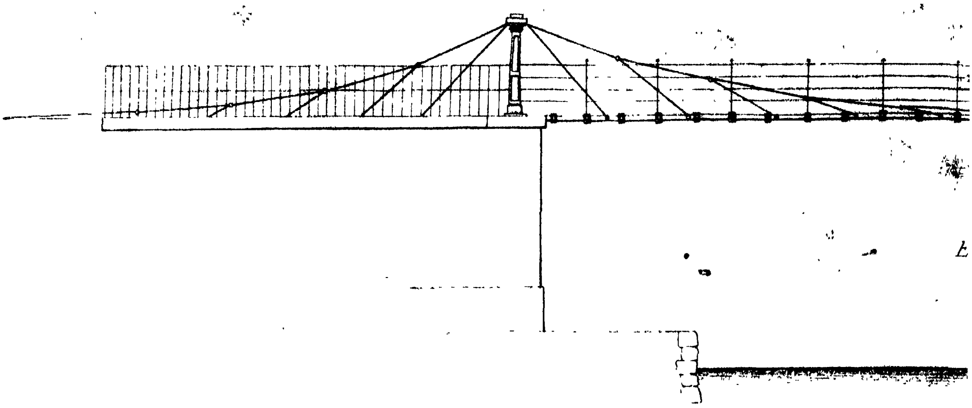
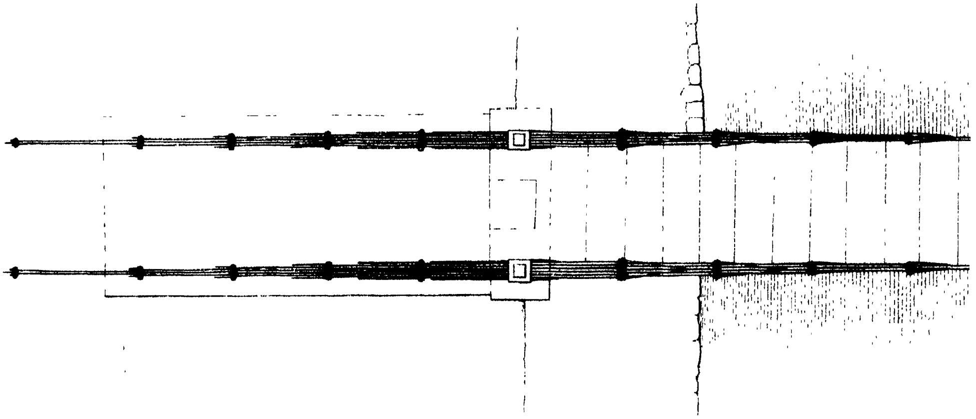
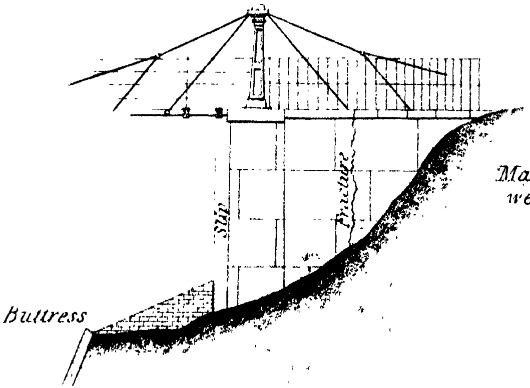
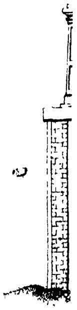






Partial Elevation shewing the fracture & extent of the Slip.

Manner in which the Copings were displaced laterally.



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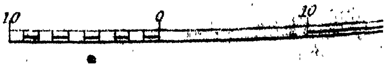

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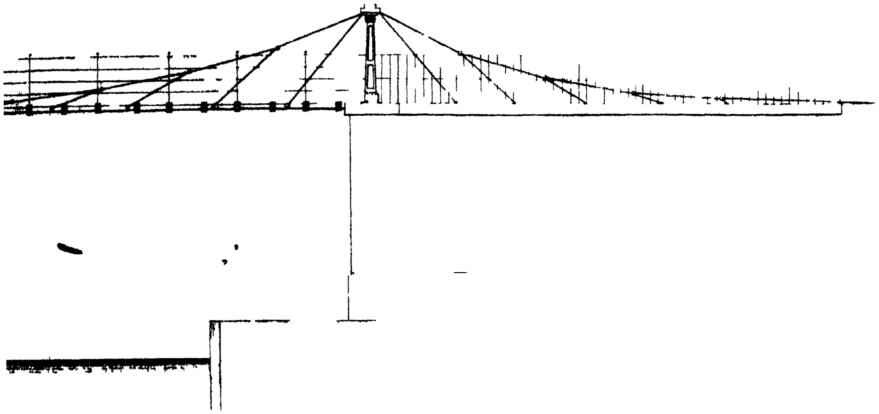

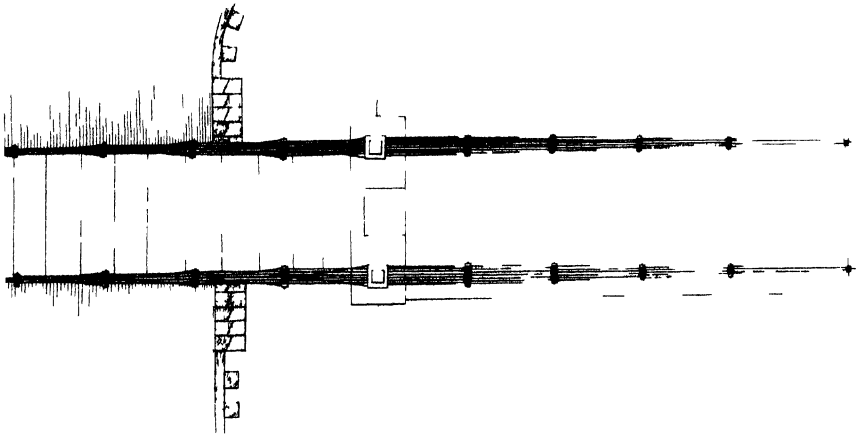

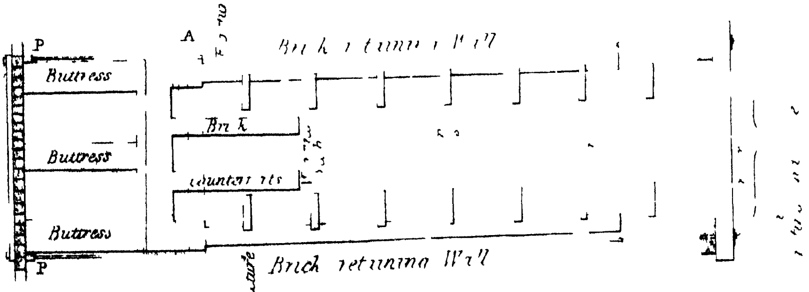

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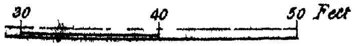

Plan of the Foundation Mooring Slab &c
shewing the Fracture and Slip the Buttress
and Back [illegible]

DREDGE'S S

Over

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Fig 1

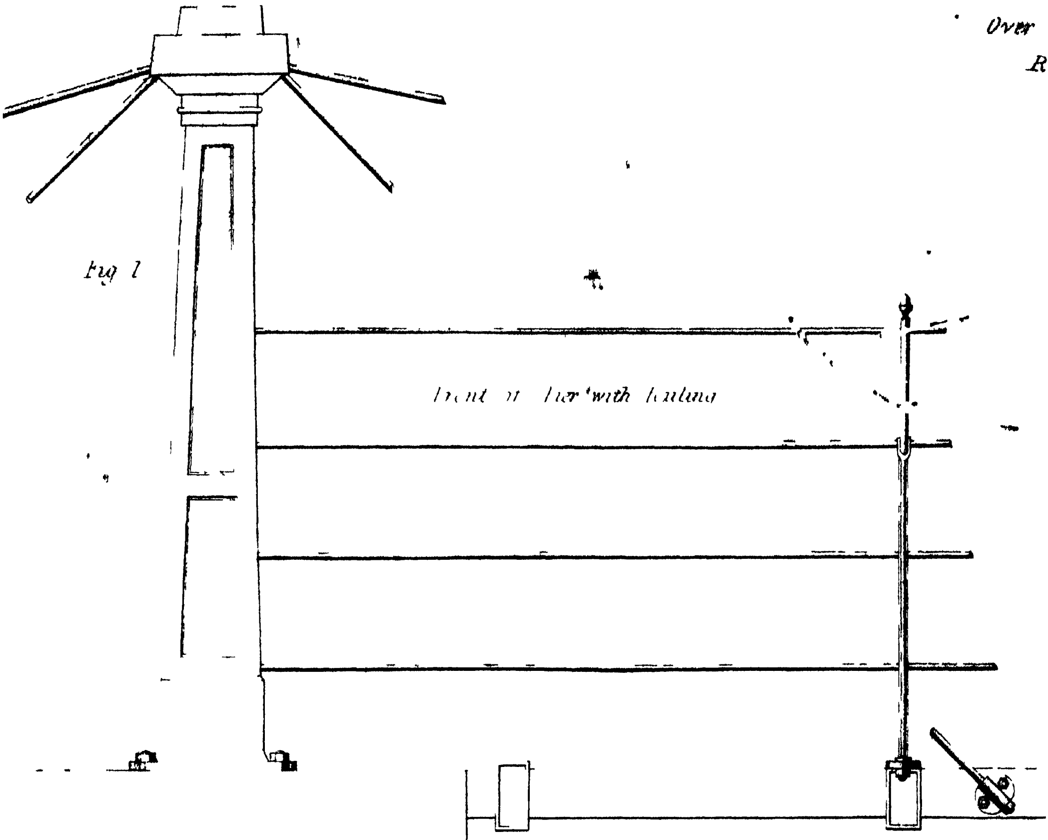
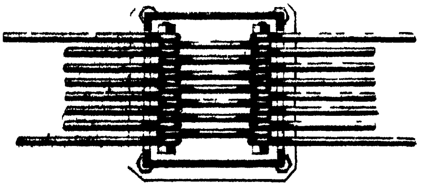
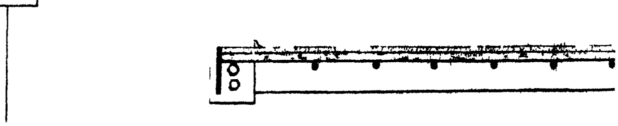
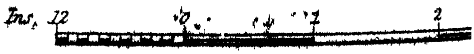


Fig 4



Sectional Plan of Top of Pier





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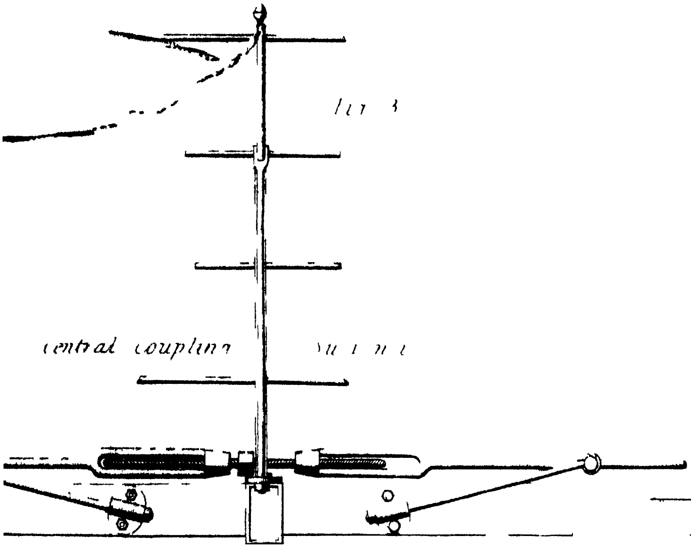

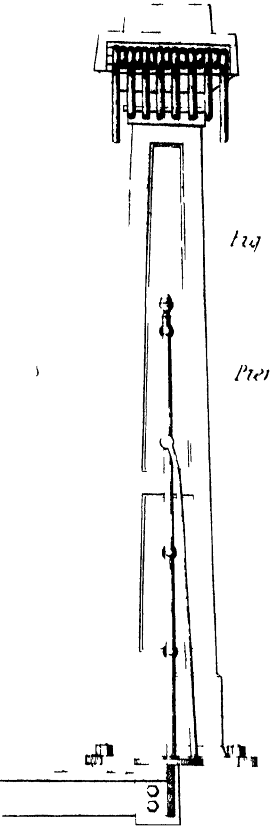

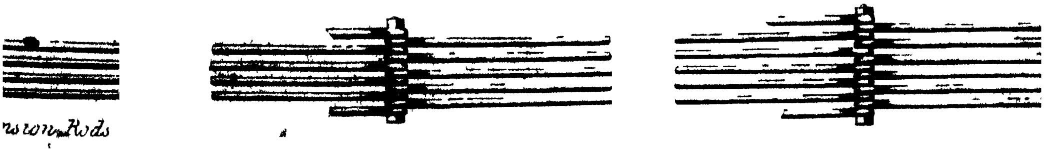

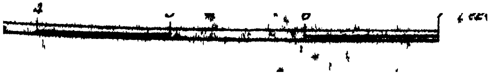

IX.—*Description of the Balance Gates at the Compensation Reservoir of the East London Water-Works at Old Ford, designed and erected by* THOMAS [illegible], Esq., C. E.

[illegible]ESE gates were designed for the purpose of discharging the body of water collected in the reservoir during the rise of the tide, in order to supply the mills lower down the River Lea, which might otherwise have been injured by the amount withdrawn from the river by the pumping engines of the Water Company.[1]

They differ in construction from common flood-gates, being made to work upon a vertical shaft or spindle as a centre, and having an equal surface of gate on each side of that centre, so that whatever pressure of water there may be on one side of the gate tending to force it open, there is as great a pressure on the opposite leaf to keep it shut; being therefore in all cases equally balanced, a very slight working power (sufficient to overcome the friction of the working parts) will either open or close them.

When the gates are closed, and it is wished to keep water in the reservoir, in order to prevent the effect of any vibration upon them causing them to leak, a shaft is introduced, upon which three excentrics are cast, which, when applied to the gates, forces them against the abutment and against each other, and thus prevents any leakage.

When the gates are to be opened, the excentrics must first be relieved from their pressure upon the gates, and then the quadrant and pinion will be worked to open the gates, which requires but a very small exertion of power.

The following Plates will, I hope, prove sufficiently explanatory, with the references accompanying them, to give an idea of the construction and mode of working the gates.

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[1] It was a condition that the water from the reservoir should be discharged in a very short space of time: with the ordinary sluice gates it would have taken above an hour to open the same width of water-way that with the present balance gates does not occupy ten minutes; and hence the chief reason for their adoption.

Plate XXVI. Fig. 1 shows the plan of the piers and abutments of the bridge, forming three openings, each of which is occupied by a pair of gates.

(A) shows the plan of the sills against which the gates abut when they are closed, the position of the gates when open being shown by dotted lines; (B) is a section through the gates when closed, showing the position of the excentric shaft, and the ratchet for keeping it in close contact with the gate; and (C) shows the plan of the upper part of the gate.

Fig. 2 is an elevation and section, showing the openings, with th[illegible]d, foot-bridge passing over them. In this bridge, the collar which e[illegible] upper part of the spindle is framed.

(*a*) is a section of the abutment and pier, with an elevation of the bridge, the gate being removed; (*b*) is a section through the piers and bridge, showing the centres upon which the gate turns; (*c*) is an elevation of the gate in its place.

Fig. 3 is a plan of part of the trussed bridge, showing the castings in which the collar is fixed, and the mode of trussing and connecting the bridge, in order to enable it to resist the horizontal strain to which it is exposed.

Every precaution was taken to secure the foundations of the piers, apron, and sills: inverted arches were turned between the piers, and sheet piling driven above and below the apron.

Plate XXVII. contains plans, sections, and elevations of the gate, with the cast iron spindle, sockets, &c.

Fig. 1 is an elevation of the gate complete, as fixed with the quadrant by which it is moved.

Fig. 2 is a plan of the same.

Fig. 3 is a horizontal section through the gate, and fig. 4 a plan of the bottom of the same, showing the cup at the bottom of the spindle upon which the gate turns.

Figs. 5 and 6 are views of the two ends of the gate, the former showing the plates screwed on to the part against which the excentrics work, the latter giving also a view of the spindle.[2]

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[2] The frame of the gate is English oak, the planking the best Memel fir; the timbers are rebated out for the reception of the plank, which, when fixed, is flush with the surface of the timber: it is two inches thick, and is fixed to the timber at the end, and at all the crossings, with screws ⅝ths in diameter and 5 inches long, which go 3 inches into the solid timber.

The joints, when the plank is fixed, are caulked so as to be water-tight; the meeting-posts are made to fit accurately; and the pivot and step or socket are made true, so as to allow of the least possible leakage.

BALAN

Compensation Reservo

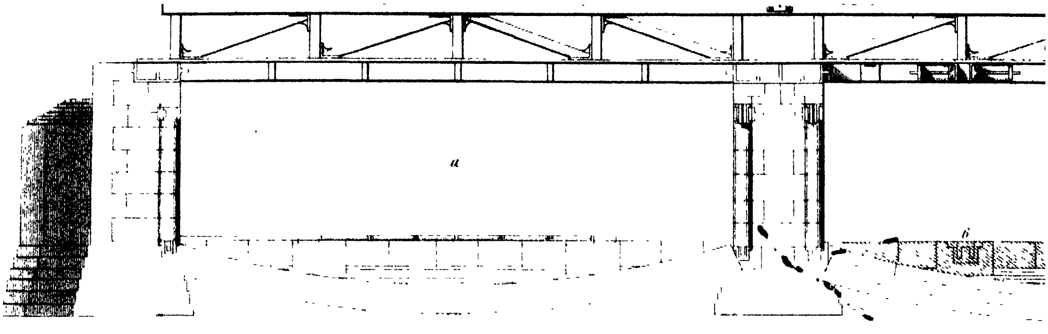
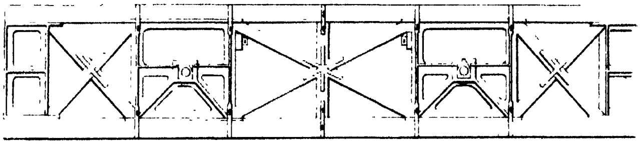
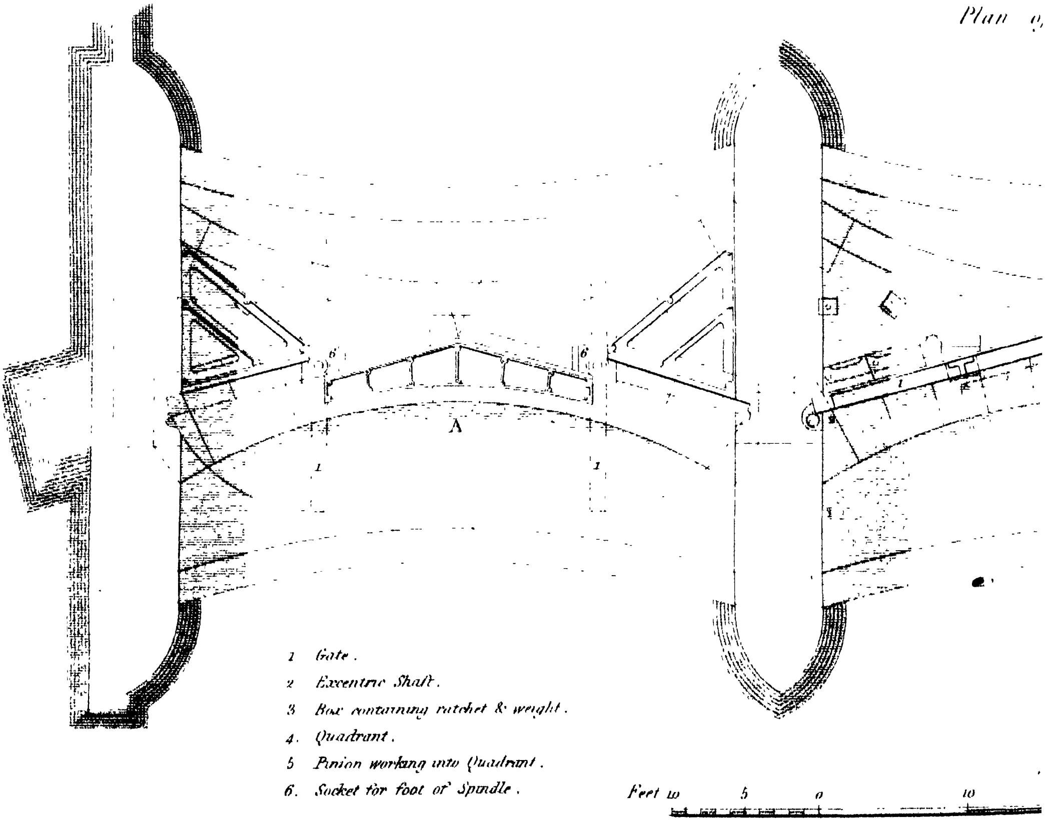


Fig. 3.



Plan of Bridge.

Plan o

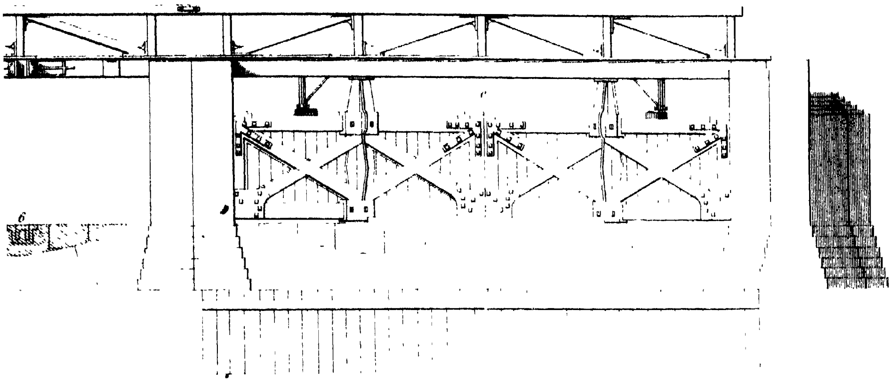


1. *Gate.*
2. *Excentric Shaft.*
3. *Box containing ratchet & weight.*
4. *Quadrant.*
5. *Pinion working into Quadrant.*
6. *Socket for foot of Spindle.*

Plate XXVI

ATES.

ndon Water Works.



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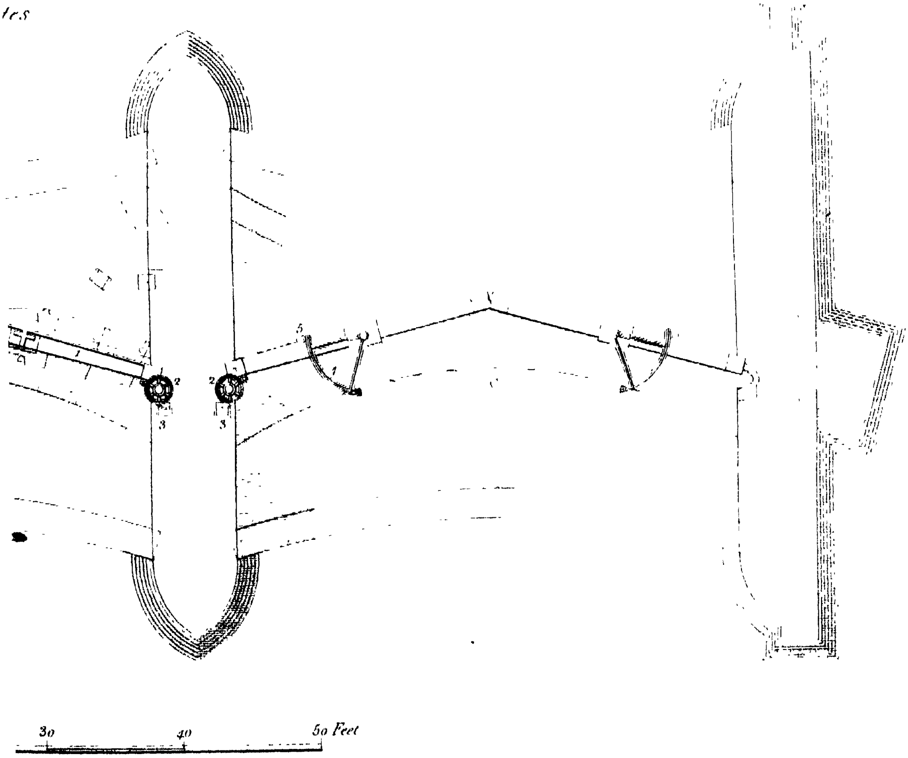

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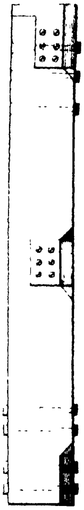
Fig. 1

Front Elevati

Fig. 5.



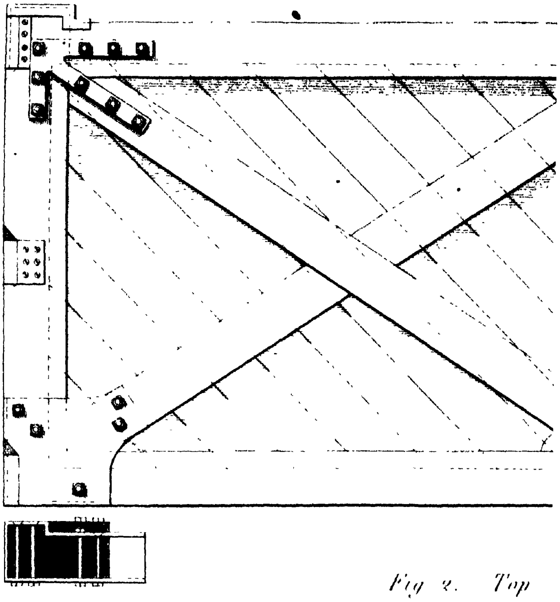
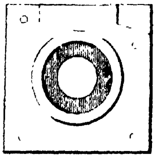


Fig. 2. Top

Fig. 8.



Scale of Feet

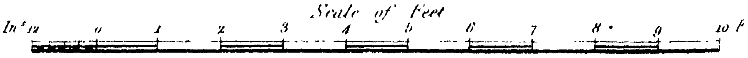


Fig. 9.

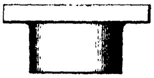


Fig. 3. Horizont

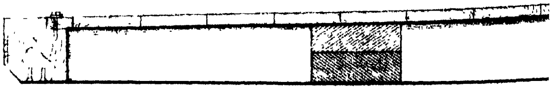
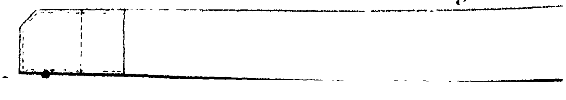


Fig. 10.

Fig. 4.— Pla



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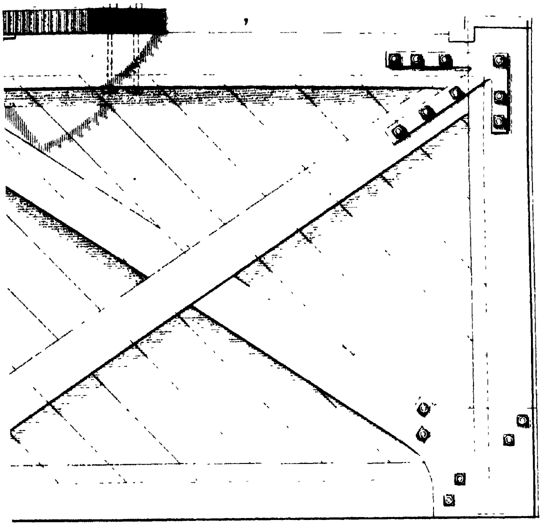
Gate.



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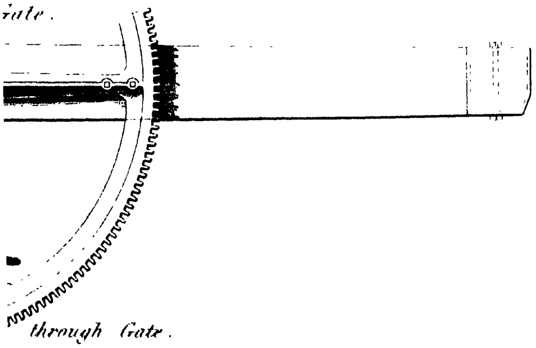
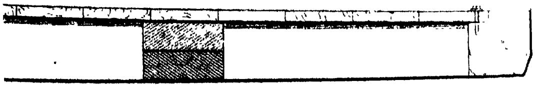
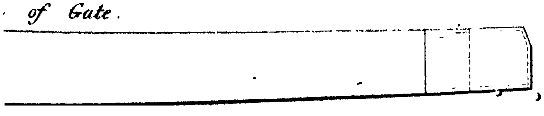


through Gate.



of Gate.



End View.

Fig. 6.

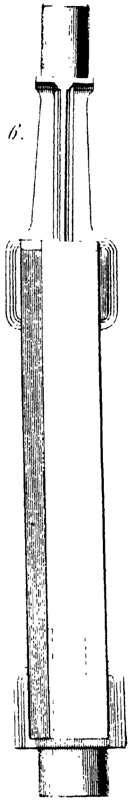
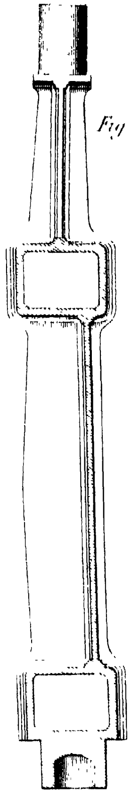
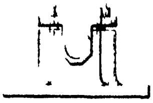
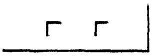


Fig. 7.

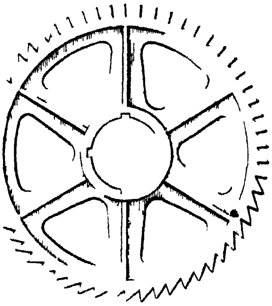


Transverse Section thro' centre of Gate





Under side of Wheel shewing Ratchet

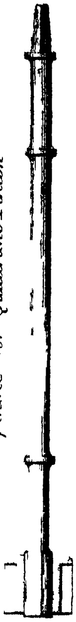


Section of Wheel

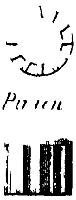
Plate for [illegible] Block

Side Iron

Step piece for [illegible] Spindle



Spindle for Quadrant Pinion



Pinion

Fig 4

Plan of Sill Piece

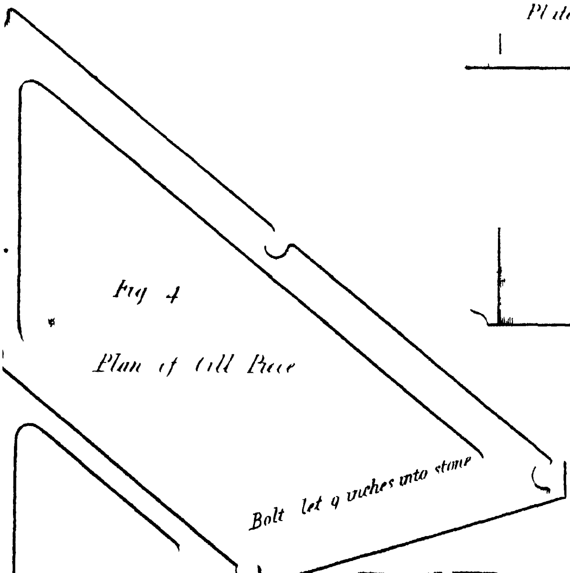


Fig 9

Fig 10

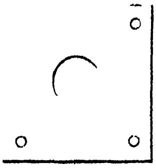


Fig 7

Fig 6

Elevation of Side next Gate

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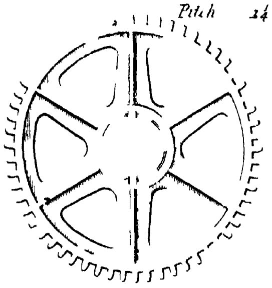
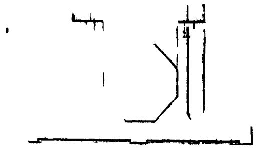
Diam' to Pitch line ft in

Pitch 2¼





Plummer block for Eccentric Spindle

Wheel for Eccentric Spindle

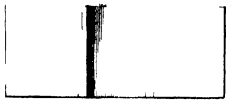
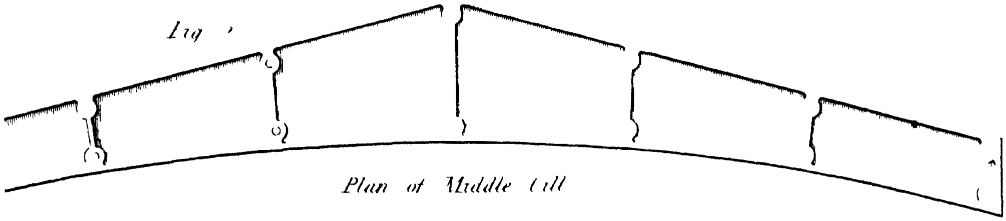


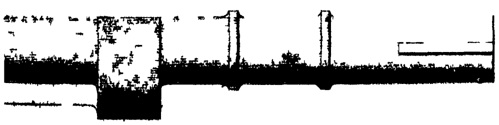
Fig 1 Front View

Fig 2



Plan of Middle Cill

Fig 3 End View



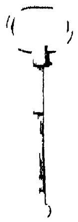
1 Foot

6 7 8 9 Feet

1 Foot.

4 5 6 7 Feet

Fig 5



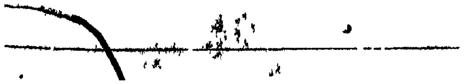


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Fig. 12

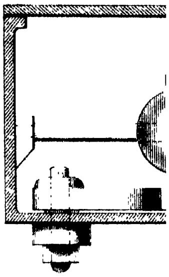


Fig. 3

Frame for carrying Upper Bearing of Gates.

Bottom Side.

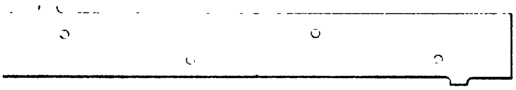


Fig 1 Plan

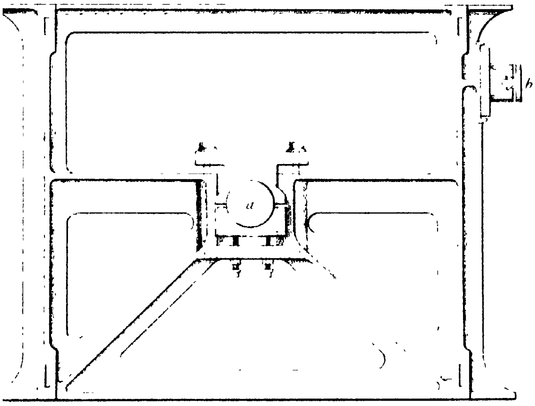


Fig 4

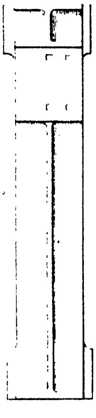


Fig 6.

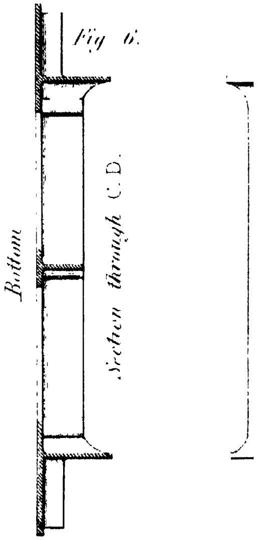
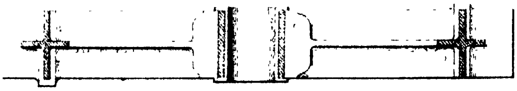
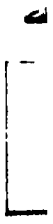


Fig 2.

Transverse Section.





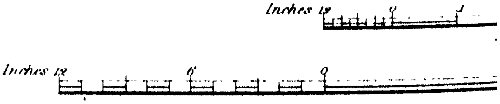


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Fig 13

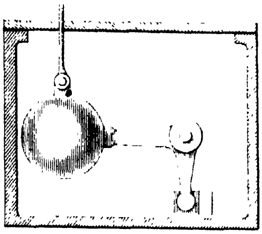
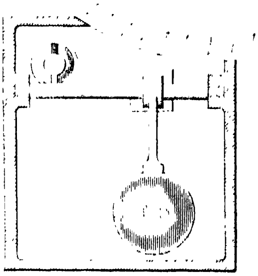


Fig 14



ying Trussing of Bridge.

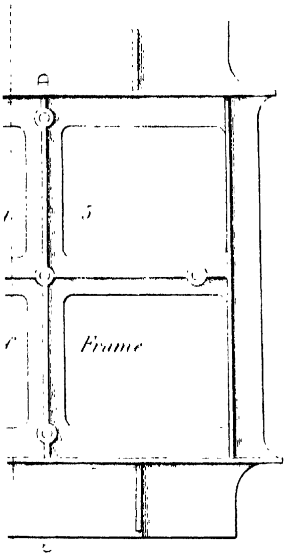
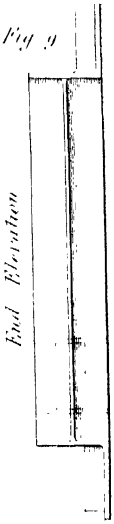


Fig 9



Frame to carry Trussing

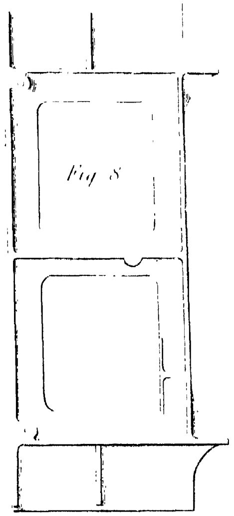
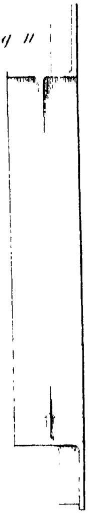
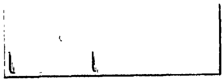


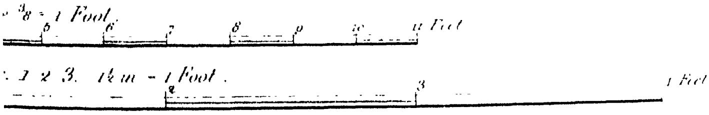
Fig 11



Side Elevation.

Fig 10





J H Le Keux.

Fig. 7 is a transverse section through the centre of the gate, showing the form of the spindle.

Figs. 8, 9, and 10, are views of the socket in which the spindle works.

Plate XXVIII. gives plans and sections of various details of the machinery and fittings.

Figs. from 1 to 6 show the cast iron sills, which are bolted down to the floor, and against which the gates abut when closed. Figs. 7 to 10 show the details of the excentric spindles. The remaining figures give the details of the wheels, pinion, ratchet wheel, &c., for working the excentric.

Plate XXIX. shows the details of the castings for the bridge.

Figs. 1 to 4 give the plans and sections of the casting which receives the upper end of the spindle; it also carries the plummer block for the shaft by which the pinion which works in the quadrant is moved.

Figs. 5 to 7 show the cast iron frame bolted to the piers from which the trussing of the bridge proceeds, and against which it abuts; while figs. 8 to 11 show the plans and sections of the similar frame bolted on to the abutments.

Figs. 12, 13, and 14, show the details of the lever and weight which act upon the click or pall, which fits into the teeth of the ratchet wheel upon the excentric shaft, in order to prevent it from moving back when once brought up hard against the gate.

The whole of the work is very well put together, and has been in operation ten years, answering its object completely.

The above description has been compiled from the data furnished to me by Mr. T. Wicksteed, under whose superintendence the gates were erected, who also kindly furnished me with the drawings from which the Plates have been reduced.

W. D.

X.—*Description of a small Observatory erected at Chatham, for the use of the Officers of the Corps of Royal Engineers. By Capt.* H. D. HARNESS, *R. E.*

WHEN the course of surveying appointed for the instruction of those cadets from Woolwich who might be named as candidates for the Royal Engineers, was removed from the superintendence of the Directors of the Ordnance Survey, and made a part of the practical course at Chatham, Captain Denison, the officer appointed to superintend this branch of study, justly considering that an engineer ought to be prepared to make an astronomical survey if required, suggested that the ordinary problems of practical astronomy should be added to the course. He provided at his own expense, and lent to the establishment during his stay, and for some time after he had left it, an altitude and azimuth instrument and a portable transit instrument. The Board of Ordnance allowed a hut which had been used as a temporary pontoon store, to be adapted for the transit instrument, and a small wooden building with revolving dome, about 8 feet in diameter, to be constructed for the altitude and azimuth instrument; and Major-General Pasley applied to the Royal Astronomical Society, of which he is a member, for the use of a clock, and a clock was accordingly lent to him. Thus originated the addition of an observatory to the means of obtaining information afforded to the corps by the Chatham establishment. At a later period, a small refracting telescope was purchased by the Board of Ordnance, and another wooden building with revolving dome, 10 feet in diameter, was constructed for its reception; and finally, the instruments which had been lent by Captain Denison were purchased from him.

The wooden buildings above mentioned were, however, unfit for the permanent accommodation of the instruments; the clock became useless during the winter, and the divisions on the altitude circle of the altitude and azimuth instrument have suffered more than they would have done in a better building. The discomfort also of remaining in a little wooden hut, and with scarcely room to move on a cold night, was enough to discourage those who might otherwise wish to avail themselves of the facilities afforded. In 1840, therefore, Major-General Pasley made an application to the Inspector-General of Fortifications for a proper building, and forwarded a plan for one. Shortly after an observatory, in conformity with that design, was ordered to be built, and it was completed in September, 1841. It is now well provided with all the necessary means for an officer to acquire a practical acquaintance with different methods of obtaining latitude and longitude, and it is probable that when the opportunity thus offered to the corps is generally known, many officers will wish to come to Chatham to avail themselves of it.

Plates XXX to XXXIII.

The arrangement of the observatory, and most of the details of its construction, will be seen from the accompanying plans, sections, &c., which have been drawn from measurement since the completion of the building, by Serjeant March, of the Royal Sappers and Miners. The site selected for it is the same as that occupied by the wooden huts before mentioned; it is about 100 yards to the north-east of the north-east angle of the north gun-shed of Brompton barracks, being a part of the space between and close to the junction of the two roads leading respectively from Prince's Hard, and St. Mary's guard-room, to Brompton. As all engineer officers must be well acquainted with the locality, they will be able to understand its situation from this description. The altitude of the floor of the building above the average high water of the Medway is 104 feet; the distance from the river about 900 yards. The distance from the barracks is not inconvenient. The meridian is clear to the north to within 30 minutes of the horizon, and in this direction a meridian mark might be erected at a distance of about 2½ miles: to the south the meridian is clear to within two degrees, and by cutting down a few more trees it can be cleared to within one degree, if any particular object should ever render it desirable. The soil is a very strong gravel, and it will be seen by the plans that a good depth has been given to the foundations, and that the pillars for the instruments have broad bases. The material is brick in cement below the ground, half cement half sand being used above. Hoop-iron bond was introduced under the large dome above the bressummer: the roofs of the calculating and transit rooms, and the large dome, are covered with zinc, the small dome with painted canvass; the shutters to the openings through the roofs are also covered with canvass to avoid weight. The arrangement of the large dome is shown in Plate XXX.; four balls carry it: before the wood-work was covered it turned easily by the pressure of the hand, but since the zinc covering has added to its weight, some force is required; it is not, however, generally necessary to use a lever, but two are attached to the wall to assist its motion. The small dome turns very easily.

If the roads to Prince's Hard and St. Mary's were thoroughfares of any importance, their proximity would be very inconvenient; but after tattoo it is very seldom that any thing passes to create a greater disturbance than the field-officer of the day going his rounds. His passing, however, is sufficient to destroy the reflection of a star when the mercury rests on the pier under the small dome; and the passage of a waggon, such as those occasionally employed taking straw to the straw-yard behind the gun-shed, occasions a perceptible vibration in the clock pier: the former of these piers is about 17, the latter 26 feet, from the nearest part of the road.

In the interior arrangements, the only particulars requiring to be pointed out are, that the clock can be seen, either direct, or by reflection from a looking-glass attached at pleasure on either side of the clock-face, in every position of an observer at the equatorial, or by an observer on either side of the transit pier: that the upper half of the door between the instrument and the calculating room being glazed, permits the clock to be seen by a person sitting at the table and before the fire in the latter apartment: that the spaces on each side of the fire-place afford convenient places for cupboards for the books and smaller instruments: that the irregular space to the right of the porch, on entering, affords a cupboard for the lamps, oil, &c.; and an opening through the wall in this part permits access to the space below the floors: this opening is seen in elevation to the left of the equatorial pier in Plate XXXI. Lastly, a cupboard is formed in the thick part of the wall, near the letter *d* in Plate XXXII., in which eye-pieces, turnscrews, sweet oil, &c., are kept.

Since the only object of the observatory is to afford opportunities for practising the use of portable instruments, the observations are not likely to possess any general interest; yet as supplying tests of the relative value of different modes of determining latitude, longitude, time, and azimuth, with portable instruments, they may afford fit subjects for future Papers. The officers of the corps may probably, however, feel an interest in hearing what instruments the building contains.

The transit instrument is one of Troughton and Simms's 2½-feet instruments, with iron stand. A bright star of the first magnitude, as (α) Lyræ, may be observed with it within about an hour of noon; and from a single observation of a star near the equator, time may apparently be found with it within about a quarter of a second of the truth, the errors of adjustment being known and allowed for. It is intended to observe the moon, and moon-culminating stars, as often as possible; and if any of our officers at foreign stations have opportunities of observing the moon's transits (to Hong Kong an instrument has been supplied), they will probably be able to obtain some corresponding observations by applying to Chatham. It can hardly be necessary to say that where an instrument is available, they may thus render valuable assistance to geography, by fixing more accurately than has yet been done, another point on the earth's surface.

The altitude and azimuth instrument is also by Messrs. Troughton and Simms; it is one of those described in their catalogue as a 12-inch instrument, both circles being of that diameter. The azimuth circle is read by four verniers, the vertical by two microscopes. It stands on a repeating tripod. It has been used for determining latitude by meridional observations, and also as a transit instrument to practise the method of obtaining latitude by observations on the prime vertical. Its position when in use is under the eastern or small dome.

The telescope of the equatorial is by T. Jones, of Charing Cross; its focal length is 44 inches, its aperture 2¾ inches; it is furnished with eye-pieces of different powers from 37 to 120, and with a spider's-line micrometer. It was mounted on its present pier by Messrs. Simms.

The only real observations made with it have been of a few of the eclipses of Jupiter's satellites. Occultations have been looked for, but none recorded.

The observatory also contains an 18-inch repeating circle of Borda's construction, the work of Messrs. Simms, and presented to it by the Court of Directors of the Hon. East India Company. General Pasley was requested by them to choose an instrument, and after much consideration decided, that considering the objects of the observatory, variety in its instruments was of much importance, and that our officers ought not to be unacquainted with an instrument so generally used on the continent as the repeating circle. When in use it occupies the pier under the eastern or small dome, the altitude and azimuth instrument being then removed. Very satisfactory observations for latitude can be obtained with it: of three consecutive observations made by Captain Howorth, R. E., after a very brief acquaintance with the instrument, the results were,

25th Oct.	4 circum-meridian zenith distances of Fomalhaut	51°	23′	35·7″
,,	,, ,, ,, ,, (γ) Cephei	51	23	35·5
26th	,, ,, ,, ,, Polaris	51	23	42·5

the mean of which is believed to be within half a second of the truth.

In addition to the foregoing there are two 6-inch sextants, with stands; a reflecting repeating circle of 4 inches radius, made by Dolland; and a reflecting circle of Troughton's construction, of 5½ inches radius; a chronometer regulated to mean time; a clock to sidereal time. The clock lent by the Astronomical Society was returned in November last, being replaced by one purchased for the observatory from Messrs. Molyneux, and which, judging from the six months' trial it has had, appears to be a very good instrument.

Fig. 1.

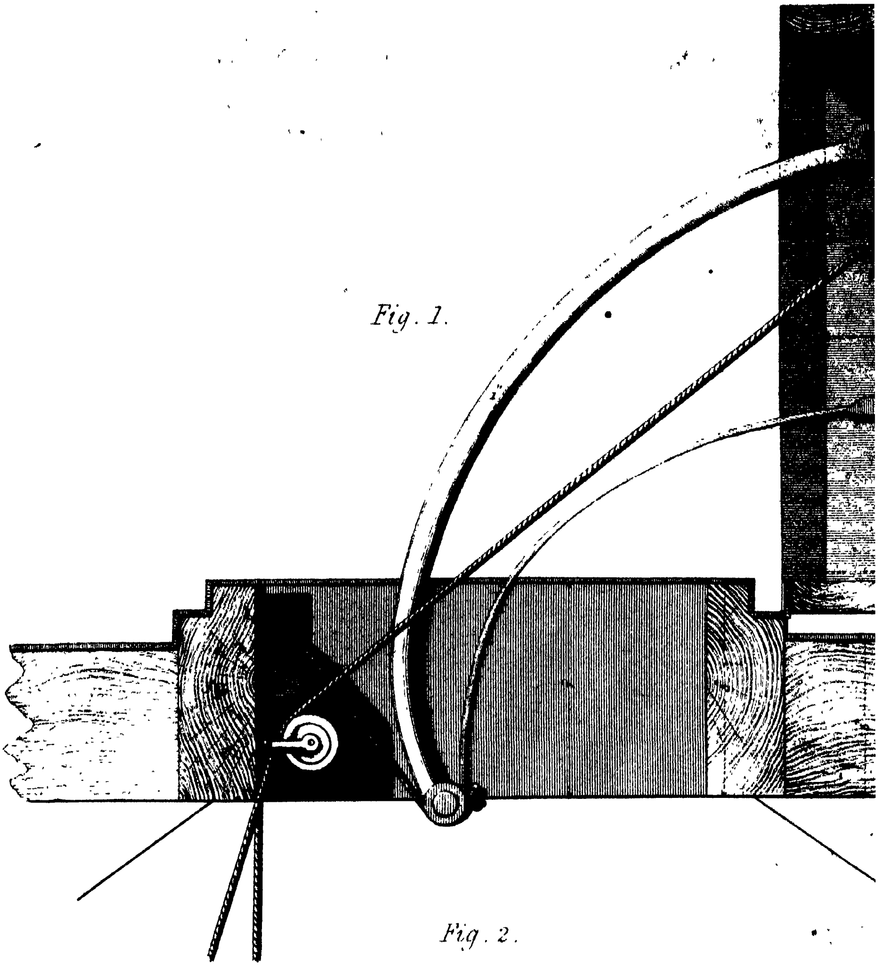
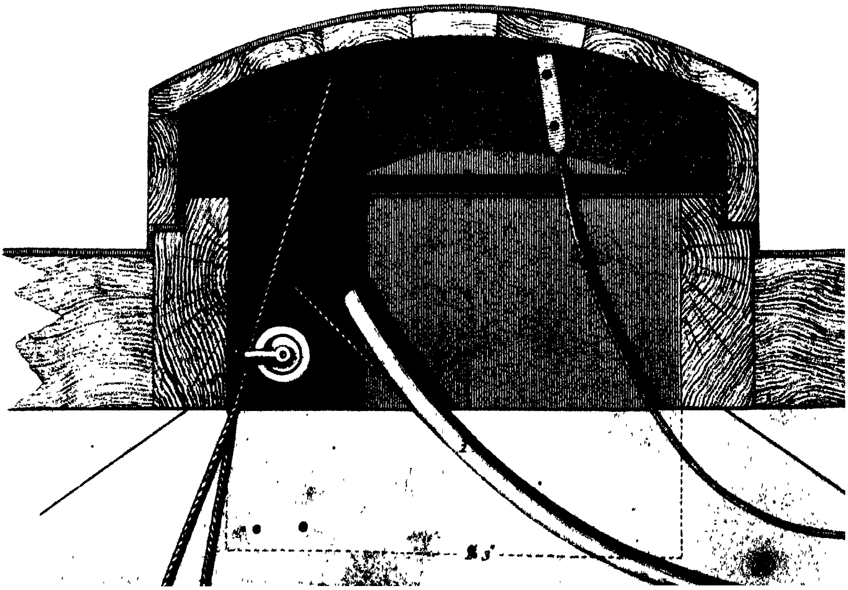


Fig. 2.



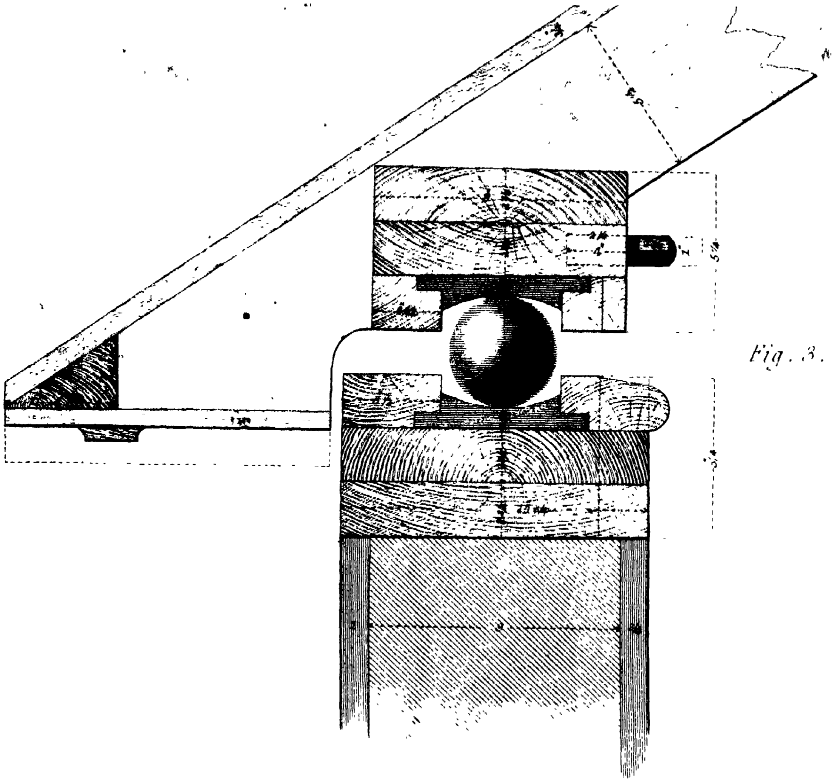


Fig. 3.

Fig. — 1 — Is a section through the top of the Dome — Open

„ — — 2 .... do .... do — .. Shut

Fig. — 3..... Shews the construction of the lower part of the dome, and how it is supported upon the walls four balls are used M. is one of the oak pins which are placed at intervals of 6 2 inches round the dome, for a laver to work against in turning it round.

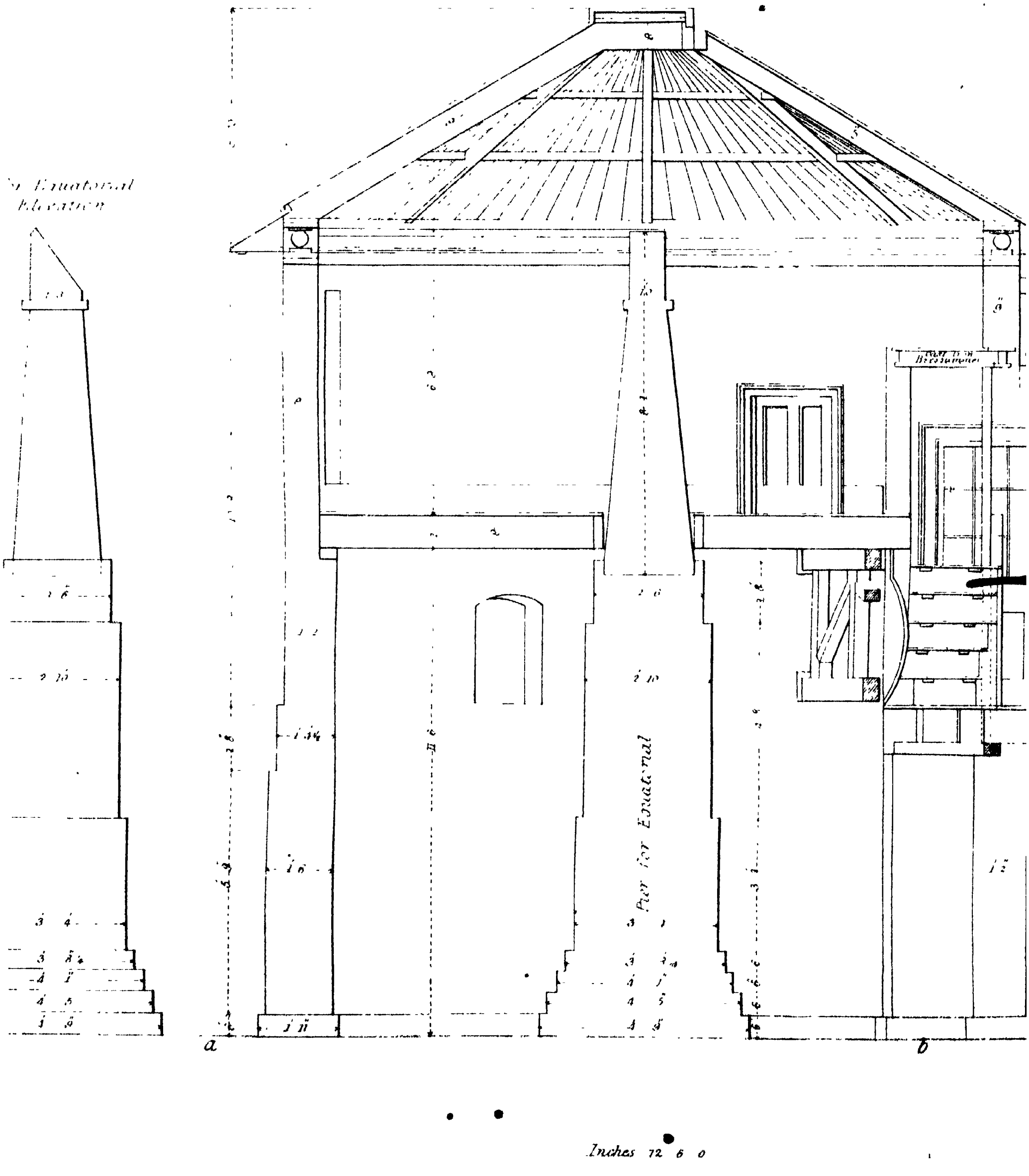
Scale of Figs. 1. 2. & 3.

3 0 1 Foot

ROYAL ENGINE

Section c

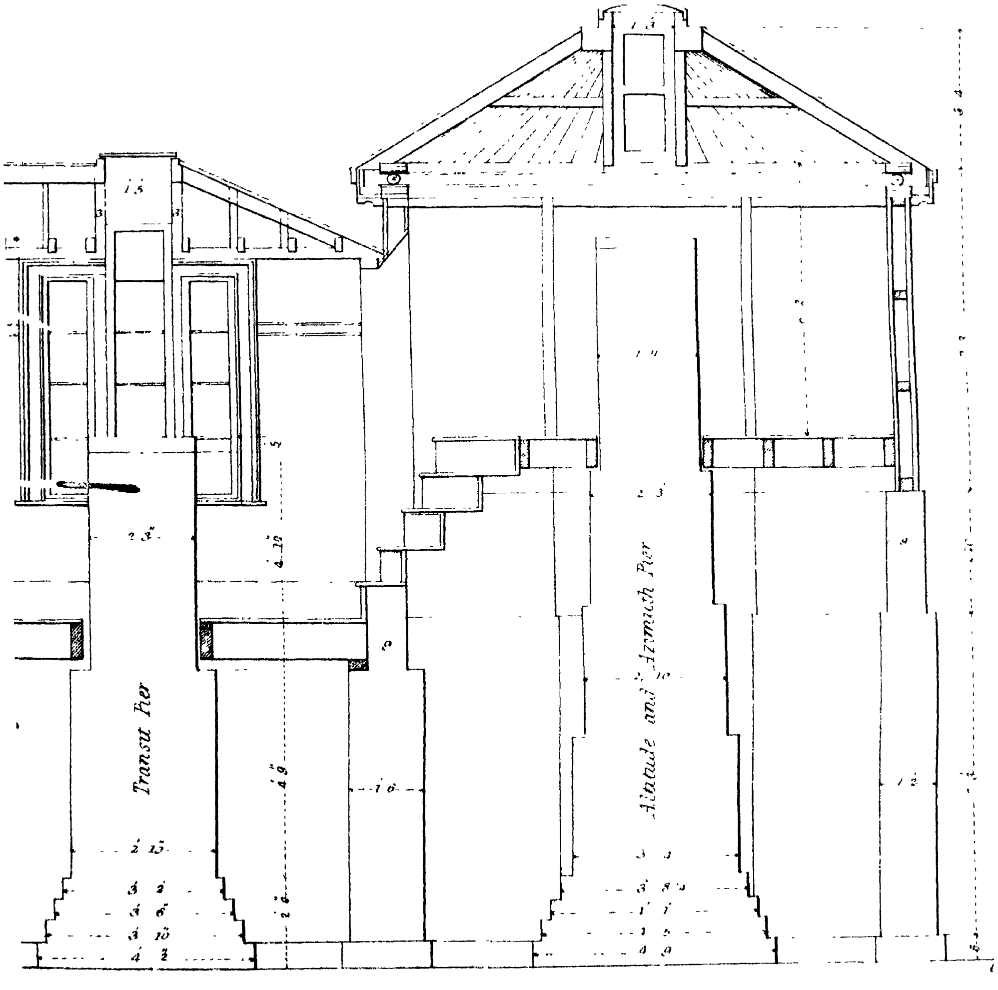
Through the Equatoria

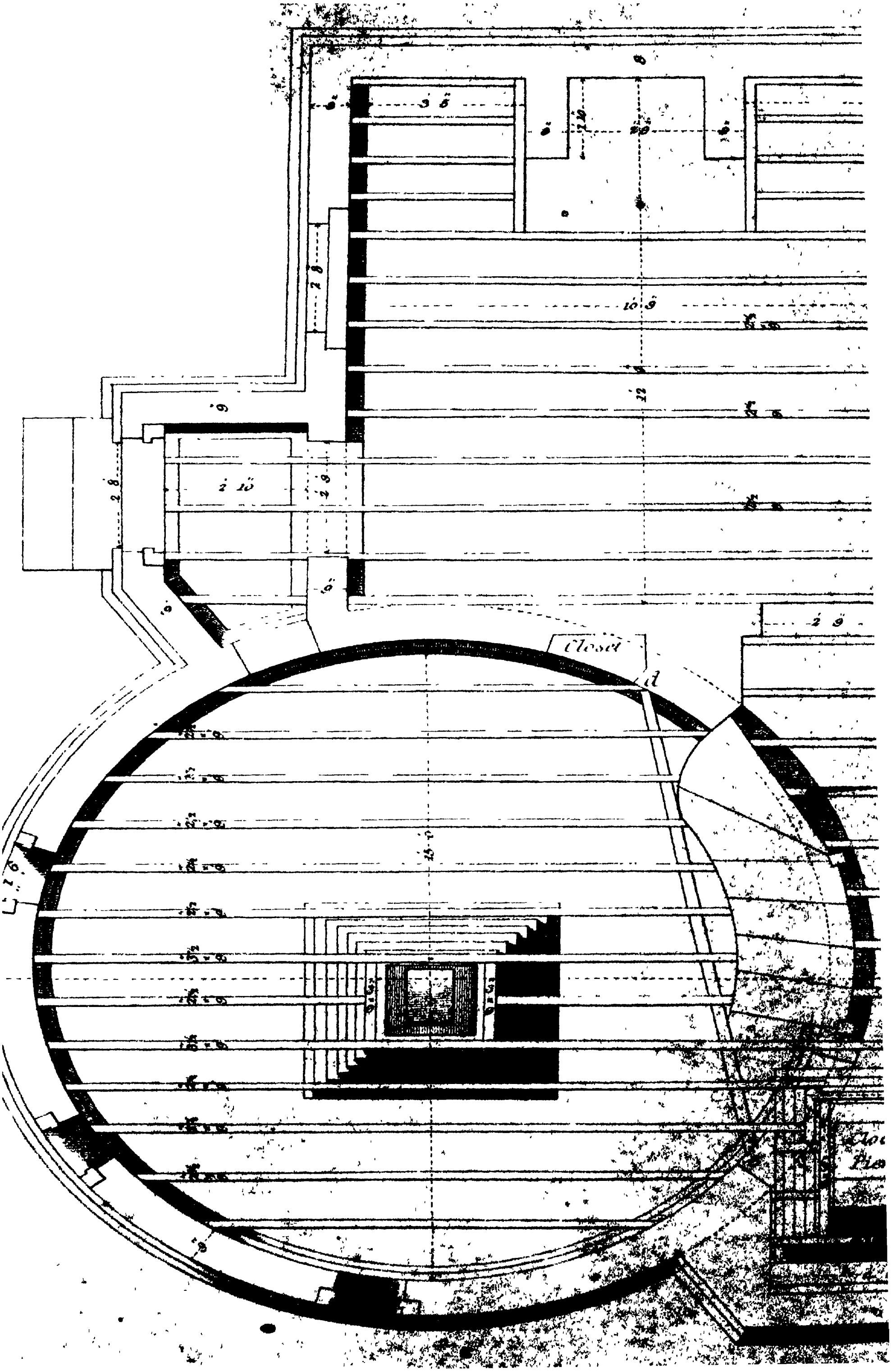


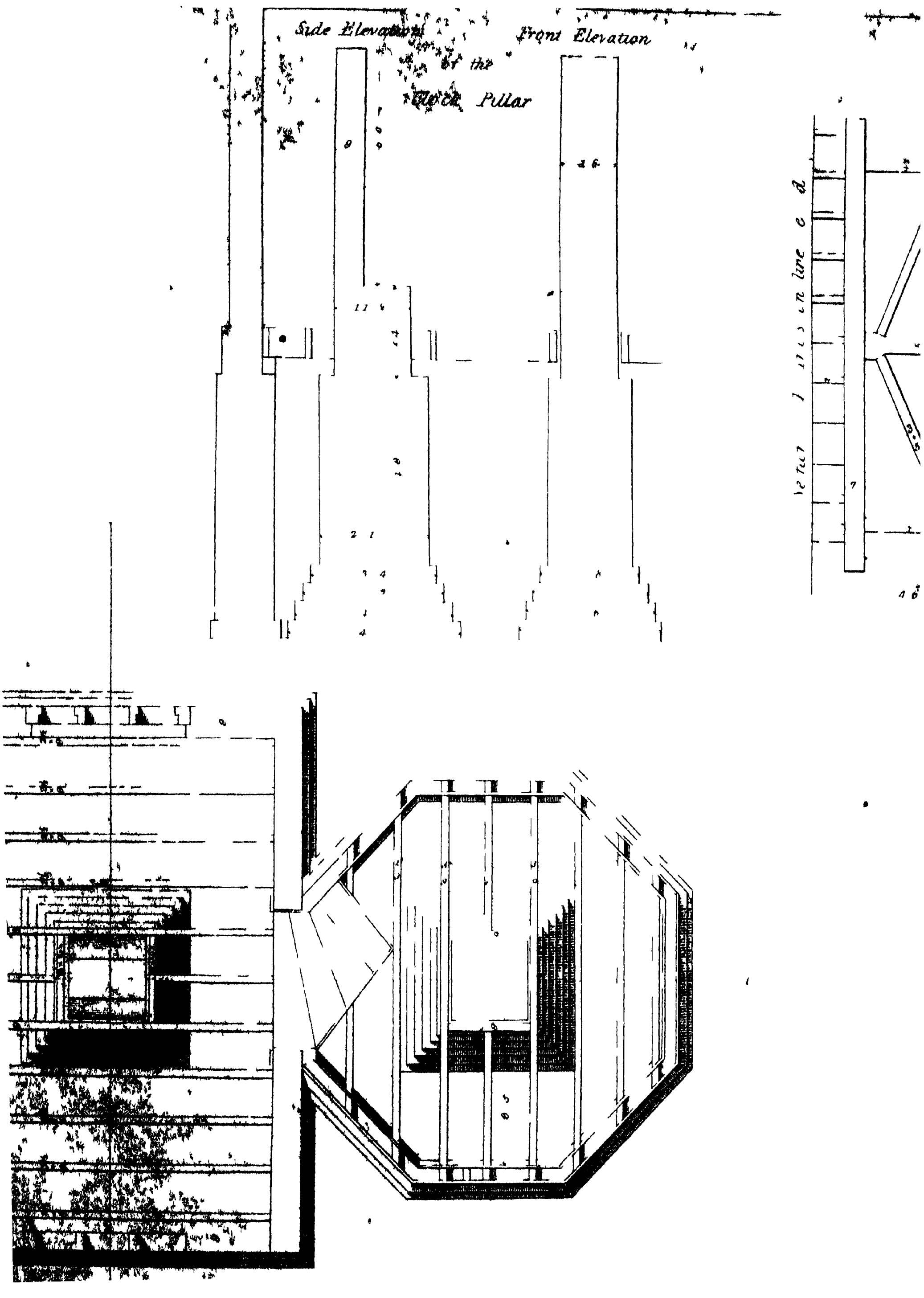
VATORY, CHATHAM.

B. C Plate I.

ltitude and Azimuth Rooms.

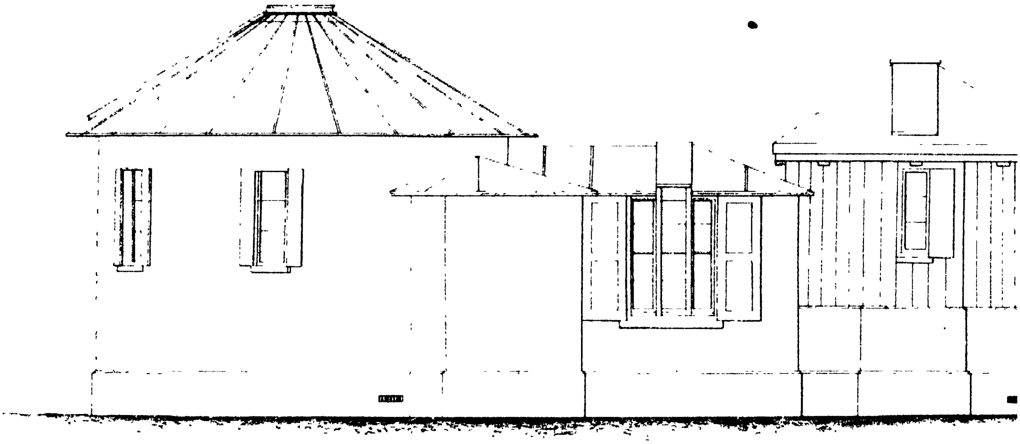



Closet
d
3 6
2 10
10 9
12
2 8
9
2 10
2 8
2 9
1 6
25 7

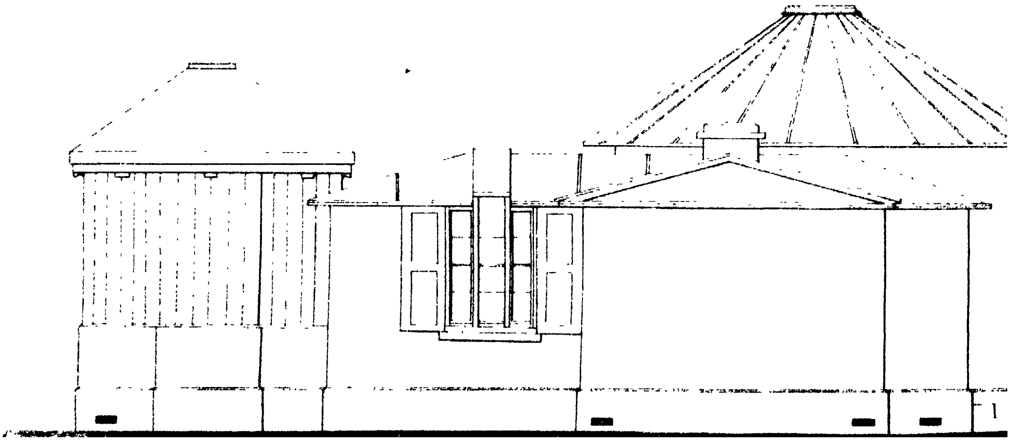

Side Elevation
Front Elevation
of the
Clock Pillar
Section in line c d

ROYAL ENGIN

South Front.

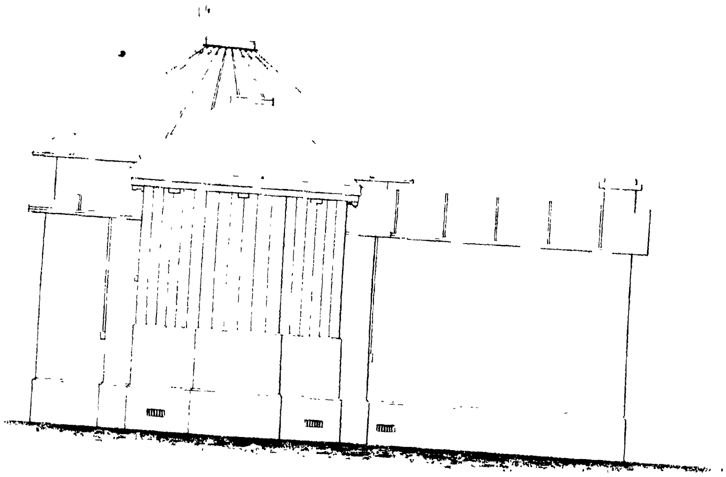


North Front

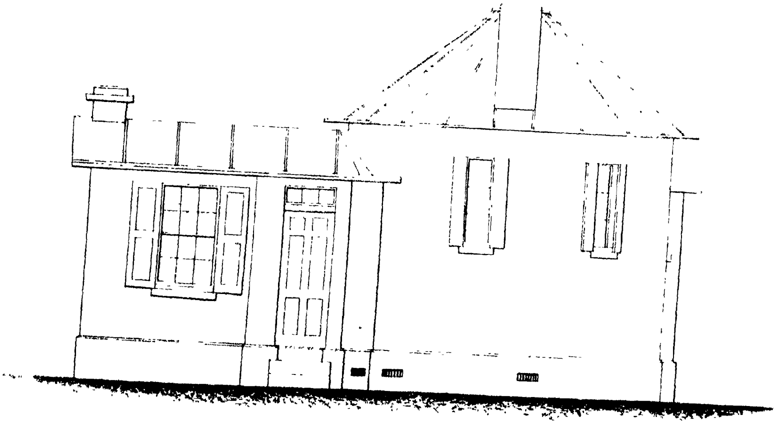


RVATORY, CHATHAM.

East Front



West Front



XI.—*Experiments* carried on at Chatham by the late Lieutenant Hope, Royal Engineers, on the Pressure of Earth against Revetments, and the best Form of Retaining Walls.*

Soon after Lieutenant Hope joined the Royal Engineers' establishment, Lieutenant-Colonel Sir Frederick Smith, its director, considering it desirable that experiments on retaining walls should be made, and that no better exercise could be given to a young engineer than the direction of experiments on an intricate question, ordered Lieutenant Hope, in addition to the ordinary exercises of the establishment, to give his attention to the subject, and propose a series of experiments. This order was fully obeyed by Lieutenant Hope; he gave the attention of a powerful and ingenious mind to its theory, and suggested experiments which were made exactly as he proposed them; and although, as many of the results can now only be collected from rough memoranda and unfinished documents, they will be comparatively valueless, yet they may, even in their present shape, serve at least as a memorial of the exertions this young officer made in the profession he had chosen, and to connect his name permanently with our corps; and while those who knew him are regretting the friend they have lost, this brief account of his experiments may enable those who did not know him to regret the early death of a brother officer of so much ability.

Lieutenant Hope considered that the action of the earth should be the subject of separate experiments, for that no correct opinion respecting it could be arrived at from experiments in which the strength of the wall is concerned. At the same time, however, that he carried on experiments upon the action of the earth, he also caused brick walls of different forms to be built in succession, on the same site; and that these experiments might be advantageously used in comparison with results obtained from models (such as those by Major-General Pasley), in which the extreme case of a perfectly rigid revetment is assumed, he only laid the bricks in wet sand, assuming thereby the opposite extreme of a revetment composed of small parts connected only by their friction. Among his notes the following additional reasons are given for not employing mortar or cement:

"1st. That if mortar were used, the experiments would be affected by the difference in the quality of the mortar, and also by the time that the walls were allowed to stand before they were backed with earth. 2nd. By not employing mortar, the resistance to the pressure of the earth, which is opposed by the weight of the wall, is separated from that which is the effect of the cohesion of the mortar. 3rd. The same bricks might be used over again, without sustaining the loss of time and material which takes place in cleaning them, and consequently the experiments might be conducted on a larger scale than if mortar were used."

With respect to the experiments with walls, the information left is nearly complete; but with reference to those for ascertaining the action of the earth, which were fully as interesting, the memoranda are imperfect. When Lieutenant Hope left Chatham, it was his intention to arrange these experiments during the leave of absence allowed to him before going to Gibraltar;[1] and although he was unable to do this, they ought to be first described, because they were always considered by him as preliminary to those with brick-work. The following are his notes on this part of the subject:

"Before entering upon the question of which form of revetment will resist the pressure of the earth behind it with the least quantity of masonry; the nature of the pressure of the earth, and the manner of its action, must be considered. Various theories have been brought forward from time to time, in order to solve this problem; some extremely absurd, while others show much ingenuity and refinement.

"M. Mayniel, a French officer of Engineers, in his 'Traité sur la Poussée des Terres,' has collected into one volume the researches, theoretical and practical, of the different French authors up to his own time (1808); and has likewise given a report of his own experiments at Juliers. But the only theory worthy of consideration is that of M. Coulomb, and that has the fault of being too analytical, it being impossible to follow clearly with the mind the various steps of his investigations. The experiments at Juliers were carried on with great care, and, as far as they went, may be considered to have given consistent and satisfactory results.

---

[1] Lieutenant Hope left Chatham on the 10th February, 1844, and died at his mother's house, near Edinburgh, on the 24th March, 1844.

" In conducting a course of experiments to determine the nature of the pressure of earth on retaining walls, I should first endeavour to divest the problem of all the complications with which in ordinary practice it is surrounded; as the cohesion of the soil,—the effect produced on it by moisture,—the irregularities in the mass, some particles being much larger than others,—the weight of the wall,—the resistance of the foundation, &c., &c.

" By employing very fine sand, perfectly dry, the first three difficulties are overcome; and by the arrangement of the apparatus supporting the plane to be acted on, others are obviated.

" As the apparatus will afterwards be described in detail, let us first consider what are the objects to be effected by it.

" It appears necessary to determine,—

" 1st. The amount of pressure produced on the vertical plane by the action of the sand behind it.

" 2nd. The direction with reference to the horizontal in which this force is exerted.

" 3rd. The different effects produced at different depths below the surface, observing whether the direction of the force, as well as its magnitude, vary with the depth.

" 4th. The quantity and form of the mass of earth which exerts pressure on the wall.

" 5th. The manner in which this mass acts, whether as a whole solid, or as an infinite number of separate particles.

" When these subjects have been investigated, I should propose to vary the conditions; proceeding step by step, so as to arrive, if possible, at last, at a general result which may be applicable in practice."

Lieutenant Hope proposed with the above objects to make various experiments with fine dry sand; then similar experiments with shingle; and lastly, with earth of considerable tenacity. He also proposed "to try the effect produced by clay, to dry it until it cracked, and then to pour water upon it."

The experiments were confined, for want of time, to sand and gravel. The following will convey a general idea of the apparatus employed.

A box was made, of which the first of the annexed diagrams is an isometrical sketch, and the second a longitudinal section. The interior length from *a* to *b*, fig. 2, or from the back to the suspended board against which the earth acted, was 2 feet, the depth and breadth 1 foot, so that the board presented 1 square foot to the pressure of the sand or gravel contained in the box.

Fig. 1.

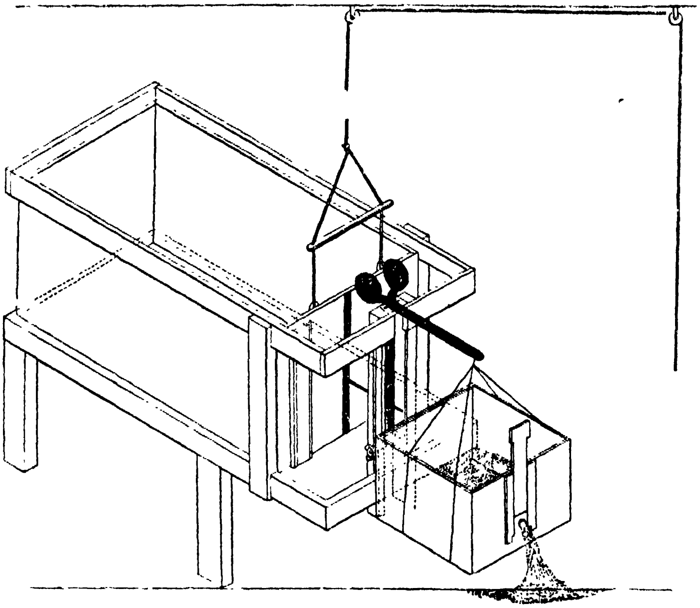
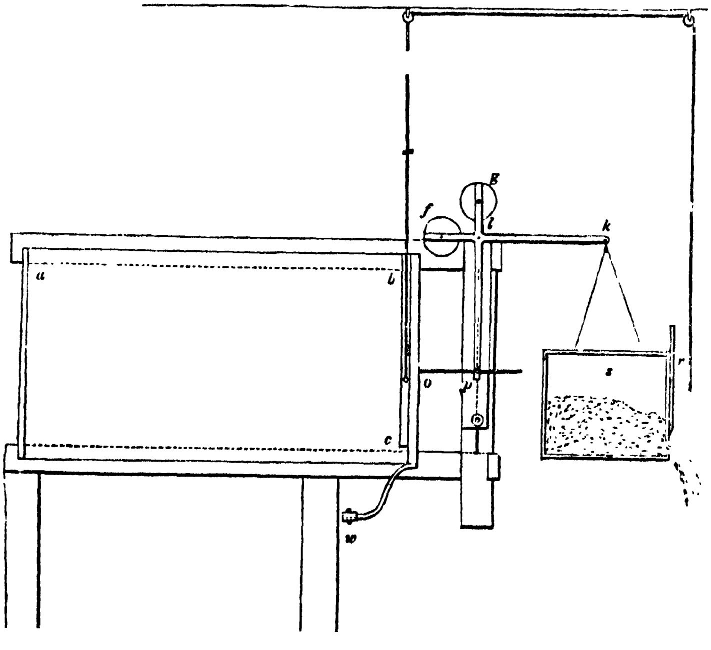


Fig. 2.



The board, *b c*, of which fig. 3 gives a separate view, was suspended by a cord from the ceiling, and, after passing over two pulleys, was connected with a counterpoising box of sand, like *s* in fig. 2: the cords being attached to the back of the board, a bent lever with a weight *w*, adjustable by a screw, was attached to the bottom, and the board was always so adjusted by this weight as not to rest in either direction against the cords. The horizontal pressure of the earth against the board was opposed by the box of sand acting by the bent lever *k l p*, having its fulcrum at *l*, on the horizontal rod *o p*, pressing against the board at *o*; *f* being a counterpoise to *l k*, and *g* a counterpoise to *l p o*. The side pieces, to which the axis *l* was attached, could be raised or lowered, so as to vary the position of the point where *o p* acted against the board, and thereby afford means for determining the position of the centre of pressure of the earth employed. The weight of the box *s*, and of the sand remaining in it, when a forward motion took place, afforded a measure of the horizontal thrust: the weight of the box mentioned above as attached to the suspending cord, gave, in a similar way, the vertical pressure. In both cases the experiments were made by letting the sand run from the box, as shown by the diagram, until motion occurred, when the slide *r* was pushed down.

FIG. 3.

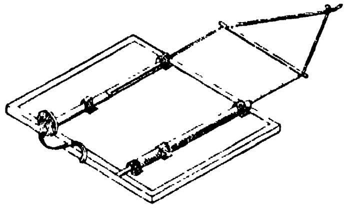
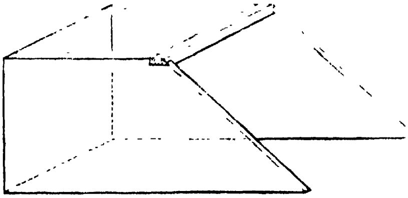


FIG. 4.



To increase the depth of the box, a piece shown in fig. 4 was made capable of being added to the top. To ascertain by experiment the depth of the prism of earth in action against the wall, a sliding board was made that could be inserted, as shown in fig. 5, at different inclinations, to reduce the earth to the quantity contained between it and the suspended board: the surface of this board was rendered similar to a surface of the earth employed, by adding cross-cleats to retain a layer of the earth. And because in reasoning on the subject, Lieutenant Hope found it difficult to conceive the actual motion which took place in the particles behind a wall, when any motion occurred in the wall itself, and considered experiments which would show their motion important in endeavouring to ascertain their relative action, he substituted a plate of glass for one of the sides of the box, and another for the suspended board, ruling both with vertical and horizontal lines, as shown in fig. 6: he then caused the box to be filled with layers of different coloured sands, equal in thickness to the space between the lines on the glass; and on moving the front plate of glass by a screw, *t*, very small quantities at a time, he was enabled to trace on paper, ruled like the glass, the successive changes in the coloured layers of sand: in these experiments the breadth and height were reduced to 8 inches.

Fig. 5.

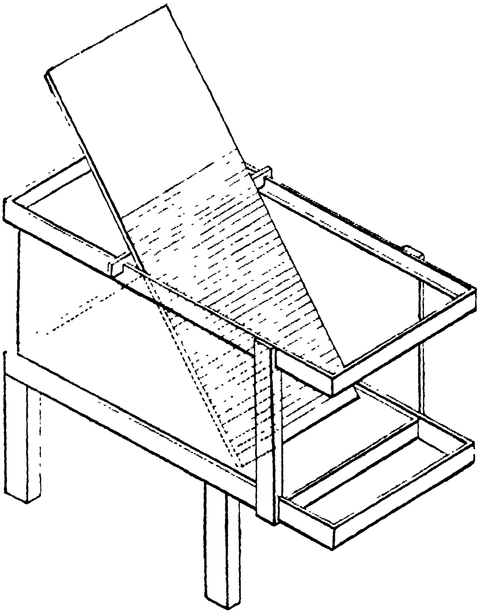
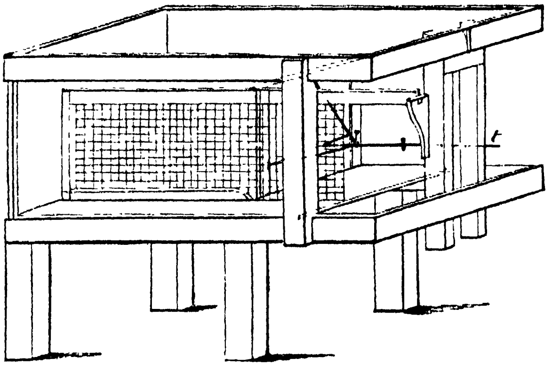


Fig. 6.



In the first application of the above apparatus dry yellow sand was employed, the weight of a cubic foot of which, when lightly thrown together, was 91 lbs.; when shaken together, 98½ lbs. And the first object was to ascertain the vertical and horizontal forces exerted on the back of the suspended board, the arrangement being that shown in figs. 1 and 2, but the back of the moveable board being smooth. The horizontal force was found, by two experiments, to be about 10 lbs.; the vertical force was not determined, but shown to be considerably less than 2 lbs.

The back of the board was then roughened, and a mean of seven experiments, the sand being on a level with the top of the board, gave for the horizontal force 9 lbs. 7 oz., and for the vertical force 4 lbs. 13 oz.

The piece shown in fig. 4 being added, and the sand heaped up at its natural slope, 1 foot above the top of the board, a mean of four experiments gave for the horizontal force 13 lbs. 1½ oz., and for the vertical force 6 lbs. 1 oz. The natural slope appears to have been about 35¼°, or to have had a base of 17 inches for 1 foot of height.

There was much greater difficulty in determining the vertical force than the horizontal; and it was remarked, that the line of separation on the top of the sand, in the first experiments, or before the additional height of sand was employed, was 7½ inches distant from the back of the board, whereas the bisection of the angle formed between the natural slope and the vertical gave a distance of 6⅕ inches.[2]

The centre of pressure against the board was found to be as nearly as possible at one-third of its height from the bottom.

When a moveable board was introduced, as shown in fig. 5, the horizontal force was not materially affected until the base of the prism was reduced to 2 inches, its height being 12 inches. The results were as follows:

	inches.		lbs.	oz.			
Base of prism,	7¾	. . Horizontal force,	9	0½	. . Mean of	4	experiments.
,, ,,	6⅕	,, ,,	9	4	,,	4	,,
,, ,,	4	,, ,,	9	0½	,,	1	,,
,, ,,	3	,, ,,	8	2¼	,,	2	,,
,, ,,	2	,, ,,	8	2	,,	1	,,
,, ,,	1	,, ,,	5	5½	,,	2	,,
,, ,,	½	,, ,,	3	0	,,	1	,,

---

[2] This remark was made with reference to the result obtained from Coulomb's analysis, viz., that the line of separation bisects the angle between the natural slope and the back of the wall.

These experiments were repeated with gravel of which the weight of a cubic foot was 95½ lbs., and the natural slope 37°, or requiring a base of 16 inches for a height of 12 inches.

Base of prism.	Horizontal force producing First movement.		Horizontal force producing Final movement.		No. of experiments.
inches.	lbs.	oz.	lbs.	oz.	
8	9	3	6	12	7
6	9	14¼	7	8¼	7
4	8	14	7	5⅕	7
2	6	3⅓	5	12	7
1	4	6	4	3	7

Lieutenant Hope considered the great proportional pressure exerted when the base of the prism was very much reduced to be in a great degree owing to the friction against the sides of the box being a less proportional part of the whole pressure of the smaller than of the larger prisms; and he made this a subject of investigation.[3] The results obtained from the experiments with

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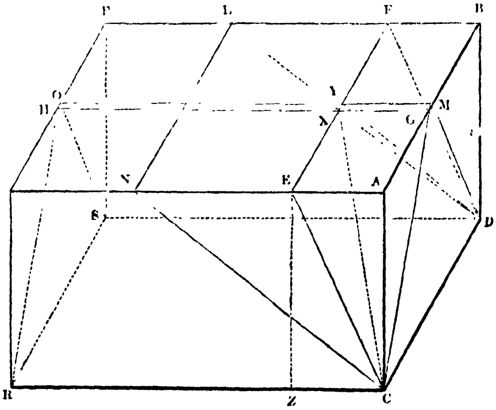
[3] The following extract from Lieutenant Hope's memoranda explains his mode of estimating the friction.

"To determine the amount and effect of the friction:



"Let A B C D P Q R S be the box full of gravel, of which the side A B C D is moveable, and let N L C D be the natural slope of the gravel, or, in other words, the slope it would assume if the moveable side A B C D were removed, and it were allowed to run out.

"Let E F C D be the plane of maximum thrust, which is found to bisect the angle N C A.

"Take A G = A E, draw G H parallel to A Q.

"The angle A C G will be equal to the angle A C E = ½ A C N.

"Therefore as E F C D A B is the prism of maximum thrust against A B C D, so is G H C R A Q against A Q R C.

"The pressure of the last-mentioned prism against A Q R C will cause friction upon that plane which will prevent the prism E F C D A B from sliding down the plane E F C D. But only so much of that prism G H C R A Q as presses upon the surface A E C can retard the motion of the prism E F C D A B. The pyramid C A G X E, which is cut off from the prism C H G R A Q by the plane E F C D, will be all that presses upon A E C.

gravel corrected for the effect of the friction against the sides of the box were compared by him with the calculated horizontal pressures, as follows:

		lbs.	oz.		lbs.	oz.
"When no board is used, or when base of prism exceeds 12 inches	Horizontal pressure,	9	3			
	Friction, by theory,	3	6			
		12	9	Theoretical pressure,	12	8
Base of prism, 4 inches.	Experiment,	8	13			
	Friction,	2	4			
		11	1	Theoretical pressure,	11	$0\frac{1}{2}$
,, ,, 2 ,,	Experiment,	6	$3\frac{1}{3}$			
	Friction,	1	2			
		7	$5\frac{1}{3}$	,, ,,	7	$5\frac{1}{4}$
,, ,, 1 ,,	Experiment,	4	6			
	Friction,	,,	7			
		4	13	,, ,,	4	$12\frac{4}{5}$

"This pyramid is supported upon the two equal and equally inclined planes C G X and C E X, and therefore half its weight may be considered to be borne by each.

"The same is taking place at the other side by the pressure of the pyramid D B M Y F against the plane D F B. Therefore the motion of the prism E F C D A B down the plane E F C D is retarded by the friction on the plane on which it slides, and by the friction of the two pyramids C A X G E and B D M Y F upon the planes A E C and B F D; but as both these pyramids only act with half their weight, the friction of the gravel against the sides of the box may be considered to be caused by the pressure of one square pyramid which slides down the plane of maximum thrust, the height of which pyramid is the height of the box, and its base formed by a square, the side of which is equal to the base of the slope of maximum thrust.

"In order to find the friction on A E C it is necessary to know the weight of the pyramid C A G X E, the content of which must be first ascertained.

Content of C A G X E $=$ area of A G X E $\times \frac{1}{3}$ C A.

,, ,, $=$ A G $\times$ A E $\times \frac{1}{3}$ C A.

,, ,, $=$ base of inclined board $\times$ base of plane of maximum thrust $\times \frac{1}{3}$ height of box.

"To find the friction generally:

"If i denote the bases of the plane at which the moveable board forms the incline in inches,

m, the bases of the plane of maximum thrust in inches,

s, the weight of a cubic foot of gravel in lbs.,

h, the height of the box in inches,

It cannot be clearly traced how the quantities set down above as "friction by theory," and "theoretical pressure," were obtained: those under the former head do not exactly agree with the results which would be obtained from the formula at the end of the investigation in the note; and that formula must only be considered to afford an approximate value of the friction, as the investigation does not appear to be quite correct. It is given as an additional proof of the attention Lieutenant Hope gave to the subject. If the account of these experiments had been prepared by himself, the consideration they would then have received from him would certainly have removed all errors and discrepancies.

Content of pyramid $= i\,\frac{m\,h}{3}$, of which $\frac{m\,h}{3}$ is constant.

Weight of ditto in ℔s. $= i\,\frac{m\,h}{3} \times \frac{s}{1728}$,

If $s = 96$ ℔s.

Weight of pyramid $= i\,\frac{m\,h}{3} \times \frac{96}{1728} = i\,\frac{m\,h}{54}$.

"But the pressure of the pyramid upon A E C is equal to its weight multiplied by the tangent of the angle of maximum thrust.

Pressure = weight × tan A C G = weight × $\frac{m}{h}$.

$\quad ,, \quad = i\,\frac{mh}{54} \times \frac{m}{h} = \frac{im^2}{54}$.

"The friction caused by this pressure resists the motion of the prism E F C D A B down the plane E F C D, and will be equal to a greater force applied horizontally.

"To find the horizontal effect:

"Let f be the effect of the friction in the direction C E,

f × sec A E C will be ,, ,, A E

$= f$ cosec A C E

cosec A C E = cosec 26° 34′ = 2·236.

"Therefore the effect of the friction on the horizontal thrust $= f \times 2{\cdot}236$.

"But the co-efficient of the friction = tang 23° = ·4245,

"Friction of pyramid $= \frac{im^2}{54} \times$ tang $23^\circ = i \times \frac{36}{54} \times {\cdot}4245 = i \times {\cdot}283$,

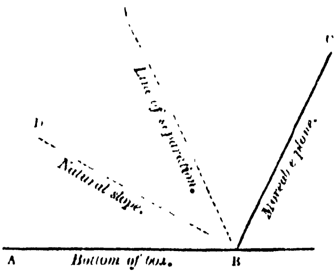
"And horizontal effect will be $i \times {\cdot}283 \times 2{\cdot}236 = i \times {\cdot}6328$.

"The co-efficient of friction was found by filling a box, 9 inches × 4½ in. × 3 inches, with gravel, and inverting it on a smooth board, the gravel alone touching the board, and raising the latter until the board slid down it.

"The mean of four experiments across the grain of the wood gave the angle of friction 22°, the mean of four with the grain 24°."

The experiments made with layers of coloured sand behind a glass in the apparatus shown by fig. 6, do not appear to confirm the result of Coulomb's theory, viz., that the angle of the prism of maximum thrust is half that contained between the natural slope and the back of the wall. Those who witnessed these experiments were much pleased by the very clear exhibition afforded of the portion of sand acting against the moveable plane, and the very decided line of rupture which appeared through the several layers of sand when a little motion was given to the front plane. Memoranda, principally in pencil, remain of the following twenty experiments. The natural slope of the sand by a mean of ten observations appeared to be 34°. The line of separation was sometimes quite straight, but more frequently a little hollowed, or rather more inclined at the upper than at the lower part.

Inclination of Moveable plane—Line of separation.				No. of experiments.
ABC	ABE	DBC	DBE	
°	°	°	°	
45	42½	11	8½	1
54	45	20	11	1
63	52¼	29	18¼	2
64	56	30	22	1
71	58	37	24	4
76	61	42	27	1
77½	65½	43½	31½	1
78½	64½	44½	30½	1
80	66	46	33	1
90	66	56	32	3
114	74	80	40	1
116	69	82	35	1
120	75	86	41	1
129	85	95	51	1



With respect to the experiments with brick walls, Lieutenant Hope wrote as follows:

"The experiments recorded in the following pages were undertaken with a view to determine the relative strength of the different forms that are usually given to revetments. In the experiments that were formerly made upon the subject at this establishment, small wooden models, for the most part 26 inches in height, behind which gravel was piled up to a certain height, were used to represent the various revetments.

It cannot be clearly traced how the quantities set down above as "friction by eory," and "theoretical pressure," were obtained: those under the former ead do not exactly agree with the results which would be obtained from the rmula at the end of the investigation in the note; and that formula must ly be considered to afford an approximate value of the friction, as the vestigation does not appear to be quite correct. It is given as an additional oof of the attention Lieutenant Hope gave to the subject. If the account of ese experiments had been prepared by himself, the consideration they would en have received from him would certainly have removed all errors and screpancies.

Content of pyramid $= i\,\frac{m\,h}{3}$, of which $\frac{m\,h}{3}$ is constant.

Weight of ditto in ℔s. $= i\,\frac{m\,h}{3} \times \frac{s}{1728}$,

If $s = 96$ ℔s.

Weight of pyramid $= i\,\frac{m\,h}{3} \times \frac{96}{1728} = i\,\frac{m\,h}{54}$.

"But the pressure of the pyramid upon A E C is equal to its weight multiplied by the tangent of e angle of maximum thrust.

Pressure = weight × tan A C G = weight × $\frac{m}{h}$.

,, $= i\,\frac{mh}{54} \times \frac{m}{h} = \frac{im^2}{54}$.

"The friction caused by this pressure resists the motion of the prism E F C D A B down the plane F C D, and will be equal to a greater force applied horizontally.

"To find the horizontal effect:

"Let f be the effect of the friction in the direction C E,

$f \times$ sec A E C will be ,, ,, A E

$= f$ cosec A C E

cosec A C E = cosec 26° 34′ = 2·236.

"Therefore the effect of the friction on the horizontal thrust $= f \times 2{\cdot}236$.

"But the co-efficient of the friction = tang 23° = ·4245,

"Friction of pyramid $= \frac{im^2}{54} \times \tan 23° = i \times \frac{36}{54} \times {\cdot}4245 = i \times {\cdot}283$,

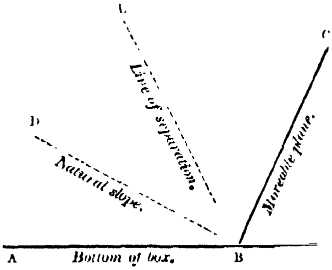
"And horizontal effect will be $i \times {\cdot}283 \times 2{\cdot}236 = i \times {\cdot}6328$.

"The co-efficient of friction was found by filling a box, 9 inches × 4½ in. × 3 inches, with gravel, and inverting it on a smooth board, the gravel alone touching the board, and raising the latter until the board slid down it.

"The mean of four experiments across the grain of the wood gave the angle of friction 22°, the mean of four with the grain 24°."

The experiments made with layers of coloured sand behind a glass in the apparatus shown by fig. 6, do not appear to confirm the result of Coulomb's theory, viz., that the angle of the prism of maximum thrust is half that contained between the natural slope and the back of the wall. Those who witnessed these experiments were much pleased by the very clear exhibition afforded of the portion of sand acting against the moveable plane, and the very decided line of rupture which appeared through the several layers of sand when a little motion was given to the front plane. Memoranda, principally in pencil, remain of the following twenty experiments. The natural slope of the sand by a mean of ten observations appeared to be 34°. The line of separation was sometimes quite straight, but more frequently a little hollowed, or rather more inclined at the upper than at the lower part.

Inclination of Moveable plane—Line of separation.				No. of experiments.
ABC	ABE	DBC	DBE	
°	°	°	°	
45	42½	11	8½	1
54	45	20	11	1
63	52¼	29	18¼	2
64	56	30	22	1
71	58	37	24	4
76	61	42	27	1
77½	65½	43½	31½	1
78½	64½	44½	30½	1
80	66	46	33	1
90	66	56	32	3
114	74	80	40	1
116	69	82	35	1
120	75	86	41	1
129	85	95	51	1



With respect to the experiments with brick walls, Lieutenant Hope wrote as follows:

" The experiments recorded in the following pages were undertaken with a view to determine the relative strength of the different forms that are usually given to revetments. In the experiments that were formerly made upon the subject at this establishment, small wooden models, for the most part 26 inches in height, behind which gravel was piled up to a certain height, were used to represent the various revetments.

" The comparative merits of the forms represented by these models were determined by their stability: this stability was measured by the weight in pounds, which, when applied in a horizontal direction to the tops of the models, was necessary to overset them. The results of the experiments on these small models were afterwards confirmed by trials with larger ones, 8 feet 8 inches in height. The whole course of experiments was very complete; the results exhibited little discordance, and the conclusions which were derived from them have been safely followed.

" Still, as there were doubts as to the correctness of some of the principles upon which these experiments were based and conducted, it did not seem superfluous to try a series of experiments with real walls.

" In the experiments with models, it was taken for granted that the wall was one solid mass, which, when it was unable to support the pressure of the earth behind it, would turn over on its foot, remaining perfectly rigid, while its centre of gravity rose and described an arc of a circle of which the foot of the wall was the centre. The counterforts being fastened on to the walls with iron bolts, precluded the possibility of any separation taking place; and thus insured a degree of solidity which no large mass of masonry could possess.

" The criterion by which the strength of the models was tested, was not the amount of stability which they possessed when so thin as to be nearly overturning by the pressure of the shingle behind them, but the stability which they possessed when so thick that the effect of the pressure of the shingle, instead of making their stability less than that which they possessed when no shingle was in rear of them, had, on the contrary, the effect of increasing it.

" If a wall be so thick that the pressure of the earth behind it has no effect in diminishing its stability, it matters very little what form is given to it, so far as the support of the earth is concerned. But if a wall of any given height, built in a certain form, is perfectly capable of supporting the earth behind it, as well as all the additional weight that may be casually thrown upon it; and a wall of another form must have a considerably greater thickness to be able to support the same; the first wall has a positive advantage over the second, and its form should only be rejected if it is exposed to some serious disadvantage, to counteract which will entail a greater expense than the difference in price between the material and labour in the two walls.

" This is the state of the case between the leaning and counter-sloping retaining walls, at least such is shown by the experiments lately tried at this establishment; and the only other point to be considered is whether the expense which it is said must ultimately be incurred in pointing the exterior face of the leaning, will amount to the loss of labour and materials by adopting the counter-sloping form.

" Those revetments which are exposed to the fire of artillery, and are consequently liable to be breached, must necessarily be made much thicker than the mere support of the ramparts, &c., require; and therefore there can be no doubt that of the two forms in this case, the counter-sloping is to be preferred.

" But in counterscarp and gorge revetments which cannot be attacked by artillery, no greater thickness should be given than is necessary for the support of the earth behind, and for incidental weights passing over it. If the miners of an attacking army have reached the back of a counterscarp, it matters very little whether they have 4 or 8 feet of masonry to cut through; if the counterscarp is to be blown in, the difference of thickness is of still less consequence. It is therefore certainly of great importance to diminish the expense of the construction of all the counterscarp and gorge walls of a fortress, by adopting the most economical form.

" If the case be viewed in this light, the value of the different forms of revetments have, with the experiments with models, been estimated by a false criterion; and therefore, while no one would think that the profiles which have been recommended on the strength of those results are in any instance too weak, still it is reasonable to suppose that they may, in many cases, be too strong."

The first wall was commenced on the 14th of October, 1843. It was 20 feet 6 inches in length, and its section was rectangular, the back and front being vertical; the thickness 1 foot 11 inches, or 2½ bricks. On the 7th of November it had attained a height of 8 feet 3 inches, and was backed with earth to a height of 8 feet 2 inches, but was observed to have inclined from the perpendicular about 1½ inch.

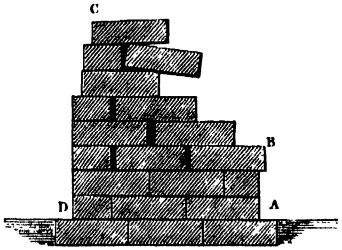
About half-past 3 in the afternoon of the 9th of November, the height of the wall and of the backing of earth being 10 feet, it turned over and fell in one mass. The following measurements of the deviation from the perpendicular were taken about an hour and a half before it fell.

Height from foundation. feet.	Deviation from perpendicular. East end. inches.	Centre. inches.	West end. inches.
1	0	0	0
2	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{1}{2}$
3	1	$1\frac{1}{4}$	1
4	$1\frac{3}{8}$	$1\frac{7}{8}$	$1\frac{3}{8}$
5	$1\frac{3}{4}$	$2\frac{1}{8}$	$1\frac{3}{4}$
6	$2\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{1}{4}$
7	$2\frac{5}{8}$	3	$2\frac{1}{2}$
8	3	3	3
9	$3\frac{1}{4}$	$3\frac{1}{4}$	$3\frac{1}{4}$

The distance of the top of the slope of earth formed after the fall of the wall, from the back of the wall, varied from $3\frac{2}{3}$ to $5\frac{2}{3}$ feet; the average of eight measurements giving 4 feet 9 inches.

" The annexed sketch shows that the whole wall was not thrown down by the pressure of the earth behind it, but that the bottom was prevented from rising and turning over the point A by the friction on the back C D. If mortar had been used in the construction of the wall, its stability would have been much increased by the cohesion on the surface B C. If the cohesion of the mortar were very great, the whole of the bottom of the wall, as well as its foundation, would be lifted up, and would fall over along with the wall. The height of the line of rupture B C, above the bottom of the foundation, would depend upon the strength of the mortar used. In no instance is it likely to be so high as in the sketch.

Sketch of the east end of the wall after it was thrown down.



" The second wall was built for the purpose of discovering whether additional strength is gained by reducing the thickness of a wall and throwing the material thus saved into counterforts: half a brick was taken from the thickness of the last wall, and thrown into counterforts; these were placed at central intervals of 10 feet, and were 2 feet 3 inches in thickness, and 1 foot 11 inches in length.

" The counterforts at the ends should properly only have been half the thickness of the centre one, as there was no wall beyond them; but as there was a danger of their being forced out laterally if made so thin, a breadth of 1 foot 6 inches was given to them."

This wall was commenced on the 12th of November. On the 25th, when it had attained a height of 8 feet 3 inches, it was observed after heavy rain to have bulged between the counterforts about 1¼ inch.

" 14th December.—The wall had reached a height of 12 feet 10 inches, had inclined from the perpendicular about 7½ inches, and had bulged between the counterforts about 4½ inches. At about a quarter before three o'clock it separated from the west counterfort, and moved forward about 1 inch. A fissure was visible between the wall and the centre counterfort; the eastern end remained steady. The wall continued to move forward gradually, and at ten minutes past three fell down. It separated first at the west counterfort, and fell over in one mass, except a slight break at the centre. The centre counterfort fell a second or two after the wall; the west one, a second or two after the centre; the east one remained standing.

" This experiment shows that additional strength is gained by using some of the material for counterforts; for this wall, which had the same number of bricks in each course that the first had, reached a height of 12 feet 10 inches, while the first fell at 10 feet. The fact of the counterforts falling after the wall proves that they strengthened it materially by tying it back; when mortar is used, how much must their effect be increased. After the fall of the wall, the counterforts became themselves small revetments of nearly the same thickness as the wall, and consequently equally unable to sustain the pressure of the earth behind them."

On the 10th of December a leaning revetment was commenced, of the same dimensions as the last; the inclination ⅕th of the height; the object being to determine the advantages gained by the inclination.

" A slope of ⅕th was selected, being that which Vauban gave to the exterior face of his walls, and also that which has been laid down by many engineers as the greatest batter that should be given to the faces of walls, on account of the moss and other vegetable matter which are certain to take root and grow on the surface, if it incline much from the vertical, and which, it is said, destroy the face of the masonry, and occasion a great expense for pointing.

" On the 27th of January, 1843, the wall had attained a height of 11 feet 3 inches, and was observed to have bulged about ⅓rd of an inch in each of the intervals between the counterforts. On the 16th of March the height was 14 feet 6 inches, and the west counterfort separated from the wall about half an inch. On the 3rd of May the height was 20 feet 6 inches; and on the 5th, nothing having been done to the work in the interval, the bulge between the east and the centre counterfort was found to be 2¾ inches; between the centre and the west counterfort, 1¾ inch; at the centre counterfort, 1 inch. It was greatest between 6 and 9 feet from the foot of the wall.

"When this wall had reached a height of 21 feet 2 inches, it was determined not to carry it higher. The labour of wheeling earth to the top was very great, and it was impossible to retain the sides of the bank behind it at any steep slope; the sod-work with which they were revetted came down four times, and was built up each time with a greater base. Chesses were finally used, which were kept in their places by baulks lashed by cables to a strong post in the centre.

"After two days' heavy rain (the 23rd and 24th of August), the ropes confining the baulks were broken, and the sides of the bank fell down. The bulge between the counterforts had not visibly increased for the last two months, and there seemed no symptoms of the revetment being about to give way.

"The bulge between the counterforts was 2½ inches at about 8½ feet from the bottom of the wall; in front of each counterfort, at the same height, the bulge was 1½ inch; so that the wall between the counterforts bellied out about 1 inch at that height.

"It is very probable that this wall would have stood for years without giving way any more; for where no mortar was necessary at first, none would be required afterwards, and therefore moss, &c., might be allowed to grow on the face without any fear of injuring the cohesion of the mass. Whether the roots of shrubs, insinuating themselves and growing among the joints of the brick-work, might succeed in forcing out whole bricks, is another question.

"Three walls had now been built of different forms, having each the areas of their horizontal sections equal, or, in other words, having the same number of bricks in each course. The results had been as follows:

The rectangular wall	without counterforts,	height 10 feet	0 inches,	fell.
Do.	with do.	„ 12 „	10	„	do.
Leaning wall	with do.	„ 21 „	6	„	stood.

"To confirm these results, two walls were built similar to the two last, but only half their size. Experiments were not made with larger walls, because the labour and materials required would be more than the establishment could supply."

On the 12th of September, an upright rectangular wall with counterforts was commenced. Length 10 feet 9 inches; thickness 9 inches; centre counterfort 1 foot 1½ inch square; end counterforts 9 inches wide, and 1 foot 1½ inch long. The intervals, from centre to centre of the counterforts, were therefore 5 feet; and the clear intervals, 4 feet ¾ inch. On the morning of the 15th of September, the height being 5 feet, it was observed to have inclined over ⅓rd of an inch during the night. On the 3rd of October, the height being 8 feet 6 inches, it had bulged slightly about 2½ feet from the bottom. On the 4th of October, the height being 9½ feet, "it was observed about half-past eleven to be giving way; it continued moving gradually until ten minutes after one, then advanced more rapidly from the earth in rear of it, and about a quarter after one the whole fell forward. The average height of the earth in rear was 6 inches less than the height to which the wall had been carried."

The leaning revetment was commenced on the 15th of September. Its length was 11 feet 1½ inch; thickness 9 inches; each of the three counterforts was 1 foot 1½ inch square; the central intervals therefore were 5 feet, and the clear intervals 3 feet 10½ inches. On the 25th of September, the height being 12 feet 6 inches, the wall bulged about ¾ths of an inch from the inclined line of the face, and bellied between the counterforts about ⅓rd of an inch. On the 3rd of October the height was 14 feet 6 inches, and the wall had a bulge beginning about 2½ feet from the ground, and extending to about 7 feet. In the middle of this interval, or about 4 feet 9 inches above the foot of the wall, the deviation from the original face was found to be half an inch at each counterfort, and an inch between the counterforts. On the 4th of October, the wall having attained a height of 16½ feet, "a crack about ⅛th of an inch in width extended from a height of 2 feet to 11 feet above the ground, and at a horizontal distance of 2½ feet from the left counterfort.

"The right half of the wall fell at three o'clock the same afternoon, having first separated into two portions; the outside quarter fell completely to the right, and the other straight to the front. The left half fell about twenty minutes after four; the outside quarter fell completely to the left, and the other straight to the front; the large rent before observed in this half having previously widened."

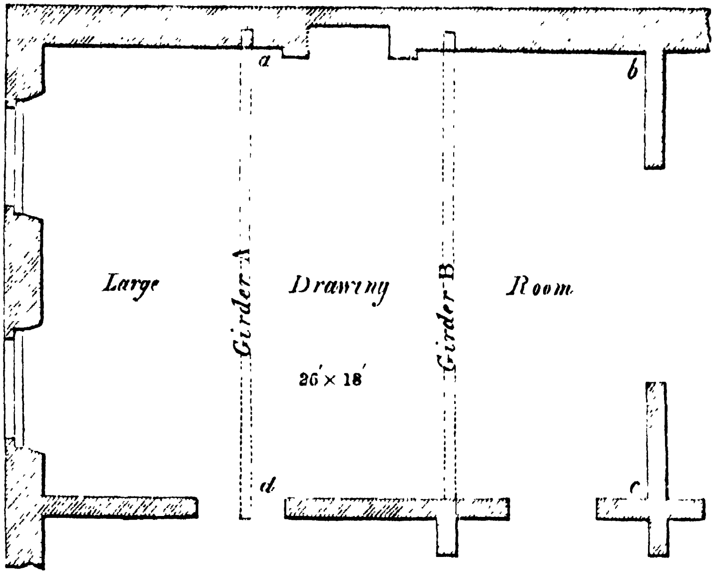
A counter-sloping revetment was next built, 22 feet 3 inches in length, 4½ feet thick at bottom, and diminished by steps at the back of half a brick each, so as to be equivalent to a counter-slope of one-fifth: the three counterforts were parallel to the back of the wall, and their length was 1 foot 11 inches, their width 2 feet 3 inches, and their central intervals as in the second and third experiments.

This wall was commenced on the 3rd of October, 1843, and on the 6th of December, when it had reached a height of 10 feet, it was observed to overhang 1½ inch at the centre, and ¾ths of an inch at the ends. On the 23rd of January, the height being 15 feet, it overhung opposite the left counterfort 2½ inches, opposite the centre 3 inches, and opposite the right 3 inches; between the centre and the right counterfort it bellied outwards a little, overhanging the base about 3¼ inches. There is no further record of this experiment. It is well remembered that the fall of this wall was daily expected, but it did not take place. At the height to which it was carried, the quantity of material in the wall was nearly double that in the first leaning revetment when of equal height, and nearly four times that in the second, which reached a height of 16½ feet.

The papers from which these memoranda have been compiled do not contain any concluding observations on the results, but end abruptly with the condition of the counter-sloping revetment when its height was 15 feet. The opinion expressed by Lieutenant Hope in conversation was in favour of leaning revetments with narrow counterforts at short intervals, and the experiments appear to justify that opinion. He wished to continue them with a view to determine an arrangement by which the material used might be reduced to the smallest possible quantity; and he conceived that the face of the revetment might be a mere shell, hardly exposed to any pressure, the earth being chiefly supported by its friction against the sides of thin but frequent counterforts. Had he completed a series of experiments with this object, he would probably have arrived at some modification of the counter-arched revetment which could be advantageously adopted as an economical construction in civil works.

XII.—*Account of the Failure of a Floor in Edinburgh, in* 1833.

By Lieut.-Col. THOMSON, *R. E.*



As more instructive lessons are obtained from failures than even from successful operations, I am induced to bring forward an account of the failure of a floor which took place in March, 1833, attended by loss of life to one individual, and serious wounds and bruises to many others.

Above is a plan of the room in Piccardy Place, Edinburgh, in which the sale of pictures belonging to the late Lord Eldin took place, the floor of which gave way when crowded with persons attending the sale. *a*, *b*, *c*, *d*, represents the area which fell in when loaded with people, measuring $17' \times 18' = 306$ feet superficial. Supposed weight 15,680 ℔s., that is, 80 people at 14 stone each, giving a load of 51 ℔s. ℘ foot superficial.

On examining the floor after the accident, the cause of the misfortune was evidently the faulty construction of the floor. The builder had made use of a coarse-grained timber for the two girders A and B. The scantlings of these were only 6″ × 12″ each. The girder B had several large knots in it, at one of which, in the centre, it gave way. An attempt had been made to strengthen it *by bolting pieces of old oak to one side of it, but they were not long enough to reach from end to end of the beam, but consisted of two lengths, which met in the middle, where the girder failed.*

The room below the drawing-room, viz., the library, is 16 feet high; and, notwithstanding that from 70 to 80 persons fell in when the floor gave way, only one was killed. Many, however, were wounded more or less. The room having been carpeted, and the carpet nailed down, was a fortunate circumstance, for it caused the floor to hold together, and to form inclined planes, by which the people slid down rather than fell, so that they hurt each other by their weight, and the weight of the forms, &c., which fell amongst them.

If the depth of the girder were fixed (as it was in this case) at 12″, the breadth ought to have been 13″ instead of 6″ for a span of 18 feet, but 15″ × 7″ or 14″ × 8″ would have been better proportions, with a smaller consumption of material, giving a somewhat greater depth of floor; but this could have been of no consequence, seeing that the room below had an ample height.

Floors should be constructed strong enough to carry a weight equal to 160 ℔s. ꝑ foot superficial, and this floor failed under a load of 51 ℔s. ꝑ foot superficial, as before stated; showing, in a strong point of view, the great importance due to the subject, not only as regards the scantlings, but the quality of the timber employed for such purposes.

ROBERT THOMSON,
Lieut.-Col. Commanding R. E., Ionian Islands.

Corfu, 30th June, 1843.

XIII.—*Report on the Construction of an Iron Beacon at the Harbour of Black Rock, Connecticut.*

(Extracted from the Appendix to the Report furnished by the Topographical Branch of the United States' Engineers to Congress.)

Washington, October 20, 1843.

Sir,

I have the honour to state that the iron beacon at the harbour of Black Rock, Connecticut, is completed, and I submit herewith a Report upon the same.

The harbour of Black Rock lies about 18 miles westward of New Haven; it is accessible at extreme low water for vessels drawing 10 feet, and at high water it may be entered by vessels drawing from 16 to 18 feet. As a harbour of refuge, it is more resorted to, perhaps, than any other on the Sound, the depth of water being sufficient in all cases for that class of vessels which are usually employed in the navigation of this great thoroughfare.

In 1829 a beacon of stone was built at this place, under the orders of the Treasury Department, at a cost of about $6000: this beacon was entirely destroyed by a gale of wind in less than one month after it was erected. In the year 1835 it was rebuilt, at an expense of nearly $9000; in the spring of 1836 it was injured by a gale of wind so seriously that in all probability it would have been entirely demolished by the recurrence of the first heavy gale; it was then repaired, with a guarantee from the contractor that he would maintain the beacon in its position for a period of five years; this was effected at a cost to the United States of $6500. One year after the expiration of this guarantee (in 1842) the beacon was again so much injured by a gale of wind, that the whole structure must have fallen, had not the long stone of which the upper part of the beacon was constructed been held together in place by the wooden spar or mast which was used for supporting the cask; the stones were laid around this spar, and it served to prevent them from separating from each other. Thus it will be seen, that within a period of 12 years, three stone beacons have been destroyed at this place, and that the cost to the United States has been upwards of $21,000.

In March, 1843, an appropriation of $10,000 having been made by Congress for rebuilding the Black Rock beacon, the Secretary of the Treasury, as you are aware, applied to the Secretary of War to allow this beacon to be constructed under the direction of the Chief Topographical Engineer; by your orders this work was intrusted to my superintendence, and I have the honour at this time to submit a detailed description of the same.

The beacon stands one mile and a half south of the entrance to the harbour, and is exposed to all winds from east-north-east around by the south to west-south-west; from the east it is entirely open to the rake of the sea for a distance of 60 miles.

When the first beacon was built, in 1829, a large quantity of rubble stone was carried in vessels to the proposed site, and then thrown into the water around a single rock called the 'Old Huncher,' and upon which there had been an iron spindle in former years. This rock was conical in shape, about four feet in diameter at top, and bare at very low water; upon this loose stone, thus deposited, the superstructure was reared, and, when the beacon was overthrown, the materials of which it was composed were of course added to the rubble stone bed, and they in turn became the foundation for the beacon of 1835.

In the examination which I made of the site in June, preparatory to making the final plan for the iron-work, I ascertained that the stone below low water had, apparently, remained unmoved for a long time; and I subsequently found, by inquiring of Captain Wilson, the contractor who had repaired the beacon in 1836, and who had maintained it in repair for five years, that such was the fact, while, as he stated, and it was evidently true, the stones between low water and high water were thrown about by the force of the sea in every gale. This was fully exemplified, too, by the appearance which the injured part of the old beacon presented. The base in that part below low water was entirely undisturbed, the breach being between high and low water mark; all the stones below low water remain, as stated by Captain Wilson, as they were when the beacon was repaired in 1835.

There being no stone of sufficient size at the old beacon into which the iron shafts of the new structure could be secured, I found it necessary to procure elsewhere such as were suitable for the purpose, and to transport them to the site, and imbed them below the line of low water, in order that the sea might not disturb them after they should be laid.

Description of the Stone Foundation.—The beacon, according to the general plan which I had made and submitted to you on the 20th April last, was to be elevated 36 feet; and for this height I decided to give the iron shafts a spread or base of 16 feet, with an inclination towards the centre of about one to six. In order that there should be sufficient strength in the stone to resist any tendency there might be to fracture at the holes which were to receive the feet of the shafts, I adopted the dimension of 20 feet as a suitable diameter for the stone bed designed for the shafts to be secured to: this dimension gave a distance of about 2½ feet from the centre of the shaft holes to the edge of the stone at top, while at the bottom of the stone, where the strain is less, it would be two feet. The bed, then, is composed of six pieces of hammered granite, 2½ feet thick; the middle stone is round, and is 8 feet in diameter; the five outer stones are 6 feet wide by about 12 feet in length, each stone weighing nearly 12 tons; the stones are cramped and dowelled together with 1½-inch round copper, two at each joint, the cramps 2 feet long, and the dowels 10 and 12 inches long. The excavation, which was made in what may be called the artificial island, (for at low water an extent of 105 feet from east to west, and 88 feet from north to south, is exposed,) for the reception of the stone bed, is a few feet north-west from the old beacon; it was 26 feet in diameter, and 3 feet below *ordinary* low water. When the excavation was completed, a layer of concrete, composed of five parts of hydraulic lime to eight parts of sand, was spread over the bottom of the pit, by means of a trough of wood, for the foundation-stone to rest upon. After the stones were laid, which was effected by means of a heavy pair of shears and a 'lewis,' the unoccupied space in the pit, around the outside of the stone bed, was filled with concrete and rubble stone, flush with the top of the foundation-stone. As it was only at or near low water that this part of the work could be carried on, that is to say, ordinarily about 3 hours per day, in good weather, considerable time was necessarily consumed in getting in the foundation. From the day the shears were erected to the day the stone-work was completed, was just five weeks.

Description of the Iron-work.—The figure of the beacon is that of a truncated pyramid. It is formed by six wrought iron shafts, five of them 36 feet 7 inches in length, standing in the periphery of a circle of 16 feet diameter, and one, 36 feet long, at the centre. The outer shafts incline towards the middle, in such proportion as to fall at the top within the circumference of a circle of 3 feet diameter. Each of these shafts is composed of two pieces of equal length. The diameter at foot of the lower piece is 5¼ inches, and at top 4 inches. The diameter of the upper piece is 4 inches at foot and 3 inches at top. They are united by a cast iron socket of 3 feet in length, 2½ inches thick at the joint of the shafts, which is at the middle of the socket, 2 inches thick at the top and bottom, and 1 inch thick elsewhere. The top of the lower shaft is made concave, and the bottom of the upper shaft convex, fitting one into the other. At the distance of 1 foot from the joint of the shafts, a steel key, 2 inches deep by ¾ of an inch wide, passes through the socket and each shaft, to secure them together. The sockets inside, and 18 inches of the ends of the shafts, are turned and accurately fitted to each other. At a distance of 2½ feet from the foot of the lower shafts are four shoulders, 1 foot long, and projecting at the lower extremity 1 inch from the shafts, to form points of support for the same at the surface of the foundation-stone. Above and below the joints of the shafts, and at distances of 9 feet and 18 feet, respectively, above the top of the stone, are two sets of braces, extending from the middle shaft to each outer shaft, and from one outer shaft to another, making ten in each set. These braces are of wrought iron, 2½ inches square. The extremities are secured by 1¼-inch screw bolts to cast iron collars. These collars are strengthened by two wrought iron bands, and are firmly attached to the shafts by steel keys. The space between the collar and shaft, and between the keys, is filled with zinc. The braces are secured to the collars in such a manner that they serve for ties in case of any unforeseen strain acting from the interior of the beacon, such as might possibly be occasioned by ice or any other floating body.

The tops of the shafts are provided with shoulders, to support a cast iron cap, composed of five arms, each 3 feet in length and 4 inches in width, strengthened by a rib or flange of 3½ inches in depth. The shafts pass through this cap 18 inches from the centre of it, and are there keyed in place. A wrought iron band, 3 inches wide and 1½ inch thick, is shrunk upon the extremities of these arms, to add to its strength. From the ends of the arms of the cap, 3 feet from the centre, braces of 2-inch round iron descend 4½ feet to the main shafts, and are there secured by screw bolts passing through their extremities, and through the shafts also. At this junction of the braces with the shafts, a wrought iron band, similar to that which encircles the cast iron cap, is fitted and bolted. At a distance of 4½ feet, again, below this second band, is a third band, similar to the two others, and similarly secured by screw bolts through the shafts; finally, there are ten panels or gratings, 4½ feet long, corresponding in shape and dimension with the spaces found between the shafts and the wrought iron bands. These gratings are made of boiler iron $\frac{3}{16}$ths of an inch thick, with eight horizontal and three vertical slats or bars, 3 inches wide, riveted together. The horizontal slats are 3 inches apart; but, at the distance of 500 yards, the top of the beacon presents the appearance of an opaque body, 9½ feet long by 6 feet wide at the top and bottom, and 4½ feet wide midway of the same.

The feet of the iron shafts penetrate the stone foundation 2½ feet, and are secured in their places by heavy iron wedges, fitted to the unoccupied spaces between the sides of the holes in the stones and the shafts. The holes being inclined, and the braces between the shafts being immoveable, it is evident that the feet cannot be withdrawn from their places without rupture. Now, the braces are of 2½-inch square iron, and the thickness of the stone outside of the hole is 2½ feet, and this would seem to present sufficient strength to resist a shock from any ordinary cause.

In addition to the concrete around the outside of the stone, the cramps and dowels to secure the same together, there are five iron ties of 1½ inch diameter, extending from a collar of 2-inch wrought iron which surrounds the middle shaft, to each of the outer shafts, to which they are firmly and securely attached by means of heavy iron stirrups; the ends of the ties are finished with screws and nuts, and by this means can be kept in a constant state of tension. This arrangement was resorted to as an additional means of preventing any tendency there might be in the outer foundation-stones to separate themselves from the middle stone.

The beacon, as finished, stands 34 feet above low water, and 3 feet higher than the old beacon; the cage or grating is painted black, and the shafts vermilion red. A model of the work, upon a scale of 1 inch to a foot, will be deposited in the bureau; this, with the plan in detail accompanying it, will convey all the information in reference to the construction which may be required.

The iron-work was executed in Boston, by Messrs. Cyrus Alger & Co., under the immediate superintendence of Mr. Lester; the entire weight is upwards of 19,000 lbs.

The foundation was prepared, and the beacon erected in place, by Mr. Benjamin Pomeroy, of Stonington, Connecticut, under a contract made with him for that purpose.

The entire cost of the iron-work and foundation was about $4600, and the time consumed in the construction was three months.

I had it in contemplation at one time to coat the inner work with zinc, by means of electro-galvanism; but I found that too much time would be required for preparing the necessary tanks and apparatus. I venture, however, to hope that another occasion may present itself, and that in the more important structure of the 'screw-pile light,' (which, I trust, I shall one day see executed upon our shores,) the galvanizing process may be successfully applied.

In conclusion, I beg to call your attention to one or two of the more important advantages which this application of one of the principles of Mitchell's screw-pile to the construction of light-houses and beacons presents.

In a very exposed situation, a light or a beacon, if built by masonry, can only stand when the best description of work is introduced; this, of course, involves great expense and much time. The mode of construction for such situations must, in principle, be similar to that adopted for the Eddystone and Bell Rock lights; and this, as all know who understand the subject, would, in the case of our own coast, present an insuperable objection: for example, the Bell Rock light, on the coast of Scotland, cost £360,000, or $1,800,000, and four years were required to build it; this, too, in a situation where the rock upon which it is placed is bare at low water. The Eddystone was neither so costly, nor did it require so much time to complete it, still ——— dollars would with us justly be considered out of the question for a single light.[1] There are many places upon our coast at which the 'screw-pile light' could be erected at a very moderate cost, far less, indeed, than that of a light-ship; notwithstanding this, there are at this time not less than five floating lights in Pamlico Sound, on the coast of North Carolina. The Middle Ground, in Long Island Sound, upon which there is only 3 feet at low water, and at which a light-boat is now maintained, is, of all others, the most suitable point to make the first experiment upon with this description of light.

In reference to the durability of wrought iron exposed to the action of sea water, I have not a great deal of information to impart; still I have some which bears upon this question. Upon many of the reefs in Long Island Sound, and

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[1] The Car Rock beacon, on the coast of Scotland, cost $25,000; six years were required for the construction. It was intended to build it entirely of stone; but, when half finished, the upper part was constructed of cast iron. The cast iron beacon on York Ledge, Maine, is an exact copy of the Car Rock beacon; it cost $10,000.

more particularly in Fisher's Island Sound, it has been the practice, for many years, to erect wrought iron spindles, of about 4 inches diameter, and from 15 to 25 feet in height; such spindles last from fifteen to twenty years, unless carried away by ice. The contractor, who placed several of these spindles, informed me that one upon a reef in Fisher's Island Sound had been up twenty years without being renewed; the wasting takes place principally between high and low water, and in this particular case the size of the spindle is reduced from 4 to 2 inches in diameter.

If, however, the zincing process, or if a precipitate of copper be resorted to, there is every reason for believing that the iron thus protected would last twice or three times twenty years.

In short, economy in cost and in time, and the application of the principle of the screw-pile in situations where masonry could not be resorted to without inordinate expense, would seem to be advantages in themselves sufficient to justify extensive experiments in a branch of the public service of such importance as that of our light-house system.

Very respectfully, your obedient servant,

W. H. SWIFT,

Captain, Topographical Engineers.

Colonel J. J. ABERT,
Chief Corps Topographical Engineers.

XIV.—*Railways.* *By* G. DRYSDALE DEMPSEY.

IN the series of Papers of which this is the first, it is proposed to offer a condensed account of the engineering and mechanical operations and structures which are combined in the making and equipment of a railway.

To do this as efficiently as the limits of the allotted space will allow, it is proposed to select examples from works already executed, presenting a useful collection of materials and facts, arranged so as to be adapted for ready application by Royal Engineers and others on whom may devolve the conduct of similar works at home and abroad.

Without any pretensions to a complete history of any individual railway, the work will aspire to the character of such a record as will assist an engineer in applying his professional knowledge with readiness and certainty in the design and execution of the works required for any line committed to him.

It will be evident that the subject comprises two main and consecutive divisions, viz.: first, the formation of the railway as a road or track; and secondly, the furnishing of this road with all the fittings and appurtenances by which it is adapted to the purposes of traffic.

Thus, the one division includes the levelling of the original surface of ground, the raising or lowering it as may be necessary, including tunnelling, the construction of bridges and viaducts to sustain the line over valleys, roads, or rivers, or to carry roads, &c., over the railway; and also the arrangement of rails and their supports,—constituting technically the *permanent way*,—by which the road is specially adapted for the rapid and uniform passage of engines and carriages.

The second division comprehends stations and their fittings, locomotive power and all arrangements belonging thereto, with carriages, &c.

Before commencing the construction, or indeed deciding the course of a railway, there are some preliminary considerations respecting its lateral and vertical deviations from a right line, and also the width of surface that will be required for the railway, which need the careful attention of the engineer. These deviations constitute the curves and gradients, and the width of surface is determined by the intended gauge of the line and slopes of its cuttings and embankments.

Although involving considerations of a somewhat theoretical character, these subjects claim a portion of our space, in order to exhibit briefly what has been advanced in the way of theory, and what has been adopted by engineers in their practice.

SECTION I.

CURVES, GRADIENTS, GAUGE, AND SLOPES.

The theory of a perfect railway requires that it shall follow a right line on plan, and be uniformly level from end to end.

These two conditions are made impracticable by the interposition of hills, rivers, towns, dépôts, &c., between the intended termini of the line, which must be avoided, or crossed, or passed within certain limits; by the difference of levels of the intended termini; the undulations of the surface of country through which the route will pass, &c.

But all such deviations from the theoretical line are ruled in their nature and extent by circumstances peculiar to the railway system as hitherto carried out by means of steam locomotive power.[1]

Curves.—The principles regulating all lateral deviations are, *first*, that they can be made only in curves, angles being incompatible equally with the speed to be attained on railways, and with the constantly parallel axes of the four or six-wheeled machines impelled upon them; *secondly*, that as the perfect condition is a right line, so does comparative perfection consist in the minimum amount of deviation from it, that is, in the largest possible radius of curvature; and *thirdly*, that in order to impose the least diminution of speed, small curves

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[1] It is necessary to remark that the peculiarities of curves, gradients, &c., which distinguish the Dalkey branch of the Dublin and Kingstown Railway, which is now worked upon the atmospheric system, will be disregarded in this series of Papers, which will be devoted to the details connected with the steam locomotive system. The little experience yet had of pneumatic propulsion would exclude it from these Papers, while the great importance deservedly attached to it entitles it to a separate history.

should always be near to stations or stopping-places, and that the more distant curves are from these, the larger should be their radius.

To estimate the effects of curves, let us conceive a railway to consist only of one horizontal rail, traversed by a vertical wheel of infinitely small breadth, impelled by a force exactly sufficient to move it at a given velocity. Even with this arrangement we know that the wheel could not be made to deviate from a rectilineal course, without an additional power, equal to its çentrifugal force, be applied to it, or without reducing the velocity of its motion.

If the rail, being curved, present a level surface, and the periphery of the wheel be made of some appreciable breadth, say two inches, it is evident that a rubbing action must take place, tending to wear away the one edge of the wheel and the other edge of the rail, until the former shall assume the figure of the frustum of a right cone having its apex at the intersection of the centre of curvature of the rail with a horizontal line produced from the axis of the wheel; and the rail, in like manner, will become worn to an inclined surface to suit the conical surface given to the periphery of the wheel.

Beyond the power lost in overcoming the centrifugal force of the wheel, there will, therefore, be a further loss incurred by this friction between the wheel and rail.

But if the railway consists of two parallel rails at some distance, say 5 feet, apart, and is traversed by carriages having two or three pairs of wheels, each pair fixed to one axle, and the two or three axles made, by their connexions with the carriage frame, to revolve always parallel with each other, several such carriages being linked together in one train, and impelled by one engine, it will be seen that not only will this friction be much increased, but that the resistance arising from the centrifugal force will be so likewise.

The wheels on the inner rail will be attempting to describe a smaller curve than the wheels on the outer rail, and will be made to rub backwards upon the rail, while the outer wheels are getting over the excessive space; thus producing a severe torsion of the axles and straining of the frame and the parts connecting it with the axles. The centrifugal force of each pair of wheels may, moreover, be regarded as acting in a direction different from that of each other pair of wheels, and an engine drawing several carriages thus situated will have to overcome the sum of these forces. In reference to this latter effect, it must be also noticed that on entering and leaving the curve, whether in a right line or a curve of contrary flexure, the engine and each of the carriages in succession will be taking a still more different course than over the curve of equal radius, thus augmenting the effect alluded to.

To mitigate the evils consequent upon the adoption of curves, two expedients have been introduced, viz., giving a conical form to the wheel-tires, and raising the outer rail.

By making the tires of the wheels conical, the bases of the cones being towards each other, it is assumed that when the centrifugal force drives the flange of the outer wheel towards the edge of the rail, and, at the same time, withdraws the flange of the inner wheel from its rail, the diameters of the wheels are rendered practically unequal, in exactly the manner required in order to get rid of the dragging which takes place when equal and cylindrical wheels are made to describe curved lines.

The extent to which this inequality should amount depends, 1st, upon the radius of the curve; 2nd, the sizes of the wheels; 3rd, the distance at which they are placed apart, in other words, upon the *gauge* of the railway; 4th, the velocity at which they are impelled; and 5th, the extent of play allowed between the gauge of the rails and the width across the outside of the wheel-flanges.

Of these five elements there are two, viz., the radius of curvature, and the velocity, which are, of course, various over different parts of the line, and for which, therefore, the same carriages and engines cannot be equally well adapted. One of these, however, may be made somewhat to counteract the other; that is, the velocity may be modified according to the curve traversed, reduced speed producing less centrifugal force, thus forcing the wheels less from their central position, and creating less difference of diameters. It follows, that in order to render the conical wheels available the speed must be reduced in proportion as the radius of curvature is reduced.

The other expedient, viz., raising the outer rail over curves, was recommended, with other suggestions, by Tredgold, in his 'Practical Treatise on Railroads and Carriages,' first published in 1825.[2] The following is quoted from the second edition of the Treatise, published in 1835.

" When a considerable degree of curvature is given to a railroad, the rails of the outer curve should have a slight rise to the middle of the curve, and the rails should be stronger in a lateral direction in both lines. The object of making a slight ascent to the middle of the curve of the outer rail, is, to

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[2] According to Weale's 'Scientific Advertiser,' in the third number of which publication, dated February 20th, 1838, appeared an interesting memoir of this justly celebrated man.

counteract the tendency of the carriage to proceed in a straight direction, without its rubbing so forcibly against the guides, as we have observed in cases where roads have had a considerable curvature. Straight lines ought to be obtained, if possible; but when it is determined to accomplish any object by means of a curved line, the rails should be cast or formed of the proper figure, as no combination of straight rails can be rendered free from angles, which both cause an irregular motion, and a great increase of lateral stress on the rails." (Pages 135-6.)

The object being to counteract the tendency of the flanges of the wheels to rub against the outer rails, (as impelled by the centrifugal force,) it will be seen that *this expedient does, to some extent, destroy the purpose sought by making the wheel-tires conical.*

Hence it will be readily conceived, that a very delicate and exact adjustment of these contrivances is needed, in order that they shall produce their desired effects.

De Pambour was, it is believed, the first to treat these matters analytically; and as the result of his reasoning, (the general correctness of which is commonly conceded,) we may quote his statement,[3] that with an average velocity of 20 miles an hour, a radius of curve of 500 feet, wheels 3 feet diameter, gauge of railway equal to 4·7 feet, and 2 inches play of the wheels between the rails,—the least inclination that should be given to the tires of the wheels is $\frac{1}{12}$th, that is, the tire should belong to a cone, the radius of whose base is to its axis as one is to twelve. He goes on to state,[4] that

"It is customary to give an inclination of $\frac{1}{7}$th. The motive for making it so considerable, is to prevent all possibility of the flange rubbing against the rail, either in case of a strong side-wind, or in case of some fortuitous defect in the level of the rails, by which the waggons would be thrown on the lower rail. Having seen above that, with an inclination of $\frac{1}{12}$th, there would be no danger of the flange rubbing in the curves, that danger will be still more impossible with an inclination of $\frac{1}{7}$th."

Pambour also determines that with this radius of curvature, velocity, inclination of tire, gauge of line, and size of wheels, the outward rail should have a surplus elevation of 2·83 inches.[5]

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[3] 'A Practical Treatise on Locomotive Engines upon Railways,' pages 286, &c. (Weale, 1836.) The first edition appeared in French early in the year 1835.

[4] Ibid. page 289.

[5] Ibid. page 287.

Solving his formulæ for some usual cases, he produces[6] the following

Table of the Surplus Elevation to be given to the Outward Rail in the Curves.

Designation of the Waggons and the Way.	Radius of the curve in feet.	Surplus of elevation to be given to the rail in inches, the velocity of the motion in miles, per hour, being—		
		10 miles.	20 miles.	30 miles.
	feet.	inches.	inches.	inches.
Waggon with wheel, 3 feet	250	1·14	5·60	12·99
	500	0·57	2·83	6·56
Way, 4·7 feet	1000	0·29	1·43	3·30
Play of the waggon on the way, 1 inch	2000	0·15	0·71	1·65
	3000	0·10	0·47	1·10
Inclination of the tire of the wheel, $\frac{1}{7}$th	4000	0·07	0·36	0·83
	5000	0·06	0·28	0·66

Considering, however, the extreme difficulty, if not impossibility, of realizing in practice the exact conditions and proportions determined by these inquiries, it may reasonably be doubted whether by far the larger part of the friction, straining, and loss of power belonging to curves, without these expedients, does not still remain, with their inevitably imperfect execution.

Moreover, there is another effect arising from the conical tires, which was thus referred to by the editor of the 'Railway Magazine:'[7]

"It is plain, from the conical structure of the wheels, that if the upper surface of the rail be horizontal, the whole of the pressure must lie on the inner edge of the rails, and be constantly tending to thrust them outwards. This must not only twist the rails out of their vertical position, and thrust them out, but the whole wear and tear being on one edge, and, as it were, on a line, the wheels themselves must wear in grooves, and the rails rub away on the inner edge alone, both of which have already happened on the Liverpool line."

This is usually sought to be corrected, either by inclining the surface of the sleeper or support for the chairs so as to throw the top surface of the rails downwards to suit the wheels, or by forming the chairs so as to hold the rails in this inclined position, or by inclining the top surface of the rail itself.

This method, however well adapted for straight lines, evidently tends, upon curves, to destroy the proper condition of the wheel upon the outer rail, the top

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[6] 'A Practical Treatise on Locomotive Engines upon Railways,' page 290.

[7] No. 10. December, 1836. Page 405.

surface of which should incline downwards from the other rail, rather than towards it, in such manner that the surfaces of both rails should coincide with a line directed to the point wherein the produced axis of the wheels would meet the centre of curvature of the railway.

In like manner it will be understood, that the raising of the outer rail is directly destructive of this desirable relation between wheels and rails; and we are thus obliged to recognize some imperfections even in the theory of the expedients referred to, although it may be difficult to conceive how the defects resulting from curves can be practically and completely surmounted.

Without careful experiments (which it is believed have never been made) upon the relative power requisite to move a given load over a straight and a curved line, respectively, both with and without the expedients described, and also with wheels and rails formed to the true conical line, tending to the centre of curve and wheel-axle produced, neither the exact defects of curves, nor the value either of present remedies, or of others that may be proposed, can be satisfactorily ascertained.

As might be predicated from our present state of uncertainty on this subject, we find that the practice of engineers, in the adoption of curves, differs most widely; some securing curves of large radius, at great sacrifices of cost; and others, again, choosing very small ones, on considerations of minor economy.

Thus, on the Great Western Railway, "the curves are in general very slight, chiefly of 4, 5, or 6 miles radius. Mr. Brunel considered, that even a mile radius is not desirable, except at the entrance to a dépôt, where the speed of the engines is always greatly slackened. And, except in these instances, the only deviation from his rule, which he has admitted, is in the curve, about ¼th of a mile below one of the inclines, where the radius is ¾ths of a mile."[8]

In his evidence on the projected Brighton Railway, in 1836, Mr. R. Stephenson stated, that the line he proposed had no curve of smaller radius than 1½ mile, which he considered a very convenient radius for passenger traffic.

From a quotation which will presently be made, under the head "Gradients," it will be seen, however, that Mr. Stephenson would not limit the minimum of curvatures even to ¾ths of a mile, if other circumstances of a sufficiently important character dictate the choice of smaller curves.

On the Birmingham and Gloucester line, (which is curved nearly throughout

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[8] 'Railway Magazine,' vol. i. page 418.

its whole length,) on the Edinburgh and Glasgow, and on other railways, the general radius of the curves is 80 chains or 1 mile;[9] while on the Chester and Birkenhead, Birmingham and Derby, Arbroath and Forfar, and others, this is the *minimum* radius adopted for the curves.

The Taff Vale Railway (a single line) was reported in April, 1841,[10] by Sir F. Smith, then Inspector-General of Railways, as having curves of the following radii and length.

	miles.	chains.	
10 chains radius	,,	26	in length.
11 ,, ,,	,,	7	,,
12 ,, ,,	,,	18	,,
7 ,, ,,	,,	7	,,
15 ,, ,,	2	41	,,
20 ,, ,,	2	22	,,
22 ,, ,,	2	13	,,
25 ,, ,,	,,	29	,,
26 ,, ,,	,,	37	,,
28 ,, ,,	,,	21	,,
30 ,, ,,	1	8	,,
40 ,, ,,	1	5	,,
60 ,, ,,	,,	20	,,
80 ,, ,,	1	40	,,

These curves appear to have been adopted to avoid repeated crossings of the river Taff by viaducts, and also to save the formation of some lofty embankments; but Sir F. Smith thought it necessary to propose "that a suggestion should be offered to the Directors of the Taff Vale Railway, recommending them to call upon the engineer to fix the maximum rate of speed to be used round such of the several curves as have a shorter radius than ½ a mile," although it did not appear that any difficulty had been experienced in working the engines round these curves "at a velocity of upwards of 20 miles an hour."

The Manchester and Leeds Railway has curves generally of 60 chains radius, and some which are still less.[11]

The Northern and Eastern Railway joins the Eastern Counties line in a sharp curve, but it is mainly very straight, occasionally extending for several miles in a perfectly straight direction. The gradients are also good.

[9] Whishaw's 'Railways of Great Britain and Ireland.' 4to. 1842. (Weale.)

[10] Report of the Officers of the Railway Department, page 132. 1842.

[11] Whishaw's 'Railways of Great Britain and Ireland.'

The London and Birmingham has been constructed through a difficult country, but with a special view to good curves and gradients. The result is the judicious adoption of moderate curves and gradients.

Each of the lines here referred to has gradients corresponding mainly with the character of its curves, sharp curves and steep gradients being usually allied, and *vice versâ*. Nevertheless, we cannot escape the inference that some, if not much, of the startling difference of the average velocities attained on these five railways,—as exhibited in the following tabular statement, compiled from the 'Third Report of the Officers of the Railway Department,' 1843,—is due to the difference of their curves only.

Northern and Eastern . . .	36	miles per hour.
Great Western	33	,, ,,
London and Birmingham . .	27	,, ,,
Manchester and Leeds . . .	24	,, ,,
Birmingham and Gloucester .	23½	,, ,,

The last line is distinguished by its very steep gradients and planes, as will be noticed presently.

At or near termini and junctions, which are always arrived at, and departed from, at a very diminished speed, a small radius may be safely used: thus the Chester and Crewe line leaves the latter terminus in a curve of 18 chains radius; and the Grand Junction joins the Liverpool and Manchester in two curves of 10 chains radius each: but throughout the line the greatest possible curvature should be aimed at. Even in approaching first and second-class stations this rule must be kept in view, for the latter ought to be passed by mail and some other trains at full speed, and it may be sometimes essential that the former should also.

GRADIENTS.—The deviations from a horizontal level, constituting the inclinations or gradients of a railway, have to be considered with a careful reference to economy in the construction of the line, involving the quantity of earth-work, of tunnelling, of bridge-work, &c., &c.; and also with a reference to the attainment of the desired velocity from station to station, and to the constant expenses incurred in engine power, and in wear and tear of engines, carriages, and brakes, in working the trains over these inclinations.

Widely differing opinions as to the proper limits of inclination are held and have been acted upon by the several eminent engineers, under whose management British railways have been constructed. By quoting briefly from these opinions, we shall be possessed of the reasons on which they are built; and an after reference to the practical features of construction and of results obtained upon some existing lines, may assist us to judge of the value of these opinions. The attempt to deduce positive rules from these would be about as difficult as it would be supererogatory, for the actual circumstances of each case present peculiarities which the judgment of the engineer must estimate, and his discretion can alone provide for.

In a Paper on the '*Economy of Railways in respect of Gradients*,' by Mr. Vignoles, read at the tenth meeting of the British Association for the Advancement of Science, held in September, 1840, the author "disclaimed asserting that sharp curves or steep gradients were preferable to straight and level lines; but he would endeavour to show that good practicable lines might be and had been constructed, on which trains sufficient for the traffic and public accommodation could and did move at the same, or nearly the same velocities, and with little, if any, additional expense. On an average, the hitherto ascertained cost of the principal lines might be divided thus:

Land	10	per cent.
Stations and carrying establishment .	20	,,
Management	10	,,
Iron	10	,,
Works of construction proper . .	50	,,
	100	

though of course these items differed considerably in various railways; but in general it might be said that the works of construction constituted one-half of the whole first cost." Mr. Vignoles stated "that he had analysed railway expenses of working, and had reduced them to a mileage,—that is, the average expense per mile per train, as deduced from several years' experience and observations of various railways under different circumstances, and with greatly different gradients, some of which lines were enumerated. The result on passenger and light traffic lines was, that the total deductions for expenditure from gross receipts was 3*s*. per mile per train; 2*s*. 6*d*. being the least, and 3*s*. 4*d*. the highest; and that this average seemed to hold good, ***irrespective of gradients or curves***."

This extraordinary inference, coming with weight from the engineer here quoted, might yet have acquired additional interest, had the data been exhibited along with it. That the lower rates of expenditure accompanied the *slight gradients, and the higher the steep ones, could be understood more readily* and accredited upon less evidence than the proposition above quoted. The Report of the Paper proceeds thus:

" Particular lines might, from local circumstances, differ in detail, but he was satisfied that the following detail was a fair average approximation:

	s.	*d.*
Daily cost of locomotive power and repairs	1	6
Annual depreciation, sinking fund, and interest on stock, tools, shops, and establishment	0	6
Daily and annual cost in carriage department	0	4
Government duty, office expenses, police, clerks, guards, management, and maintenance of railway	0	8
	3	0

" It was not found practicable to distinguish the additional expense, if any, arising from curves or gradients; but as three-fourths of railway expenses were quite independent of these curves, such addition must be small; especially as in the North Union Railway, a line which had 5 miles out of 22 in the gradients of 1 in 100, or nearly 53 feet per mile, the total expenses were less than on the Grand Junction Railway, and several other lines." [12]

This statement seems sufficiently important to warrant the quotation in this place of some of the details connected with the line referred to, the North Union, which connects Preston with the Liverpool and Manchester Railway at Parkside.

The gradients, as given in Mr. Whishaw's work, already quoted, are as follow:

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[12] 'Civil Engineer and Architect's Journal,' vol. iii. p. 422.

Length of planes. Yards.	Ratio of inclination.		
203½	descending at the rate of		1 in 100.
1368	descending	,,	1 in 330.
1518	ascending	,,	1 in 330.
1100	ascending	,,	1 in 100.
3520	ascending	,,	1 in 330.
760	ascending	,,	1 in 100.
1660	ascending	,,	1 in 440.
2750	descending	,,	1 in 660.
1584	ascending	,,	1 in 100.
350	ascending	,,	1 in 330.
946	ascending	,,	1 in 100.
1210	ascending	,,	1 in 330.
616	ascending	,,	1 in 100.
958	ascending	,,	1 in 528.
770	descending	,,	1 in 100.
3740	descending	,,	1 in 330.
1298	descending	,,	1 in 100.
462	descending	,,	1 in 330.
1100	descending	,,	1 in 100.
814	descending	,,	1 in 330.
209	level.		
253	descending	,,	1 in 100.
990	descending	,,	1 in 330.
1326	descending	,,	1 in 754.
660	level.		
1320	ascending	,,	1 in 2200.
1754	ascending	,,	1 in 586.
1232	ascending	,,	1 in 440.
4664	descending	,,	1 in 406.

39,135 yards, or 22·236 miles.

" The ascending planes rising 1 in 100 from Preston to Wigan amount to 5006 yards, and in the opposite direction to 3624½ yards, or together 4·90 miles, being equal to more than one-fifth of the whole length.

" This is an important fact, as showing the inutility of spending large sums of money in reducing hills and filling up valleys to so great an extent as has been done on many of the great lines of the kingdom, for the purpose of making the gradients as easy as possible." [13]

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[13] 'Whishaw's Railways of Great Britain and Ireland,' 4to. 1842. Weale.

The average cost per mile of this railway was £23,157. 5*s*. 6*d*.; the receipts for the first half of the year 1840, £32,394. 3*s*. 11*d*. (including £467. 16*s*. 5*d*. derived from the carriage of coals, and £500 rental); and the disbursements for the same period were £16,396. 3*s*. 4*d*., about 50 per cent. of the receipts. The cost of the locomotive department was at the rate of £7546. 3*s*. 6*d*. per annum; and of maintenance of way £1200 per annum, or about £50 per mile.

Interesting as these figures are, however, as relating to an individual railway, and satisfactory as showing a cheap construction through a rugged country and bad strata, and showing also a moderate rate of expenditure, both for engine-power and road repairs, it must be observed that they do not warrant the general inference that steep gradients may be adopted with equal advantage to easy ones; neither do they afford the materials for an advantageous comparison with other lines which have cost more money both in original construction and in current expenditure.

Thus, in a comparison on this subject made by Mr. Brunel, in reference to the system of easy gradients adopted by him on the Great Western Railway, the data are explained on which is founded the following "Table of the comparative effects of the same engine, with the same consumption of fuel, and travelling at the same speed on the level, and on the four gradients of 4, 10, 16, and 20 feet per mile.

	Comparative effective power.	
	Ascending.	Descending.
Level	170	170
4 feet per mile	134	226
10 feet per mile	100	400
16 feet per mile	77	1305
20 feet per mile	66	The load once in motion would *run* of itself.

"Hence," Mr. Brunel proceeds, "the great superiority of a line approaching to the level is made apparent; not only is the effective power of the engine in that direction of the line which limits the load much greater, but the average work of the engine is performed more economically by the greater regularity of the resistance. On an inclination of 10 feet per mile, as I have before shown, the engine, during half the time, is barely performing a quarter of the work of which it is capable. On gradients of 16 feet per mile, the engine during half the time is barely doing more than driving itself." [14]

The economy in construction attained by the adoption of steep gradients will consist, according to the features of the country passed through, of many items; thus, the cuttings being less deep and the embankments less high, a much smaller quantity of land will be required, and the ratio of saving in this respect increases rapidly upon the proportion of height or depth avoided. A very large saving also occurs in the size and cost of bridges and cuttings, and bridges or viaducts under the embankments; and in these, also, the saving increases in a greater proportion than the difference of length or height effected; the foundations, abutments, and general dimensions being necessarily much increased in the larger structures. The passage over rivers and through towns is also, in many cases, much facilitated by keeping more closely to the original surface of the country. The smaller cuttings and embankments, moreover, require less expense in drains and culverts, &c.; and to crown the economy of the steep-gradient system, it must be remembered that those costly nuisances, tunnels, may in many cases under its adoption be either wholly avoided, or very much reduced in length; and it may, further, escape interference with some of those treacherous strata, which so much impede the progress and augment the cost of works of that kind.

The question arises, how far are these sources of economy in first cost counterbalanced by increased expense in locomotive power, or stationary engines, traction ropes, &c., or the repair of the permanent way,—and further, to what extent is the great purpose of railway travelling,—economy of time, —sacrificed by the adoption of the less level line? The latter part of this question, relating to the time occupied in the transit, seems to have been determined (as far as they extended) by some experiments made upon the Grand Junction Railway, between Liverpool and Birmingham, in the year 1839, and reported by Dr. Lardner to the meeting of the British Association for the Advancement of Science, held in that year. The hypothesis, which these experiments were designed to test, and found to confirm, is, that "a compensating effect is produced in descending and ascending the gradients, and that a variation of speed in the train is the whole amount of inconvenience that will ensue; that the time of performing the journey will be the same in

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[14] Mr. Brunel's Report to the Directors of the Great Western Railway Company, dated Dec. 13, 1838, and published in the 'Civil Engineer and Architect's Journal,' vol. ii. page 55.

both cases."[15] The result of these experiments is exhibited in the following Table, quoted chiefly from the same journal.

Gradient.	Speed.		Mean.
	Ascending.	Descending.	
One in	Miles per hour.	Miles per hour.	Miles per hour.
177	22·25	41·32	31·78
265	24·87	39·13	32·00
330	25·26	37·07	31·16
400	26·87	36·75	31·81
532	27·35	34·30	30·82
590	27·27	33·16	30·21
650	29·03	32·58	30·80
Average mean speed of the seven gradients . .			31·23
Level			30·93
Loss of speed on the seven gradients			·30

These experiments do not, however, afford any evidence upon the former part of the question before stated, regarding the *cost* of power and road repairs. On one of these points we may refer to a note appended to the Report of the Irish Railway Commissioners, made in the year 1838, and which also contradicts, essentially, the results stated in the preceding document as to *time*.

"It is agreed on all sides, that the additional force requisite to urge a load up an inclined plane or gradient, is such a fraction of the gross load (that is, with engine and tender included,) as expresses the slope of the plane, or the fraction of the height of the plane divided by its length.

"The disputed point is,—what is gained by the returning load descending the same plane? It has been maintained, that the power which is lost in causing a load to ascend a plane is gained by an equal returning load descending the plane; a deduction, however, which has been controverted by others. Without stopping here to discuss this question, the Commissioners will state the facts they have been able to collect on the subject, and which have been obtained by proposing the following queries to the engineers of the several present existing lines:

"First.—When a plane inclines so much as to give to the engine and load a

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[15] Report in 'Civil Engineer and Architect's Journal,' Oct. 1839, page 387; extracted from the able Report published in the 'Athenæum.'

tendency to acceleration, what is the greatest velocity it is deemed prudent to descend with, in comparison with the usual horizontal velocity? or, to specify more particularly, what velocity would it be deemed prudent to descend with on slopes of $\frac{1}{90}$, $\frac{1}{100}$, $\frac{1}{110}$, $\frac{1}{120}$, &c., supposing the horizontal velocity to be 25 miles per hour?

"Second.—What is the greatest slope on which it is deemed prudent to allow of acceleration, and to what amount?

"Third.—On medium slopes, what may be considered the excess of allowable descending velocities beyond the mean horizontal velocity?

"The answers to these queries were not entirely accordant; but it would appear that no advantage can be claimed for descending planes of greater slope than $\frac{1}{140}$, and that the greatest allowable increase in the descending velocity on planes between $\frac{1}{140}$ and $\frac{1}{750}$ is one-fifth of the uniform horizontal velocity: on less slopes than $\frac{1}{750}$ the gain from descent varies from one-fifth to nothing.

"It appears, therefore, that whatever advantage may show itself theoretically on descending planes, there is no practical advantage for those of greater slope than $\frac{1}{140}$; and allowing an advantage of one-fifth additional velocity for planes of less slope than $\frac{1}{140}$, and greater than $\frac{1}{750}$, we are in general on the most favourable side.

"It may be said that these descending velocities are obtained with less piston pressure, which is true; but the steam thus saved in the cylinders is commonly lost at the safety-valve, so that there is little, if any, saving of steam beyond what has been stated.

"One or two cases may now be taken by way of illustration.

"Let us suppose a load of 88 tons (tender included) to be drawn along a level plane at the rate of 20 miles per hour, and that this engine and train arrive at a rising plane, sloping 1 in 140; the engine being of the first class, viz., weight 12 tons, and tender 6 tons:—

The power absorbed is . .	1075 lbs.
88 tons, at 9 lbs. per ton . .	792 ,,
	1867 ,,

which is the pressure required on the horizontal plane."

This calculation is the same as that adopted by De Pambour, in his 'Treatise on Locomotive Engines,'[16] and assumes the retarding forces which have to be

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[16] Weale, 1836.

overcome by the power created within the locomotive engine, before any of that power is available for moving the train, as four in number; viz.—1, the friction of the engine gear independently of any load, equivalent to 6 ℔s. per ton of the weight of the engine;—2, the friction of the locomotive itself, the friction of the axles, and retardation on the line of way, equivalent to 8 ℔s. per ton;—3, the friction of the tender itself, including the increase of friction brought on the engine gear, equal to 9 ℔s. per ton of the weight of the tender;—and 4, the atmospheric pressure on the piston, which is necessarily 14·7 ℔s. per square inch. This force being employed at the extremity of the piston rod, and overcome only with the velocity of the piston, must be reduced according to the relative ratio of the velocities of the wheel and piston.—(Report of the Irish Railway Commissioners.)

Thus estimated, the power absorbed in the overcoming of these four retarding forces, in the four classes of engines adopted (after six years' experience) by the Directors of the Liverpool and Manchester and other Railway Companies, was equal respectively to 1075 ℔s., 786 ℔s., 702 ℔s., and 640 ℔s. The whole power of these several engines being found by multiplying the area of their respective pistons by the steam pressure, viz., 64·7 ℔s., (50 ℔s. per square inch added to 14·7 ℔s. pressure of the atmosphere,) and reducing this product to the circumference of the wheels in each class of engine, it appears that the

	Class 1.	Class 2.	Class 3.	Class 4.
Whole power is . .	3755	2488	2337	2090
Absorbed power . .	1075	786	702	640

The mean force necessary to overcome the friction of the best constructed carriages and waggons on a level line amounts to 8 ℔s. per ton of the gross load, and 1 ℔. per ton additional of the said gross load for the extra friction brought on the engine gear; in all 9 ℔s. per ton.[17]

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[17] We must here quote the following correction of this datum, from the Report of I. K. Brunel, Esq., to the Directors of the Great Western Railway Company, dated December 13th, 1838. (Given in the C. E. and A. Journal, vol. ii. page 54.)

"I have assumed 8 ℔s. per ton as the resistance of a train; but as the greatest part of this resistance depends upon the workmanship, the form, and the mechanical construction of the carriages, and other causes, and may be reduced by various contrivances already known, it would be contrary to all experience to suppose that it will not be materially reduced when there is an object to be gained by its reduction.

"In many experiments, with all the circumstances favourable, the resistance has been as low as 6 ℔s.

The note appended to the Commissioners' Report proceeds thus:

"To this is to be added the additional traction necessary to cause the loads to ascend the plane; we must now, therefore, add the weight of the engine itself, 12 tons; making the whole load to be raised 100 tons, or 224,000 ℔s., and $\frac{1}{140}$th part of this is 1600 ℔s. additional traction. But it has been seen that every 8 ℔. traction causes 1 ℔. additional friction on the engine gear; this makes 1800 ℔s.: the whole required force now, therefore, is 3667 ℔s.; and the velocity being inversely as the pressure, or force of traction, we have

$$3667 : 1867 :: 20 : 10\tfrac{1}{6}$$

miles per hour, the velocity of ascent: that is, the time of ascending will be nearly double that required to go the same distance on a horizontal plane, but in the return the time of descent will be the same as on a horizontal plane; so that ascending and descending a plane of this slope with a load of 88 tons, will require the same time and power as would be necessary to pass and repass a horizontal plane of one-half greater length; or, calling the length of the gradient 1, the equivalent horizontal plane will be 1·5.

"Taking now the same engine and load, and the slope of the plane $\frac{1}{500}$, let it be required to find the equivalent horizontal plane.

Here the absorbed power, as before, is . .	1075
88 tons, at 9 ℔s.	792
Traction on a level . .	1867

88 + 12 = 100 tons = 224,000 ℔s.: this divided by 500 gives 448 ℔s., which is equivalent to the traction of 56 tons on a level; and this at 9 ℔s. per ton is 504 ℔s. additional pressure. The whole pressure is, therefore, 2371 ℔s., and

$$2371 : 1867 :: 20 : 15\tfrac{3}{4}$$

miles, nearly, and

$$1867 : 2371 :: 1 : 1{\cdot}26$$

length of horizontal plane equivalent to the ascending plane. And, again,

$$1\tfrac{1}{5} : 1 :: 1 : {\cdot}83$$

"In some made by Mr. Hawkshaw, on the Great Western Railway, the resistance of a train, consisting partly of trucks, and partly of carriages, only gives 6·22 ℔s.

"It may therefore be assumed, that we have now within our reach improvements by which the resistance may be reduced to 6 ℔s."

length of horizontal plane equivalent to the descending plane. Whence 1·20 +·83 = 203 ÷ 2 = 1·015 mean equivalent plane."

The Commissioners furnish eight Tables computed from the data here quoted, and showing the horizontal lines equivalent respectively to each of a series of 18 gradients, varying from 1 in 90 to 1 in 1500; with each of the four classes of engines, and loads from 30 to 100 tons.

"It is to be observed, however, that the effect thus shown (by the Tables) is not all the effect that is due to the gradients and planes; for it is these planes which limit the amount of load. If a line is wholly horizontal, and the traffic abundant, the loads may be chosen so as to bring out the best effect; and it has been seen, that the greater the load within the power of the engine, the greater the economy of working; but when it is required to ascend planes without assistant power, the load must be taken such that it will ascend the plane with a certain velocity.

"The engines are thus obliged to work with small loads, and all the loss attending such loads must be considered to increase to the above disadvantages.

"Thus, for example, in ascending a plane of 1 in 140, with a load of 100 tons, it appears by Table V. that the force of traction would be doubled, or be equivalent to the traction of 200 tons on a level. In order, therefore, that the engine may ascend this plane without assisting power, it would be deemed necessary to reduce the load, probably to 60 tons; and then again, by referring to Table I., it appears that all the expenses of haulage are increased 36 per cent.; not only, therefore, is the equivalent horizontal plane about one-half longer than the real length of the actual plane,[18] but the expense of working the whole distance is increased 36 per cent."

A practical answer to this position was thus put forward by Mr. Vignoles, in the Paper read before the British Association in the session of 1840, and already quoted:

"It was forced on him by daily experience, that to accommodate the public convenience, the Post-Office arrangements, and business in general, it was scarcely once in twenty times that a locomotive engine went out with more than half its load, and in general the engines were only worked up to two-fifths of their full power: he was therefore conclusively of opinion, that it was much cheaper to put on additional engines on extraordinary occasions; and on such

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[18] That is, the *horizontal* distance passed over.

principle, railways should be constructed through the more remote parts of the country, so as to be made in the cheapest possible manner."

The Commissioners proceed:

"This points out the advantage of accumulating the ascents as much as possible into short steep planes, and working these planes by assistant engines, either motive or stationary: for although there is really no saving of power by this arrangement, there is a saving of time; and what is of more importance, it will not be necessary to reduce the amount of the loads below what would be otherwise considered as most advantageous for the general traffic."

Mr. Robert Stephenson, whose opinions are understood to be decidedly in favour of easy gradients, in reporting to the Chairman and Directors of the South Eastern Railway Company upon the proposed railway communication with France and Belgium, declares,—

"Though I appreciate more highly than the generality of the profession the ultimate benefits which I believe will always be found to spring from the use of favourable gradients, yet I cannot but feel, and that very strongly, that the application of precisely the same principles as those which governed me in designing the London and Birmingham Railway to the section of country now under my consideration, between Paris, Belgium, and the northern coast, must lead to consequences which the Government and every interested individual would hereafter have reason to lament."[19] The remarks from which this is quoted were made in reference to the following restrictions, imposed by the French Government upon M. Vallée, in deputing him, in 1835, to report upon the opening of a railway communication between Paris and the northern parts of the country, as well as with the kingdom of Belgium and with England.

"1. That no curve should be made under 1200 metres (three-quarters of a mile) in radius.

"2. That no gradient should exceed 3 in 1000, or, as it is expressed by English engineers, 1 in 333, or about 16 feet a mile; and

"3. That all curves of small radii should be level."

Some further materials for determining the value and cost of easy gradients will be offered in a subsequent part of this work, when treating of earth-works, tunnelling, viaducts, locomotives, &c. Meanwhile we conclude the subject at present by quoting from the useful volume of Mr. Whishaw the peculiarities of gradients upon several of our English railways.

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[19] 'Railway Times,' Nov. 12th, 1842.

Birmingham and Derby.—The terminal planes are both level, and the greatest inclination throughout the line is 1 in 339.

Birmingham and Gloucester.—The inclinations vary from 1 in 100 to 1 in 1000, excepting the Lickey incline, which ascends at 1 in 37 for a length of 2 miles 3·35 chains from the Bromsgrove Station, and excepting also a length of 1 mile 09·09 chains which descends at 1 in 84 towards a level plane of 19 chains, which joins the line to the London and Birmingham Railway. The Lickey incline is worked by assistant locomotive engines of the American kind, of which some account will be found under the heads "Inclines," and "Locomotive Engines." The summit of this railway, near the Lickey, is 400·73 feet above the level of the rails at Cheltenham, and the junction with the London and Birmingham line is 191·35 feet above the same level. The longest plane of 1 in 100 is 32·30 chains in length, and all the planes inclined at this rate are between others of less steepness. The prevailing gradient is 1 in 300, and the longest plane is 4 miles 20·05 chains in length, inclined at 1 in 300.

Eastern Counties.—This line has one plane of 2 miles 75 chains in length, ascending at 1 in 100 to the station at Brentwood.

Edinburgh and Glasgow.—The gradients vary from 1 in 880 to 1 in 5456, except one incline of 1 mile 14 chains in length, which descends from the Cowlairs towards the Glasgow Station at the rate of 1 in 43, and has been hitherto worked by stationary steam engines which are now, or are about to be, replaced by American locomotive engines. On this line there is one plane at 1 in 880, 6 miles long; another of the same length at 1 in 1056; another of 5 miles of the same inclination; one level plane 6 miles 69·72 chains in length, and one of 10 miles 59 chains in length, and inclined at 1 in 1158·66. These gradients have, however, been secured by extensive earth-works and about 1⅓ mile of tunnelling. The Abercorn cutting is 50 feet deep and nearly 3 miles long.

Grand Junction has gradients varying from 1 in 85 to 1 in 3474, and one incline (at Madeley) which extends for 3¼ miles at 1 in 177; another at Newton Brook, 1 mile in length, and inclined at 1 in 85. The entire line from Birmingham to Newton is 82·63 miles, of which 10 miles 47·44 chains are level.

Great Western, 117 miles in length, has 35 miles graduated at 4 feet per mile, or 1 in 1320;—13½ miles at 7 feet per mile, or 1 in 754·28;—19½ miles at 8 feet per mile, or 1 in 660, and 10 miles level. It has also two planes, viz.:

at Wootton Basset and Box, inclined at 1 in 100, the former being 1 mile 29 chains long, the latter 2 miles 30 chains in length. The fall from London to Bristol is 27·33 feet.

Leeds and Selby.—This line has some rather severe gradients: there are two contiguous planes ascending in the same direction, one of which is 2 miles 4·80 chains in length, at 1 in 160; the other, 1 mile 4·20 chains long, inclined at 1 in 168: these are succeeded by a level plane, 2 miles 61 chains in length, which is followed by two descending planes, one 2 miles 47 chains long, inclined at 1 in 150; the other, 3 miles 21 chains long, at 1 in 137. The whole line is 20 miles in length. At Leeds the rails are 100 feet higher than at Selby.

Leicester and Swannington has two inclines, 1 in 29, and 1 in 17, both worked by stationary steam engines.

Liverpool and Manchester, 30·66 miles in length, has one plane of 1 mile 30 chains, inclined at 1 in 88, and worked by stationary steam engines at Edgehill. The Whiston incline is at 1 in 96 for a length of 1 mile 47 chains. The Sutton incline is 1 mile 39 chains long, at 1 in 89. This line has one plane of 6¾ miles in length, inclined at 1 in 894.

London and Birmingham descends from the terminus at Euston Square for 12 chains, at 1 in 156, is then level for 13 chains, and the succeeding 59 chains are divided into four gradients ascending to Camden Town at 1 in 66, 1 in 110, 1 in 132, and 1 in 75, respectively. Four summits occur between London and Birmingham, viz., at Tring, Blisworth, Kilsby, and Berkswell, which are 332 feet 4 inches,—170 feet 10 inches,—308 feet,—and 290 feet, respectively, above the level of the Euston Station. One plane occurs which is 7 miles 18 chains in length, at 1 in 330;—29 miles 57 chains of the entire line are graduated at this inclination; and, with the exception of the 1 mile and 4 chains between the Euston Terminus and the Camden Dépôt, already mentioned, and constituting the fixed-engine planes, the most severe gradient throughout the line is 1 in 326.

London and Brighton, which is 42½ miles in length, has 32¾ miles graduated at 20 feet per mile, or 1 in 264. This line has one plane of 8 miles 42 chains, ascending at 1 in 264 from London to the Merstham summit; then occurs a level plane of ¾ mile, succeeded by a descending plane of 6 miles 69 chains, at 1 in 264. It has four other planes of about 4 miles long each, at 1 in 264 and 1 in 391, and enters Brighton in a descending plane of 5 miles 33 chains in length, at 1 in 264. Notwithstanding these long gradients, the earth-works are of a very heavy character, being at the rate of nearly 160,000 cubic yards per mile, besides the contents of the tunnels, the principal of which are at Merstham, Balcombe, and Clayton Hill.

London and Croydon descends to the New Cross Station in a plane of nearly 2¾ miles in length, at 1 in 100; and such trains as have to ascend this plane immediately after stopping at the New Cross Station, have the assistance of another engine up a part of this incline.

London and South Western has a plane of 16½ miles in length, inclined at 1 in 250, with a short level plane introduced near the middle of it. The total length of the level planes is 17 miles 22 chains; and of the planes graduated at 1 in 250, 20 miles 2 chains. The total length of the railway is 76 miles 55 chains. The difference of level between the termini is 1 foot 8 inches, but the summit of the line, distant 54 miles from London, is 392 feet above the London, and 390 feet 4 inches above the Southampton terminus.

Newcastle and Carlisle has three adjoining planes inclining in the same direction, at the rates respectively of

1 in 176	3 miles	35 chains long,
1 in 106	3 ,,	70 ,,
and 1 in 215	3 ,,	65 ,,

making in a length of 11 miles 10 chains, a total difference of elevation of 390 feet.

South Eastern has a prevailing gradient of 20 feet per mile, or 1 in 264.

Whatever ratio of inclination may be adopted for the gradients, there are two maxims which should always be adhered to, and will be found productive of economy, safety, and convenience in the working of the railway. These are, first:—Let the gradients contiguous to stations always rise towards them in each direction, so that every station shall occupy the summit of the adjoining gradients. To effect this, if the section is nearly level, will be an easy matter; but in cases where it is desired to place a station within the length of a steep gradient, it will be desirable to interrupt the inclination at this point by a short plane inclining in the other direction. Where the point destined for a station occurs at the common base of two gradients of opposite inclination, the same object should be attained by dipping each gradient somewhat lower than otherwise necessary, so as to secure a comparative eminence for the station. The value of this arrangement is twofold, consisting in the assistance it affords to engines at starting, and in the salutary check thus presented to the speed of engines and trains arriving at the station. These advantages, and the circumstances under which they are needed, are thus mentioned by De Pambour.[20]

"There is also another circumstance in which the engines are obliged to exert an additional effort. That is at the moment of starting. We have seen, in fact, that the power which, when the motion is once created, need only to be constantly equal to the resistance, must, on the contrary, surpass it at the instant that it is to put the mass in motion. The reason is plain: in the first case, it is only necessary to maintain the speed; in the other, it must be created and maintained. It is this additional effort on the part of the moving power which is improperly called *vis inertiæ*, because it is attributed to a particular resistance residing in the mass.

"The starting is, therefore, a difficult task for a locomotive engine heavily loaded. However, at that moment the engine acquires, as well as on the inclined planes, a considerable increase of power. Here again the slowness of the motion produces two effects. The pressure in the cylinder grows equal to the pressure in the boiler, which is itself augmented by the effect of the spring balance. But, notwithstanding this twofold advantage, the difficulty of starting still remains so great for considerable loads, that we should always advise giving in that point a slight declivity to the way. By that means the trains would be set in motion with more ease at the departure, and it would not be necessary at their arrival to make use, in order to stop them, of the powerful brakes, the effect of which is certainly as destructive to the wheels of the waggons as to the rails." (p. 296-7.)

The other maxim concerns long inclinations of considerable steepness, which should always be divided into two or more lengths by introducing short planes, either level, or, still better, inclining slightly in the opposite direction. These brakes or benches become as resting-places to the loaded engine, giving the engine-driver an opportunity of easing the steam pressure in ascending, and serving to moderate the speed in descent.

As connected intimately with the subject of gradients, the consideration of the effect in resisting the motion of railway trains which is due to the displacement of the surrounding air, occurs to us here, and will be duly rendered by quoting from the second Report of the Committee on Railway Constants, made

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[20] 'Practical Treatise on Locomotive Engines.' 1836. (Weale.)

by Mr. Edward Wood, to the eleventh meeting of the British Association for the Advancement of Science.[21]

"In a preceding Report of the Committee, five various modes of ascertaining the resistance to the tractive power on railways were described, and their relative merits discussed; and a variety of experiments on one of these methods, viz., by observing the motion of a load down an incline, sufficiently steep to give accelerated motion, having been made, it appeared, that the resistance increased in a degree previously unsuspected in proportion as the speed of the train increased; but in what ratio, was not then determined, owing to certain discrepancies, due principally to the varying effect of the wind at the time of the experiments. The Committee have continued to conduct their experiments in a similar manner, repeating them with various sizes of trains, at various velocities, on the Sutton incline, of 1 in 89, on the Liverpool and Manchester Railway, and on the inclines of 1 in 177,—1 in 265,—and 1 in 330, on the Grand Junction Railway."—"Three first-class carriages were allowed to descend the Sutton incline from rest four times in succession, a length of 2420 yards. It appears that the resistance diminishes until the train attains the speed of 7·58 miles per hour, after which it increases; at 4·32 miles per hour, the resistance was 6·07 lbs. per ton; at 7·58 miles per hour, 5·6 lbs. per ton. This remarkable and hitherto unobserved result is owing, probably, to the more perfect lubrication of the axles at the higher speed; a certain thickness or film of grease is formed between the brass step and the upper surface of the journal, and keeps the two surfaces more effectually apart: at the lower velocities, the pressure of the step upon the journal has a longer time to act in effecting the displacement of the fresh grease which has been supplied from the box, and the result is a greater amount of friction.[22] Eight second-class carriages were allowed to descend the Sutton incline; the friction was a minimum at 5·84 miles per hour. The following results may be deduced from the above-mentioned series of experiments:

"1. The friction was least when the train was moving at the rate of about 6 miles per hour.

"2. The total resistance was also least at the rate of about 6 miles per hour, notwithstanding the effect of the atmosphere at that speed.

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[21] Given in the 'Athenæum,' and extracted therefrom into the 'Civil Engineer and Architect's Journal,' vol. iv. p. 323.

[22] This hypothesis accounts only for one of the results observed, viz., the diminution of resistance

"3. The mean resistance of first-class carriages was never less than 5·6 lbs. per ton, and of the second class never less that 7·75 lbs. per ton: 6 and 8 lbs. per ton will represent very nearly the mean of the resistances; and these values are used in the subsequent part of the Report. The motion of these trains being observed at lower parts of the incline, where the velocities were greater than the preceding, the resistance to the train of three carriages was 8, 12, and 16 lbs. per ton, at velocities of 22, 26, and 29 miles per hour, respectively; and the resistance to the train of eight carriages was 11, 12, and 14½ lbs. per ton, at the velocities of 20, 25, and 29 miles per hour. Trains of four and of six carriages were impelled to the summit of the incline, and, the engine being detached, commenced their descent at the rate of 33 and 26 miles per hour. They descended through the first half of the incline with a mean velocity of 34 and 29 miles per hour, and through the latter half, with a mean velocity of 37 and 33 miles per hour. Other series of experiments were made on the Grand Junction inclines; and the result of the whole shows the existence of an opposing power, created as it were by the speed itself, far exceeding that hitherto suspected.

"A train of eight carriages, weighing 40½ tons, was started down the Madeley incline, 1 in 177, at speeds varying from 23 to 26 miles per hour: the mean speed attained was 25½ miles per hour. The motion of the train became uniform, so that the co-efficients of gravity and resistance were equal. The mean resistance of the train was 12½ lbs per ton. A train of four carriages was started down the incline at 40 miles per hour; half-way down the plane the velocity was reduced to 30 miles per hour, and at the foot, it was only 25 miles per hour. Four other carriages were started at a velocity of 32·7 miles per hour; they were retarded to 22·7 miles per hour, and proceeded with this uniform velocity to the foot of the incline. The results obtained in these experiments with the trains of eight carriages are of great practical importance, this being the nearest approach to the average passenger trains. 30 miles per hour is a fair average speed, and the resistance at this speed is about 15 lbs. per ton, or almost double the value of the friction only. The friction may be diminished by proper attention to the fittings, and the perfect lubrication of the axles, but its reduction is of secondary importance in the economic working of

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accompanying the increase of velocity up to 7·58 miles per hour: the subsequent increase of resistance is attributed to the displacement of the air, as explained in the body of the Report here quoted.

passenger trains, which, from their high velocity, must necessarily bring into play large and independent sources of resistance.

"The resistance to trains at different speeds being ascertained, the Committee directed their attention to the effect of external configuration on the resistance;" and from their experiments "concluded that the form of the front has no observable effect, and that whether the engine and tender be in front, or two carriages of equal weight, the resistance will be the same. The intermediate spaces between the carriages were closed in by stretching strong canvass from carriage to carriage, thus converting the whole train into one unbroken mass. The results were in favour of the train without canvass, but the differences are extremely slight: it is certain that no additional resistance is occasioned by leaving open spaces between the carriages, confining the intervals to the dimensions allowed in practice."

It must be observed here that no record appears as to the *speed* at which these experiments upon "the effect of external configuration" were tried. Upon the speed would, I apprehend, depend much of the result. The surrounding air may be in a state of comparative quiescence, or it may be moving at a slow rate in the same direction as the moving train, or in a direction opposite to, or different from, that of the train. Under either of these circumstances the rapid passage of a train at a high velocity would cleave its way through the air, and, by its very quickness, (many times greater than that of the motion of the air,) clear the way for all that followed it, giving no time to the adjacent air to penetrate between the carriages, or create any resistance after that encountered by the leading carriage or engine; whereas at a less velocity, below 7·58 miles per hour, the surrounding air has an opportunity of playing with a retarding effect between the several carriages in the train, and thus practically creating a great resistance, which of course diminishes with the augmentation of the velocity up to that speed (probably 7 or 8 miles per hour) at which the train "outstrips the wind." Deeming this suggestion entirely accordant with common sense, and consistent with the reporters' own experiments, I would beg to advance it not in preference to, but to be considered along with, the explanation they offer of the fact of resistance diminishing with the increase of speed up to 7·58 miles per hour, and referred to in Note 22.

"The Committee having ascertained that the excess of resistance, after deducting friction, required for its estimation something besides the elements of the dimensions and forms of frontage, and of continuity of surface, it becomes important to inquire what is the element exerting so powerful an influence? Their former Report contains the results of experiments with waggons on the Madeley incline, loaded to 6 tons each, and furnished with boarded fronts and sides, moveable at pleasure: the differences in the results attained were then referred to the increased frontage alone. But the experiments detailed in the present Report having been made, it became probable that the increased resistance was in a great measure dependent on the general volume of air displaced; and the Committee recommend experiments to be directed, to ascertain the effect on the resistance of diminishing and increasing the bulk of trains, the weight remaining the same."

It is very desirable that the course of experiments here recommended by the Committee should be prosecuted; more especially as those here recorded as having been already instituted, appear to warrant a somewhat different inference from that drawn by the reporters. Their assertion of the probability "that the increased resistance was in a great measure dependent on the *general volume* of air displaced," seems entirely inconsistent with the results of the experiments previously reported upon one train of eight carriages, and two others of four carriages each. From these it appeared that the eight carriages, which must have displaced twice the *general volume* of air displaced by the trains of four carriages each, yet suffered a resistance which only reduced their velocity from 26 to 25½ miles per hour; while the four-carriage trains met with resistances that reduced their velocity in one case from 40 to 25 miles per hour; in the other, from 32·7 to 22·7 miles per hour. It might have been inferred, that at any velocity above that which would allow the surrounding air to enter between the several carriages of the train, the resistance was proportioned to the *velocity* only, being unaffected by the volume of air displaced, (provided the front surface of the leading carriage or engine remains the same,) but of course liable to be overcome by the superior gravity of the mass descending the plane, as shown by the slightly abated velocity of the heavy train of eight carriages.

Gauge.—On this subject it is necessary only to quote some passages from the Reports made by Mr. I. K. Brunel and Mr. N. Wood, to the Directors of the Great Western Railway Company, in which Reports all the reasons that can be urged as affecting this detail of railway engineering are presented, and the most complete experiments yet made upon it are recorded. Before the formation of the Great Western Railway, the width adopted between the rails was 4 feet 8½ inches. Mr. Brunel at once signalized the undertaking committed to his care by adopting the gauge of 7 feet, being an excess over the previous width of 2 feet 3½ inches. The ends to be sought in the determination of the gauge appear to be,—adequate width for the machinery of the locomotive engine and for the carriages, so as to constitute them convenient and comfortable for travellers;—adequate width also for the conveyance of road-carriages and of general merchandize;—steadiness of motion, and safety and facility in passing round curves admitting a high rate of speed. These points are of course affected by the height (as determined by the size of wheels and construction) of the carriages and engines. While these considerations will determine the *minimum* width of gauge, there are others involving the expense of land, of wide bridges, viaducts, embankments, cuttings, stations, tunnels, &c., by which the *maximum* width must be limited. In the Report of Mr. N. Wood, above mentioned, and which is dated in December, 1838,[23] the reasons for the wide gauge are thus stated:

" From the documents previously alluded to, (Reports made by the Directors to the proprietary of the Great Western Railway,) from a careful perusal of Mr. Brunel's Reports, and from personal communications with that gentleman, the following appear to have been the prominent advantages expected to be derived from the increased width of gauge, and which induced the adoption of the width of 7 feet."

" *Attainment of a high rate of speed.*"—On this point Mr. Brunel remarks, " with the capability of carrying the line upwards of 50 miles out of London, on almost a dead level, and without any objectionable curves, and having beyond this, and for the whole distance to Bristol, excellent gradients, it was thought that unusually high speed might easily be attained; and that the very large extent of passenger traffic, which such a line would certainly command, would insure a return for any advantages which could be offered to the public, either in increased speed, or in increased accommodation."

" *Mechanical advantage of increasing the diameter of the wheels, without raising the bodies of the carriages.*—This comprehends what is deemed by Mr. Brunel the most important part of the advantage of an enlarged width of gauge, viz., the reduction of friction by the increased diameter of the wheels; while at the same time, by being enabled to place the body of the carriage

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[23] Printed in the 'Civil Engineer and Architect's Journal,' vol. ii. p. 58.

within the wheels, the centre of gravity of the carriage is kept low, and greater stability and steadiness of motion are expected to be attained. Four-feet wheels have been put upon the carriages at present in use upon the line, but Mr. Brunel states, that he 'looks forward to the employment of wheels of a larger diameter; and that he has been influenced to a considerable extent, in recommending the increased width of gauge, by its capabilities of prospective improvements which may take place in the system of railroads.' He observes, 'that though there are some causes which in practice slightly influence the result, yet practically the resistance from friction will be diminished exactly in the same ratio that the diameter of the wheels is increased; and considering that the gradient of 4 feet per mile only presents a resistance of less than 2 lbs. per ton, and that the friction of the carriages on ordinary railways amounts to 8 or 9 lbs. per ton, being $\frac{8}{10}$ths of the entire resistance, any diminution of the friction operates with considerably more effect upon a road with favourable, than one with more unfavourable gradients;' and he further says, 'I am not by any means at present prepared to recommend any particular size of wheels, or even any increase of the present dimensions. I believe they will be materially increased; but my great object would be in every possible way to render each part capable of improvement, and to remove what appears an obstacle to any great progress in such a very important point as the diameter of the wheels, upon which the resistance which governs the cost of transport, and the speed that may be obtained, so materially depend.'"

"*Admits all sorts of carriages, stage coaches, &c., to be carried within the wheels.*—Presuming that the adoption of wheels of a larger diameter is found beneficial, to the extent expected by Mr. Brunel, it became necessary that the carriages to be conveyed should be placed upon platforms within the wheels, to keep them as low as possible, which could not be done with carriages on railways of the ordinary width; a wider gauge seemed therefore necessary for this purpose."

"*Increased facilities for the adoption of larger and more powerful locomotive engines, for the attainment of higher rate of speed.*—Much stress has not been laid upon this by Mr. Brunel, although it has been alleged that great difficulties exist, and that considerable expense is incurred by being obliged to compress the machinery into so small a space; and consequently, that a greater width of gauge would enable the manufacturer to make a more perfect machine, and by having more space for the machinery, the expense of repairs would be lessened."

"*Increased stability to the carriages, and consequently increased steadiness of motion*, not from any danger to be apprehended, by the centre of gravity being higher in carriages of a less width; but that higher carriages are more liable to oscillate upon the railway, than carriages of a greater width and less height, and that a considerable part of the friction is occasioned by the oscillation of the carriages throwing the flanges of the wheels against the rails."

The objections which have been urged against the wide gauge are enumerated by Mr. Wood as follows:

"1st, The increased cost of forming the road track of the railway, in consequence of a greater width of base required for the superstructure of the rails and upper works. 2nd, That the carriages were required to be larger and heavier. 3rd, That the increased width of gauge caused additional friction in passing through the curves. 4th, That it entailed a greater expense of constructing the engine and carriages; increased liability to the breakage of axles, &c. 5th, That it prevented a junction of the Great Western with other railways; and, 6th, above all, That there were no advantages gained, commensurate with the increased expenses and inconvenience of such a departure and disconnexion from railways of the ordinary width; and several other objections which have been urged by different persons against the system, which it is not necessary to enumerate."

Mr. Wood then proceeds to describe the experiments instituted by him with a view to testing the validity of Mr. Brunel's reasons for adopting the gauge of 7 feet, and the objections urged against it by others. The results are stated as follows:

"We find, from the results previously enumerated, that a higher rate of speed has been attained on the Great Western Railway than on other railways. This has been accomplished by the increased power of the engines employed on that railway, above that of those on other railways: before, however, we can determine whether the increased gauge is, or is not, necessary, or best adapted for the accomplishment of this object, and to what extent, we must inquire whether engines of the power by which such performance was effected on the Great Western Railway, or such a power of engine as would accomplish that rate of speed, can be applied on railways of the ordinary width."

On this point the Report states, that "there are engines in use upon railways of the ordinary width, more powerful, in the proportion of 263 to 228, than an engine upon the Great Western Railway, which effects a rate of speed, within

3 miles an hour, of the most powerful engine on that railway. We have had no opportunity of subjecting these more powerful engines, on ordinary railways, to experiment, which would have been very desirable on the present occasion; but we find such engines, with an evaporating power of 165·26, effecting the same rate of speed on those railways, as the engine of 228·09 on the Great Western; and therefore the presumption is, that engines on railways of the lesser width of gauge, of the evaporating power of 253·21, or 263·8, would effect an increased velocity, quite equal to, if not greater, than that of the largest engine on the Great Western Railway."—"The inference which appears to me to result from these experiments is, that with engines of the same power, a greater result, and consequently a greater rate of speed, may be realized on the ordinary width, than upon the increased width of gauge of railway. If the object be to accomplish the greatest possible speed, a wide gauge is unquestionably better adapted for the construction of the largest possible engines, than the narrow gauge."—"The question, therefore, whether an increased width of gauge is or is not necessary, depends almost entirely upon the determination of what rate of speed it is advisable to attempt, or it is resolved upon to establish. If a mean rate of 32 miles an hour at full speed be sufficient for the purpose, or such increased rate as engines of the largest dimensions now in use on other railways can accomplish, then it will not be necessary, so far as the motive power is concerned, to increase the width of gauge. But if a greater rate of speed is required, the question assumes a different shape; and it must then be ascertained if an engine can be erected upon the lesser width of gauge to perform that rate of speed.

"If the object be the attainment of the rate of speed assigned by Mr. Brunel, (38 to 40 miles per hour,) the present engines, it will be seen by these experiments, cannot accomplish that performance, including all the vicissitudes of weather and other casualties; and, therefore, if a mean rate of speed of 40 miles an hour, including stops, is to be attempted, more powerful engines will be required.

"These experiments, however, show the immense sacrifice of power incidental to an extreme high rate of speed, or the accomplishment of a rate of 38 or 40 miles an hour, above that of 32 or 35 miles. If economy of conveyance is to be taken into consideration, it becomes a serious consideration whether such a system should be acted upon as that of providing for an indefinite rate of speed, or that a maximum rate should not be determined upon, and that such standard should be composed of that speed which will best suit the public conveyance generally, and at the same time comprehend every possible economy and regularity."[24]

Upon the first advantage claimed for the 7-feet gauge by Mr. Brunel, that of increased speed, Mr. Wood's experiments go to show, that if a greater width than 56½ inches be promotive of this result, at any rate, that the engines then used on the Great Western Railway did not accomplish any greater proportionate speed than engines adapted for and used upon the narrow gauge. Among the conclusions resulting from these experiments are the following:

	London and Birmingham, 4′ 8½″ gauge.	Great Western. 7′ 0″ gauge.
Extreme rate of speed	40·9 miles ⅌ hour.	45 miles.
With a load in tons of	34·5	50·0
Mean rate of speed in miles per hour	32 miles.	35 miles.
With a load in each case of	50 tons.	50 tons.
Estimated powers of evaporation stated in cubic feet of water evaporated per hour, and with a load of 50 tons in each case	163·87	288·28
Water evaporated per mile in cubic feet . . .	5·12	8·23
Consumption of coke per mile for each ton of the load, in pounds weight	·59	1·02

The engines here tried were the *Harvey Combe* on the London and Birmingham, and the *North Star* on the Great Western. The comparison between

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[24] The wisdom of the course here indicated is made apparent by all recorded experiments upon the resistance to which moving trains are subject. The results of some recent experiments upon the Sheffield and Manchester Railway, reported by Mr. Scott Russell to the British Association for the Advancement of Science at their last meeting at York (1844), show, that while the resistance at slow velocities does not exceed 8 ℔s. per ton, it becomes equal to 19 ℔s. per ton at a velocity of 23·6 miles per hour. In descending planes this amount of resistance is reduced by the gravity of the moving mass, which, increasing with the load, enables heavy trains to descend with much less resistance and consequent diminution of velocity than light ones. Thus no greater resistance is encountered by a loaded train at 30 miles per hour, than by a light train at 23·6 miles per hour. The conviction of the truth of these results will, it may be expected, lead to more moderate expectations as to speed than have commonly prevailed since the successful introduction, or rather improvement, of the locomotive steam engine. Professional experience has already dictated an ordinary speed much below that obtained upon extraordinary occasions, when *cost* of power has been temporarily disregarded.

the *Harvey Combe* and the *Æolus*, (another of the wide-gauge engines,) however, shows the performance of the latter in a still less favourable light than those of the *North Star*. The *Æolus*, with estimated powers of evaporation of 228·09 cubic feet of water per hour, consuming ·76 ℔. of coke per ton per mile, carrying only an equal load of 50 tons with the *Harvey Combe*, maintained a mean rate of speed *less* by ·4 mile per hour than the latter engine!

In replying to this Report, Mr. Brunel stated that "experiments have since been made, giving very different results, and I can prove that if an engine be properly constructed for high speeds in the manner which I have always proposed, that there is no such 'immense sacrifice of power incidental to an extreme high rate of speed, or the accomplishment of a rate of 38 or 40 miles per hour, above that of 32 or 35 miles,' and that the same engine, which was then only capable of taking 40 tons at an average velocity of 38 and a maximum of 41½ miles per hour, is now capable of taking 40 tons at an average velocity of 40 miles per hour; and further, that the consumption of coke per ton, so far from being extravagant, is not so great as that of the engines on the London and Birmingham Railway, when only travelling at a mean rate of 30 miles per hour." The experiments on which these assertions were based do not appear to have been published or in any manner detailed to the public.

On the "mechanical advantage of increasing the diameter of the wheels without raising the bodies of the carriages," the second alleged advantage of the 7-feet gauge, examined by Mr. Wood, he suggests the difficulty of deducing any definite conclusions. This appears to arise from three doubtful data, which Mr. Wood's experiments did not enable him to determine, viz.: 1, The proportion of the total resistance due to atmospheric agency, and to mechanical friction; 2, The increased atmospheric resistance encountered by large wheels over small ones; and 3, The proportion in which these resistances operate at high rates of speed. Mr. Wood, however, considered that his experiments did sanction the assumption that of the whole resistance encountered at a speed of 32 miles an hour, 22 per cent. only is due to friction, and 78 per cent. to atmospheric resistance. As it is this 22 per cent. only, which it is alleged may be reduced by large wheels, while it seems moreover probable that the 78 per cent. may be somewhat *increased* by them, the possible benefit accruing from their adoption is reduced to a very trifling amount.

The third benefit stated, as to the admission of carriages, &c., between the wheels, being a desideratum only when wheels are used of too large a diameter to allow the truck to project over them, as is commonly done with the narrow gauge, does not call for any examination until the advantage of the large wheels is determined.

The claim of the fourth advantage, viz., facilities for using more powerful engines on the wide gauge, seems sufficiently answered by the performances already quoted of the London and Birmingham and Great Western engines. Indeed, Mr. Wood stated in his Report, that Messrs. Stephenson had then (six years ago) constructed an engine for the Leicester and Swannington Railway (4′ 8½″ gauge), having an evaporating power of 263·8, only 25·20 cubic feet of water per hour less than the most powerful engine at that time built for the Great Western Railway. And the subsequent improvements in the wide engines have certainly not outstripped those of the narrow ones so as to reduce this proportion in their favour.

"The remaining proposition," says Mr. Wood, "is, that a wider gauge affords increased stability to the carriages, and consequently, increased steadiness of motion. The diagrams given will show how far this has been effected on the present portion (22½ miles) of the Great Western Railway, and certainly these documents would prove that this has not yet been accomplished. Considering, however, the causes of the different motions of railway carriages, there can be no doubt that an increased width of gauge must tend to produce that effect. In the present instance this has been counteracted by the construction and present condition of the road and carriages; and therefore it appears to me the only conclusion we can come to is, than in similarly-constructed railways the wide gauge will afford greater stability and steadiness of motion to the carriages." General observation of the motion upon the Great Western Railway, will, it is believed, confirm the fact of its greater steadiness, although probably only a part of this result is attributable to the width of gauge, something being due to the construction of the railway upon continuous wooden sleepers, to the easy gradients, and the great radii of the curves.

The six objections quoted by Mr. Wood may be thus disposed of:—First, the increased cost of forming the road-track must be admitted, although this would appear to be trivial, according to Mr. Brunel, while the difference in width of land, of embankments, cuttings, viaducts, and tunnels, does not seem necessarily great between the requirements of the narrow and the wide gauge. Mr. Brunel, in his Report to the Directors in 1838, states,—"a 7-feet gauge requires no wider bridge or tunnel than a 5-feet; the breadth is governed by a maximum width allowed for a loaded waggon, or the largest load to be carried on the railway, and the clear space to be allowed on either side beyond this. On the Manchester and Liverpool Railway, this total breadth is only 9 feet 10 inches, and the bridges and viaducts need only have been twice this, or 19 feet 8 inches. Nine feet 10 inches was found, however, rather too small; and on the London and Birmingham, with the same width of way, this was increased to 11 feet by widening the interval between the two railways."

"In the space of 11 feet allowed for each rail, a 7-feet gauge might be placed just as well as a 5-feet, leaving the bridges, tunnels, and viaducts exactly the same; but 11 feet was thought by some still too narrow, and when it is remembered that this barely allows a width of 10 feet for loads, whether of cotton, wool, agricultural produce, or other light goods, and which are liable also to be displaced in travelling,—13 feet, which has been fixed upon in the Great Western Railway, and which limits the maximum breadth, under any circumstances, to about 12 feet, will not be found excessive. It is this, and not the increased gauge, which makes the minimum width actually required under bridges and tunnels, 26 feet instead of 22 feet.

"The earth-work is slightly affected by the gauge, but only to the extent of 2 feet on the embankment, and not quite so much in the cuttings; but what in the practice has been the result? The bridges over the railway, on the London and Birmingham, are 30 feet, and the width of viaducts 28 feet. On the Great Western Railway, they are both 30 feet: no great additional expense is therefore incurred on these items, and certainly a very small one compared to the increased space gained, which, as I have stated, is from 10 to 12 feet. In the tunnels exists the greatest difference. On the London and Birmingham Railway, which I refer to as being the best and most analogous case to that of the Great Western Railway, the tunnels are 24 feet wide. On the Great Western Railway, the constant width of 30 feet is maintained, more with a view of diminishing the objections to tunnels, and maintaining the same minimum space which hereafter may form a limit to the size and form of every thing carried on the railway, than from such a width being absolutely necessary.

"Without pretending to find fault with the dimensions fixed, which have no doubt been well considered upon the works on other lines, I may state that the principle which has governed me, has been to fix the minimum width, and to *make all the works the same, considering it unnecessary to have a greater width between the parapet walls of a viaduct, which admits of being altered, than between the sides of a tunnel, which cannot be altered.*

" The embankments of the London and Birmingham Railway are 26 feet,—on the Great Western, 30 feet; making an excess of about 6½ per cent. on the actual quantity of earth-work.

" The difference in the quantity of land required, is under half an acre to a mile. On the whole, the increased dimensions from 10 to 12 feet will not cause an average increased expense in the construction of works and purchase of land, of above 7 per cent.,—8 per cent. having originally been assumed in my Report, in 1835, as the excess to be provided for."

The extent to which the second objection, that of the increased weight of the carriages, prevails is this:—a Birmingham first-class carriage weighs 3 tons 17 cwt. and 2 qrs.; a Great Western first-class weighs 4 tons and 14 cwt. The one, however, carries 18 passengers, while the other carries 24 passengers. While the weight on the four wheels is thus made greater on the Great Western than on the London and Birmingham, the gross weight per passenger is less in the former than in the latter case, being as 588 to 631 ℔s.

The 3rd objection, the greater friction produced in passing round curves, must be allowed its full force, as a general principle, although in the case of the Great Western Railway, it is much alleviated by the great radii of all the curves.

The 4th objection is of little weight, and practically the liability to breakage of axles from their increased length is not found to exist. The applicability of the 5th will depend upon the position of the railway, whether destined to be isolated from or connected with other lines of which the gauge is already determined.

There is another objection, suggested by the results of the experiments made upon the resistance offered by the atmosphere, which ought not to be overlooked, viz., the increased resistance occasioned by the greater size of frontage of carriages and engines adapted for the 7-feet gauge. The Report already so largely quoted from does not detail any experiments with carriages for the wide gauge; but as the resistance doubtless increases in the same proportion as the area of frontage, and this area is as 81 to 53 for the two gauges, the resistance arising from the atmosphere must be supposed to be much increased by the adoption of the wide gauge.

The 6th and last objection, viz., that the 7-feet gauge realizes no advantages commensurate with the increased expense and probable inconvenience connected with its adoption, amounts practically to a denial of all the reasons assigned by Mr. Brunel in favour of it; yet it appears that Mr. Wood's opinion that this objection is substantially confirmed by the results of experience, is correct, although there are some advantages gained by an increase of gauge beyond 4 feet 8½ inches, which well deserve attention in planning lines for new countries, or lines that will be beyond the liability to connexion with others already executed to that gauge. It is a curious fact connected with this subject, and illustrative of the commercial value of uniformity of gauge, that the entire of the Eastern Counties, and Northern and Eastern Railways, as yet executed, comprising about 85 miles of line, have recently been altered from the gauge adopted in their formation (5 feet), to the more general gauge of 4 feet 8½ inches,—thus involving a tremendous expense, not only in this alteration but in others depending upon it, viz., width of carriages, engines, &c., in order that these lines may eventually be susceptible of connexion with the northern lines already made to the narrow gauge.

Tredgold treated the subject of gauge thus:

"The breadth of the track ought to have some relation to the height of the load, in order that the carriage may be always in stable equilibrium on the rails; and in railroads there is another circumstance to be considered,—the pressure on the rails should not be materially altered by any slight depression of one side of the road. It may be taken as a general rule, for the width between the rails for carriages travelling at a greater speed than 5 miles per hour, that the centre of gravity should not be higher in proportion to the breadth between the rails than as 1 is to 1½."—"The width between the rails being therefore dependent on the height of the centre of gravity of the loaded carriages, and this again varying with the nature of the load and the velocity, it will be obvious we cannot do better than make the breadth between the rails such, that, by disposal of the load, the centre of gravity may be kept within proper limit in either species of vehicle, whether swift or slow. And it would be desirable that the same breadth and the same stress on a wheel should be adopted in all railways. We would propose 4 feet 6 inches between the rails for heavy goods, and 6 feet for light carriages, to go at greater speed."[25]

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[25] 'A Practical Treatise on Railroads and Carriages,' by Thomas Tredgold. Second edition, 1835, p. 118.

We have at present three widths of gauge in England, viz., 4 feet 8½ inches, 5 feet, and 7 feet: two others in Scotland, viz., 4 feet 6 inches, and 5 feet 6 inches; and one yet different from any of these in Ireland, viz., 6 feet 2 inches.

In concluding these preliminary considerations of curves, gradients, and gauge,—subjects which are held to involve so much of the current economy and commercial success of our railways,—the following Table, which has cost some pains in its compilation, may be presented as embodying some interesting facts appertaining to each of nine railways, and showing generally the value of each line, both to the proprietors, in interest for their expended capital, and to the travelling public, in rapid and economical means of conveyance.

	A.	B.	C.		D.	E.	F.	G.	H.
					According to the latest balance-sheets.				
Name of Railway.	Curves.	Gradients.	Gauge.		Cost of working for six months, per mile.	Returns for six months, per mile.	Dividend per cent. per annum.	Velocity, average miles per hour.	Charge, average pence per mile.
			ft.	in.	£.	£.	£. s. d.		
1. Dundee and Arbroath .	very slight	nearly level	5	6	183	430	5 0 0	w. 21	1·45
2. Grand Junction . . .	medium	second class	4	8½	810	1875	10 0 0	22·14	2·29
3. Great Western . . .	very slight	first class	7	0	595	1666	7 0 0	25·80	2·14
4. Liverpool and Manchester	medium	third class	4	8½	1861	3823	10 0 0	w. 23·93	2·53
5. London and Croydon .	slight, but all curved	second class	4	8½	739	1028	2 10 0	w. 20·78	1·17
6. London and Birmingham	slight	first class	4	8½	825	3606	10 0 0	24·50 or 22·14	1·93
7. London & South Western	medium	second class	4	8½	736	1617	6 10 0	21·81 or 20·26	2·28
8. Newcastle and Carlisle	severe	second class	4	8½	429	1197	4 0 0	19·42	1·89
9. North Union . . .	medium	second class	4	8½	258	1021	6 16 8	w. 22·0	2·03

The Table consists of eight columns, lettered A to H. Of these, three may be regarded as exhibiting the constructive peculiarities; three, the commercial; and, two, the public features of each line. Thus, columns A, B, and C, describe the *curves, gradients,* and *gauge;* columns D, E, and F, show the cost, per mile, of working the railway for six months,—the returns, per mile, for the same period of six months,—and the dividend per cent. per annum paid to the shareholders. All these three items are given according to the latest balance-sheets of the respective companies. Columns G and H show the average velocity in miles, per hour, of the four, five, or six daily trains on each line, and including all stoppages. For the London and Birmingham, and the South Western Lines, two rates of velocity are quoted: the first or greatest rate, is excepting the one daily slow third-class and goods train; the second or least rate, is inclusive of this train, which being taken into account, greatly reduces the average velocity. Still it appears but fair that this reduced rate should be adopted as the average. The public, consisting of *all* classes, is assumed to be interested in the *general* average velocity; the working man's eight hours are at least as valuable to him as the rich man's five hours are to those who can afford to pay higher fares; and those railway companies who find it economical or deem it politic to distinguish thus between their customers, cannot be considered as affording equal accommodation with those who do not. Column H shows the charge in pence and decimal parts made by each company, per passenger, per mile, on the average of the two or three classes of fares, as the case may be, charged by each.

The terms used in column A, as descriptive of the curves, are merely comparative, and cannot be fixed as indicative of any precise limits of curvature. The classification adopted in column B is according to that suggested by Mr. Whishaw, calling all gradients not exceeding 16 feet per mile, or 1 in 330, the *first class;* those not exceeding 52·80 feet per mile, or 1 in 100, the *second class;* and those not exceeding 80 feet per mile, or 1 in 60, the *third class.* This mode of distinguishing is, however, inadequate to exhibit the *general* character of the gradients. This could perhaps be effected by multiplying together the length and the rate of inclination of each gradient; combining these throughout the entire line, and balancing this compound quantity of inclination against the lengths of the level planes united. Yet many reasons will occur to show that this would by no means express the relative goodness or badness of the gradients as likely to affect the beneficial working of the railway. The cost of working, returns, and dividend, are quoted from the documents published in the 'Railway Times' weekly paper. The velocity and charge are from the Time and Fare Tables published under authority of the several companies; except in the four instances marked 'W.' In these cases, the Time Tables not containing the required information, the authority has been taken from Mr. Whishaw's experiments, published in his work on railways.

By this Table only an approximate comparison is attempted to be drawn between the several railways named upon the various points indicated in the columns. No statistics of this kind probably would warrant any very definite principles as to the construction or the management of a railway. It is not found that the velocity, or the fares, or the current expenses, or the average returns, vary in any assignable ratio according to the curves, the gradients, or the gauge. Although the general principles which are indicated by the evidence cited in the preceding pages are applicable in each individual case, their results are comparable only *cæteris paribus*, and as this condition of things seldom or never exists, no such comparison can serve as a practical test of the general rules observed. Its real value consists in the proof it affords that the discretion of the engineer cannot overcome, although it undoubtedly modifies, those causes of expense and difficulty in construction which belong naturally or locally to the routes which he is required to adopt.

SLOPES.—On this point of railway practice, beyond stating the evident principle that the inclination of the slopes must be determined mainly by their height and by the nature of the material excavated, or of which the embankment is composed, we propose merely to quote the slopes adopted by the engineers of some of the British railways already formed, reserving for the Second Section, upon Earth-works generally, such statements and descriptions of their construction and mode of treatment as appear desirable.

Birmingham and Gloucester.—The cuttings are chiefly through marl and lias clay. The greatest depth excavated is 85 feet (at Moseley), sloped at 1½ to 1; that is, 1½ length of base to 1 in vertical height. The highest embankment is 62 feet, sloped at 2 to 1.

Chester and Birkenhead.—For heights under 35 feet, the slopes are 1½ to 1, and 2 to 1 above that height, the slopes being soiled and sown with grass-seed.

Durham and Sunderland.—A cutting, 60 feet deep, sloped at 1½ to 1, through loose clay and sand, has occasioned considerable expense and trouble in attempts to prevent the sides slipping in.

Great Western.—A cutting east of the Brislington tunnel, of considerable depth, containing 30,000 cubic yards, has vertical sides.

London and South Western.—The slopes vary from 1 to 1, to 2 to 1, according to the strata, which consist generally of loam, gravel, sand, London clay, and flints with chalk.

Midland Counties.—The greatest depth of the Leir cutting is 62 feet, sloped at 2 to 1; the Leir embankment, 40 feet high, is formed with similar slopes.

Newcastle and Carlisle.—The Corvran Hill cutting is through clay with veins of sand intermixed; the average depth is 43 feet; greatest depth 110 feet; sloped 1½ to 1.

Newcastle and North Shields.—Cuttings through stratified clay are sloped from 2 to 3½ to 1; through unstratified, 1½ to 1. The embankments, formed mainly of small coal, are sloped from 1½ to 2½ to 1.

North Union.—Slopes for cuttings and embankments, if very trifling in depth or height, 1 to 1; if 15 feet, 1½ to 1; and exceeding 15 feet, 2 to 1.

Slamannan.—Cuttings through hard blue clay, 16 to 40 feet deep, have slopes at 2 to 1. Embankments 40 feet high, formed with same slope.

South Eastern.—The Leigh cutting, through hard white sand with some marl, sloped at 1½ to 1. The River Medway embankment at 2 to 1.

Ulster.—The material excavated and used for embanking is a loose slippery clay, and although the slopes are 2 to 1, much difficulty was experienced in preventing their failure.

SECTION II.

EARTH-WORKS, CUTTINGS, EMBANKMENTS, AND DRAINS.

The course and section of the railway, and the width of surface required, being determined, those operations included under the title of this section claim the first attention of the engineer in proceeding to form his line.

Some geological examination of the materials he will have to deal with may be supposed to have aided the engineer in determining his slopes, and this also must dictate the kind of arrangements that will be necessary for draining the railway. Thus, all stratified materials occurring in layers having an inclination to the horizon are liable to a slipping of one stratum from another, which make it necessary that all slopes through these strata should be much less steep than would be safe in unstratified materials. These slippings, caused by the passage of water, or the action of frost between the strata, must also be sought to be prevented by draining the faces of the cutting, and extending the drainage also backward for some distance, so as to collect all the water that may find its way into the neighbouring soil, and conduct it safely away before it arrives on the face of the work. A complete superficial drainage must also be provided for the water that may collect upon the surfaces of the cutting. Alternating strata of sand and clay are perhaps the very worst that can occur to the railway engineer. Soils having these same materials *mixed* are much more favourable and safe. Stony soils, or those composed of sand and gravel mixed, also become very compact and hard. Through rocks, excavations may be formed with very steep sides, although if the rocks be of a kind that is liable to disintegration by moisture, a greater flatness, which exposes the sides to the evaporating action of the sun and air, becomes desirable.

Chalk is one of the materials whose own cohesion is sufficient to keep it together if cut with faces vertical or nearly so. From some observations on chalk excavations by Mr. S. Hughes,[26] the following extracts may be usefully quoted:

" A great deal of discussion arose during the struggle between the various Brighton lines, in the session of 1837, as to the best method of forming the chalk excavations. It was argued by one party that a slope of from $\frac{1}{2}$ to 1, to 1 to 1, should be adopted for the cuttings; while another proposed to make the sides nearly vertical, contending that a slope of $\frac{1}{6}$ to 1 was sufficient. A third party proposed a system of benching at about every 15 feet in height, the successive steps to be vertical, and to be faced with rock-chalk."

Plate XXXIV. Fig. 1 represents the two latter of these suggestions, the left-hand half of the excavation showing the method of uniform slope proposed by Mr. Rastrick; the right-hand showing the system of benching and facing suggested by Mr. Gibbs.

" The South Foreland is a very remarkable face of chalk, which appears at a distance to be nearly vertical, but on approaching more closely is found to

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[26] Printed in the 'Civil Engineer and Architect's Journal,' vol. ii. page 207.

slope about ⅓ to 1. The height is about 350 feet, and a considerable quantity of *débris* has fallen to the base of the cliff. In the neighbourhood of Chatham are several chalk excavations, but none so extensive as those at Dover. East of the town, on the road to Maidstone, a cutting of about 30 feet in depth stands nearly vertical. In the fortifications of Chatham, most of the chalk, as at Dover, is faced with brick-work. One excavation, however, forming a gorge from the river to the crest of the works, has been cut for some distance without facing, with a slope of ⅓ to 1, in depth about 40 feet; another part of this gorge is faced with brick, the same slope being preserved."

Mr. Hughes states his belief of the greater cohesion of the upper beds of chalk as follows:

" From almost every instance I have been able to observe, I think it clear that the upper chalk with flints, when not much shaken, really will stand upright without scaling. At the same time it is no less certain that, below a particular depth, the chalk undergoes a very apparent and extensive decomposition, and in many cases presents a base visibly hollowed out.

" It is hardly in accordance with hitherto received opinions on the subject of chalk cuttings, to say that these will stand better in their upper than their lower beds, and yet the result of every observation made on the chalk of Kent, leads positively to the conclusion that the superior beds of chalk are less subject to decomposition than the lower. Instances in proof of this may be seen at Dover, particularly on the eastern side of the town; at Chatham, in the military works; at Rochester, and the other entrance of the Thames and Medway tunnel; and at the quarries of Northfleet and Greenhithe."

Respecting the chalk excavations on the line of the London and Birmingham Railway, it is stated,—

" The chalk of Watford tunnel is very soft and white, with numerous layers of flint, and much saturated with water, in which respect it differs from all the former kinds of chalk I have described,—these being all remarkably dry, at least as deep as they have hitherto been explored. At the northern end of Watford tunnel is the same soft white chalk with flints. The slope from the base is ¾ to 1, until within 15 feet of the surface, when the slope is increased to 1½ to 1. The cutting near Cow Roost consists also of very white chalk, much saturated, and the slopes are 1½ to 1, in 25 feet cutting. Further on the line, in a cutting near the road from Tring, the lower grey chalk occurs in moderately sized blocks. The cutting at the north end of the short Tring tunnel consists of chalk, chalk-marl, and a little gravel. The slope, which is

¾ to 1 in 35 feet cutting, stands well, and the chalk appears drier than in some of the cuttings nearer London."

Figs. 3, 4, and 5, Plate XXXV., illustrate one of the most interesting works on the London and Birmingham Railway, viz., the excavations at Blisworth. The principal excavation appears, by the sections published in the 'Public Works of Great Britain,'[27] to be about 126 chains in length, the greatest depth 53 feet. The strata intersected are—the upper soil, of a light sandy kind, with clay from 2 to 10 feet in thickness, and lying mainly in blue, yellow, and brown marl and red clay, of an average thickness of 20 feet. Under these is the limestone rock of various degrees of hardness and in beds of 1 to 4 feet in thickness, but without any mixture of shale, and having springs of water in the lower beds. At the east end of the section, the limestone rock outcrops, and the superior stratum of marl disappears. Beneath the limestone the blue shale is found; it appears to be dished on the upper surface, being about 6 feet thick at the east end, extending about 20 chains, then ranging beneath the railway level, rising again at the end of 75 chains, and acquiring a thickness of nearly uniform increase of 30 feet at the western extremity of the section, where it outcrops beneath the limestone.

At the west end, the excavation is formed to a slope of 2 feet base to 1 foot height throughout its whole depth, for a distance of 22 chains, the inferior stratum of shale being faced with rough stones. Through the next distance of 38 feet, the opening is narrowed by a winding batter[28] on each side to a section corresponding with that shown in fig. 3, Plate XXXV. The lower part, extending upward to a height ranging with the undersetting of masonry, beneath the rock, which is continued throughout the excavation, is formed to a curved batter of 106 feet radius. The average vertical height of this undersetting above the level of rails is 20 feet. The rock above is sloped at ¼ to 1, a benching of 9 feet wide being left on its upper surface, and the superior soil trimmed to a slope of 2 to 1.

The figures 3, 4, and 5, Plate XXXV., also exhibit the mode of draining adopted, with the inverts and buttresses for supporting the undersetting. Fig. 3 is a

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[27] Edited by Mr. Simms, and published by J. Weale. 1838.

[28] The French verb "bâtir," substituted by some engineers, seems no more expressive of the understood meaning of this term than the word batter, here used. We therefore retain the more common word.

cross section, one-half being taken through the wall, the other through one of the buttresses: fig. 4 is a sectional plan of half of the excavation, showing the recess wall, 2 feet 6 inches thick at top, battered in front to a slope of 2 inches to 1 foot. The centre drain, 1 foot 9 inches wide, and the cross drains, are shown in section. Fig. 5 is a longitudinal elevation of the undersetting, showing two of the buttresses with the inverts beneath in section. Midway between each two contiguous buttresses, a vertical drain or gullet is formed on the face of the wall, receiving the drainage water by oblique drains, shown in dotted lines from the puddling at the back of the wall.

The following extracts from the Engineer's Specification for this work, which will be found at length, illustrated by several magnificent folio plates, in the 'Public Works,' will explain the remaining particulars. "Wherever the shale or other soft strata lying under the limestone is found to rise above the level of the bottom of the cutting, a portion of such shale or soft strata shall be excavated from under the limestone on each side of the cutting, and replaced by walls, buttresses, arches, and inverts, as hereinafter described. The inverts to be of an invariable width of 27 feet, and to have a rise of 3 feet 3 inches, the radius being 29 feet 8 inches; the junction of which inverts with the face of the buttresses, to be always at the level of the surface of the rails. The back of the buttresses to batter outwards from the centre of the cutting at the rate of ¾ inch horizontal for 1 foot in height, as shown in the section; and the sides of the buttresses to batter out at the rate of 1 in 20 on each side, as shown in the plan and elevation. The recess walls to have the same batter at the back, corresponding with the buttresses, and the face of such walls to have a straight batter of 2 inches in 1 foot. These walls shall have three courses of footings of 1 foot each in depth, each course to step 6 inches. The bottom of the walls to be level with the bottom of the inverts and buttresses.

"At a depth never falling short of 1 foot below any wet stratum that may occur, two courses of the recess wall and buttresses to be projected beyond the back of the wall; the lower course to project beyond the upper, so as to receive a stone to rise 1 foot above the upper course, forming a drain 12 inches deep and 6 wide, to be surrounded at the bottom and back with a casing of sound puddle, and filled in at top with rubble stone, to allow the top water to have access to the drain." (This is shown on the cross section, Plate XXXV. fig. 3.)

"When the depth of the shale from the bottom of the rock to the bottom of the cutting shall be less than 14 feet, then the inverts between the buttresses shall be discontinued; and in lieu of the inverts, the buttresses shall have four courses of footings, when the depth of shale above the bottom of the cutting exceeds 10 feet, and three courses for all lesser depths. Further, when, as aforesaid, the shale, or clay, or other soft material, rises to the height of 10 feet above the bottom of the cutting, then the level of the bottom footings of the buttresses shall be 3 feet 3 inches below the said cutting, which depth shall decrease proportionally as the above height diminishes, until the rock meets the level of the bottom of the cutting."

The following account of some of the interesting earth-works on the Dublin and Kingstown Railway is extracted from the work of Mr. Whishaw already quoted. "Beyond Merrion the railway is carried by a sea embankment, which extends uninterruptedly to Blackrock. This embankment is about 50 feet wide, on a level with the rails, and about 95 feet at the base; the height being about 12 feet. It is chiefly formed from side-cuttings in the sand contiguous to the work, the whole being covered with a mass of earth, gravel, and rubbish taken from the shore. The face of the embankment is paved throughout with stones of from 1 to 12 cubic feet each, the whole being laid with a slope of 3 to 1. The foundation is carried down about 2 feet below the level of the sand; and the parapet, which is 2 feet 3 inches thick on the top, and 2 feet thick at 1 foot from the top, is finished as to its face, in the form of a parabolic curve, the object of which is to prevent the sea from washing over the railway. This parapet is 3 feet 6 inches in height. There is a cutting opposite to Blackrock House, the depth of which is about 36 feet, and the length about 7 chains, the slopes being formed at ½ to 1. The railway is again carried over the strand by a similar embankment to that already described."

The heavy earth-works upon the line of the North Midland Railway are thus described in the same work. "Among the principal works in this department may be mentioned the Oakenshaw and Normanton cuttings. The Oakenshaw cutting is in rock shale and bind, the greatest depth of which is 50 feet, and its contents amounted to 600,000 cubic yards, the greater proportion of which was led to form the Oakenshaw embankment, the average lead being about 1 mile, and the cost being at the rate of 1*s.* 7½*d.* per cubic yard, and of that carried to spoil, 1*s.* 4*d.* per cubic yard. The Normanton cutting is 55 feet at its greatest depth, and contained 500,000 yards, chiefly of rock and blue bind, the produce of which was for the most part led to form the Altofts embankment, and 70,000 yards thrown out to spoil, the average lead being 1½ mile, and the cost per yard 1*s.* 3*d.*, and of that carried to spoil, 10*d.* The slopes of cuttings are generally formed at 1 to 1, and of embankments at 1½ to 1. The whole width of cuttings is 33 feet, the top width of embankments 36 feet, and on the top surface of ballasting 26 feet. The works were let throughout (72·50 miles) in upwards of thirty contracts, varying in length from ½ a mile to 4¼ miles. The progress of the works in 1839 was so rapid, that not fewer than 450,000 cubic yards of excavation were effected per month, and the number of men employed amounted to about 8600; besides which there were 18 fixed engines working, chiefly at the tunnels."

On the Stockton and Hartlepool Railway, it is stated that "the total amount of cuttings is 340,000 cubic yards, (the length of the line is 8·175 miles,) or upwards of 41,000 cubic yards per mile. For some distance the line runs close to the sea; and here the seaward slope, or face of the embankment, is of curvilinear form, and constructed of well-puddled clay, being united with the solid clay which underlies the sand. Its stability has already been subjected to repeated tests during many very heavy seas, which have washed over it again and again; but yet it continues to stand well, and a considerable quantity of sand and shingle are already deposited at the base of the slope."

The celebrated example of Chatmoss, on the Liverpool and Manchester line, where Mr. George Stephenson contrived, at a cost below the average of other parts of the line, to get a secure foundation for the passage of the locomotive engines and heavy trains over a moss containing nearly double its bulk of water (670,000 cubic yards of raw moss forming only 277,000 yards of moss-earth), is thus described in Lecount's 'Practical Treatise on Railways,' 1839, page 46: "The depth of the moss varied from 10 to 34 feet, and its general character was such, that cattle could not walk on it; the subsoil was principally composed of clay and sand, and the railway had to be carried over it upon a level, and required cutting and embankment for upwards of 4 miles. Where the mode of doing this required an embankment, the expense of which, in the ordinary method, would have been enormous, as it must have been bottomed upon the subsoil of the moss, Mr. Stephenson contrived to use the moss itself in the following manner. Drains about 5 yards apart were cut, and when the moss between them was perfectly dry, it was used to form the embankment, and so well did it succeed, that only about four times the quantity was required that would have been necessary on hard ground. Where the road was on a level, drains were cut on each side of the intended line, by which, intersected with cross ones occasionally, the upper part of the moss became dry and tolerably firm: on this, hurdles were placed, either in double or single layers, as the case required, 4 feet broad and 9 feet long, covered with heath; on these was laid the ballast, and the method was fully successful. Longitudinal bearings, as well as cross sleepers, were used to support the rails where necessary, and the whole was thoroughly drained. In the cutting, the whole had to be accomplished by drainage entirely. Longitudinal drains about 2 feet deep were cut on each side of the intended line of railway, and when by this means the upper portion of the moss had become dry, about 12 or 15 inches in depth were then taken out, as in an ordinary case of excavation; the drains were then sunk deeper, and another portion taken out when dry, as before; and thus, by alternately draining and excavating, the depth required for the railway was attained, which in some instances was 9 feet, the embankments being as high as 12 feet. The only advantage in favour of these operations was, that the surface of the moss was higher than the surrounding country, which partially assisted the drainage; but when it is considered that, from the nature of the ground, an iron rod would sink by its own weight, it must be confessed that such an undertaking as carrying a railway along, under, and over such a material, would never have been contemplated by an ordinary mind. In a smaller moss, which had also to be crossed, and which was about 20 feet deep, although an embankment of only 4 feet high was required, the clay and gravel tipped amounted to as much as would form one 24 feet high on ordinary ground."

Figs. 1 and 2, Plate XXXV., illustrate an economical method of forming embankments and cuttings in districts where stone is plentiful, and which has been advantageously adopted on the Leeds and Selby and other lines. This consists in facing the embankment or the lower part of the cutting with rough stones, built in the rubble fashion, and with a batter sufficient to insure its stability. As adopted on the Leeds and Selby line, this facing to the embankments has a curved batter, the chord line of which forms an angle of 67° 30′ with the horizon. Embankments thus formed require to have strong parapets, as otherwise any deviation of the train from the rails would certainly be attended with terrible consequences. Where this occurs on the edge of an embankment formed of soil and sloped at 2 to 1, or thereabouts, the chances are great that the train is speedily arrested by sinking in the yielding material; but with embankments faced in this manner with steep sides, the least progress beyond the edge must inevitably overthrow the train. The great advantages of the method are, economy in quantity of earth-work to be embanked and in width of land required; also in facility of drainage, and consequent stability and durability. An open longitudinal drain or channel being formed behind the parapets, and made to communicate with vertical or oblique channels formed on the face of the stone-work, will conduct the whole of the water to the toe of the embankment, whence it is readily withdrawn by side ditches. Against these advantages, have to be considered, the increased chance of danger from the cause just explained, and the somewhat greater amount of labour, and of a more expensive kind, required in the construction. Applied to cuttings, this system of facing is free from the first of these objections, while its utility in economizing labour in excavating is much greater. A little consideration will show that the faced embankment saves only a triangular section on each side, while the faced cutting saves a trapezoidal section of nearly double area. The slope of the earth-work above is very efficiently drained by a longitudinal channel behind the top of the facing, connected either with channels on the face or perpendicular drains behind, with cross drains leading into the centre one, as shown in fig. 2.

Figs. 6, 7, 8, 9, and 10, Plate XXXV., represent the mode of forming cuttings and embankments adopted on the London and Birmingham and other railways. Fig. 6 is a half-section of an embankment, slopes 2 to 1; top width on formation-line, that is, below the ballasting, 33 feet; gauge 4 feet 8½ inches; central width between the two lines 6 feet. The slope is turfed. A bank and rail-fence skirt the bottom of the bank, and beyond there is an open ditch, 3 feet wide at top. Fig. 7 is a half-section of a cutting of a similar formation,—same slope, formation, width, gauge, &c. The upper edge of the cutting is guarded by a rail-fence on a bank; and the adjacent land is drained by an open ditch beyond, 5 feet wide at the top, 2 feet at bottom, and 1 foot 6 inches deep. Figs. 8 and 10 are enlarged views of the fences and ditches for cuttings and embankments, with ditches of different dimensions, and the posts being strengthened with spurs and struts. Hedges of quickset are planted within the fences. Fig. 9 shows a desirable method of protecting the toe of an embankment by a low underset wall of masonry, formed with a considerable batter. Another method of effecting the same purpose has been also advantageously applied, and is recommended by its cheapness. This is to erect a mound of earth skirting the lower edge of the bank, which, becoming consolidated, forms a good permanent ridge to prevent the bank spreading.

The stability of earth-works, both embankments and excavations, being so much aided by making their sides sufficiently flat, also requires that they be not too flat. The angle formed by the slope with the horizon must not exceed the angle of repose of the material: indeed, to provide for the shifting tendency of water forcing its way through the mass, and other operating causes, and, in embankments, the spreading effect of passing weights, the slope should be kept within that of the repose of the material; but on the other hand, every degree of unnecessary flatness is prejudicial (beyond being expensive in land, in material, in labour, and in time), by exposing a greater surface for the disintegrating action of the atmosphere and the weather, and impeding the efficiency of the drainage. Of course the sides of the work should be sufficiently flat to be acted upon by the sun and the wind, by which all external moisture is evaporated and the surface hardened; but in general it will be found that an angle a few degrees less than that of repose will be found to answer both the conditions of economy and stability; and a little extra attention in drainage will be found cheaper than giving additional flatness to the slopes. The banks are much preserved by covering them with turf or the surface-soil, (which should be taken care of for that purpose,) and afterwards sowing this with grass-seed. Spade-cuts, or channels, passing obliquely from the summit of the slope to the drain at the base, so as to form a repeated outline of the letter V on the face of the bank, are cheap and efficient as surface-drains. On high banks these channels are sometimes needed, intersecting each other. Semi-cylindrical drain tiles, without holes, form a more perfect conveyance for the water.

In cases where a deep cutting occurs over a sharp curve it is advisable to pare down the surface of the bank on the interior side of the curve. By this means the traffic is conducted with greater safety, as the view of the engine-drivers is much extended; and also the bank so flattened down is made more stable than it would otherwise be, such projecting points being peculiarly exposed to the weather, as similar points of a river-shore are to the tides.

The inner slope of embankments on curves may be advantageously filled in beyond the regular line, as the swelling of the mass after frost is thus allowed greater room, and there is less liability of the particles to ride over each other, which immediately occasions a rupture of the mass.

As the earth-works of a railway absorb a very large proportion of the total cost, it is evident that economy in this department is especially desirable. This depends mainly upon the nature of the material to be operated upon, and, to no inconsiderable extent, upon the season during which the work is carried on. Besides these influential circumstances, there are others, however, connected with the *manner* in which the operations are conducted, which will claim the anxious supervision of the engineer, and his duties in this respect are not much lightened by the work being usually committed to the contractors; for he has still to judge of their mode of proceeding, to estimate their future progress, to dictate measures for expediting, if necessary, and even occasionally to undertake the direction of every detail. It is therefore advisable to place before our readers a general account of the construction as usually carried on. The Plates XXXIV. XXXVI. to XXXIX. and XLII. will serve to illustrate this account.

On the method of conducting Earth-works. First; *Excavating.*—In starting an excavation through a hill of considerable height, it is desirable to get a fair face to the work, that is, one at right angles with the direction of the cutting; and from this face to start a system of gulleting or notching, by which labour is much economized. Fig. 1, Plate XXXVI., shows vertical niches cut in the face: a very little labour enables the excavator to separate the entire masses between these niches. The niches are not required much wider than may be made by the width of the pickaxe: a little undermining much assists the "getting." The consecutive operations required for an excavation are sketched in the figures on Pl. XXXVII. The cutting is supposed to have been commenced at the left end, and to have been started in the manner shown at fig. 1, Plate XXXVI. As the work proceeds into the hill, and the width is increased to provide for the slopes, it becomes desirable to run a "gullet" along the centre of the cutting, in order to bring the greatest number of waggons into use. Thus the temporary rails being laid in the gullet, a train of waggons is sent forward; these receive all the produce of the barrowing on either side, which is advantageously prosecuted in advance and alongside of the waggon-filling, for the purpose of keeping the work level for starting the next stage or layer of excavation. The sides of the gullet are shown as being notched, preparatory to widening it eventually to the full width of the cutting. As the height of the hill increases, the second layer is commenced, and side tracks are laid, inclining down on each side of the lower level. On these lines the full waggons descend on one side, and the empty ones ascend on the other. The lines may lead into three branches, one along the centre of the upper gullet, and one on each side of it, to receive the side-barrowing and carry onward the widened gullet. Horses are required for moving the filled waggons to the head of the incline, (down which they are allowed to descend by gravity, and under command of the brakes,) and to draw the empty waggons up the incline on the other side. One of the great difficulties to be guarded against in excavating, is the accumulation of water in the lower parts of the cutting. To obviate this, the bed of the cutting should always be kept inclined upwards, as shown at fig. 2, Plate XXXVI., where the dotted line represents the permanent level to be attained, and the full line, that of the work while proceeding. By this means the water may be conducted to the end of the excavation, and there discharged. The soil thus left in the bottom of the cutting may be removed after the slopes are completed and the side drains formed, without leading to inconvenience. This slight rise being preserved in all the layers, also assists the descent of the loaded waggons.

Where the " lead " is in both directions from the centre of the intended evcavation,—that is, where it is required to send the material got out to each end of the hill, the series of operations here described will be simultaneously commenced at both ends, and the excavations meet in the middle. In these cases the drainage must be effected by giving the bed a rise from each end to the centre, as shown in fig. 3, Plate XXXVI. If it be required to level the bed of the cutting as the work proceeds, a drainage may be secured by giving the rise for a short distance in front of the face of the work, as shown at fig. 4, Plate XXXVI.

Second; *Embanking.*—The ordinary, and commonly considered, quickest mode of forming an embankment is by running out to the full depth required at once, as sketched in figs. 1 and 2, Plate XXXVIII. The front end of the embankment where the formation is proceeding, called the " battery head," at the right side of the Plate, is shown as having four lines of railway. The two outer of these lines run parallel to each other to the back of the bank, whence the material to be " tipped " over the battery head is brought. The two inner tracks bend outwards, and each flows into that one of the two parallel tracks which is nearest. A double crossing, as it is called, leads from each of these tracks into the other at some distance behind the tipping-place. It will be seen on the plan that a range of full waggons, supposed to be approaching the tipping-place, is opposite to a range of empty ones, supposed to be returning for fresh loads. The order of proceeding is this: the four waggons, A, B, C, D, now occupying the head, being emptied, are returned in their alphabetical succession, as indicated by the relative positions of the four empty waggons lettered A^0, B^0, C^0, D^0, respectively. Meantime, eight filled waggons are approaching the point of activity, lettered on the Plate, A^1, B^1, A^2, B^2, and C^1, C^2, D^1, D^2. A^1 runs direct to the point just vacated by A; B^1, C^1, and D^1, each take corresponding positions at the battery head, returning in rapid succession as they are emptied, and being immediately replaced by those lettered A^2, B^2, C^2, and D^2. In this manner the two parallel tracks are always filled with full and with empty waggons, respectively, while four waggons are continually discharging their loads at the tipping-place.

One method of hastening the process of embanking is by keeping the top wider than intended eventually, and the base correspondingly narrower; an increased width for roads and tipping is thus obtained, and the extra width at the top is afterwards pared down to make good the deficiency at the lower part of the embankment.

Embanking may be carried on with equal, if not greater rapidity, by forming the bank at first to half the intended height, and following this closely with an upper tipping-place, just so much narrower than the lower one as will leave room for the waggons to pass down alongside to it. A sketch of this method is given in figs. 3 and 4, Plate XXXIV. The advantages of this mode are, that it gives a much wider tipping-place on the lower level, besides the upper one, and also, that during the time which the formation of the embankment precedes that of the top, the materials are becoming consolidated. Against these advantages must be placed the greater quantity of rails and plant required for conducting the work, and also that the subsequent completion of the upper layer, by a side slip, extending throughout the length of the embankment, prevents that thorough consolidation of the materials which is so desirable.

The most expensive course is that of forming the bank in shallow layers, running out each of them to the full length of the work, and following with the upper layers after each lower one is completed. By allowing each layer to settle (to the concave surface shown at fig. 2, Plate XXXIV.) before the next is formed, and, moreover, using beetles in ramming the earth down, an embankment will be formed of the greatest possible density and stability.

The method which combines economy with stability, in the best proportion, is by running forward the two sides of the embankment to the full width intended, leaving a central valley to be filled in at some little distance in the rear. The practical effect of this is, that the two sides become as narrow embankments, resisting the thrust of the central part afterwards put in; and alteration of form and position are much less likely to ensue with banks thus formed, than if they are carried forward with one battery head across the whole width of the work.

Both in embankments and excavations, the slopes should be dressed to the intended face, as shortly as possible after the formation is completed, and covered with turf, if possible, or at least with soil sown with grass-seed.

The implements, &c., constituting the plant, with which the earth-works of a railway are formed, consist, besides the minor tools—as picks, bars, shovels, &c.—of rails, chairs, sleepers, and waggons of various kinds. Frequently the rails used, which are very light, are of the longitudinal kind, that is, formed with a continuous bearing surface; with these rails the chairs are, of course, dispensed with, and longitudinal sleepers are employed instead of cross sleepers. In either case, the road, once laid down and put together, fulfils all its purposes with little attention or labour. If required to be shifted sideways or carried forward, a few bars are applied as levers by as many excavators, and the road is ready for work again in a very short time. As the amount of material removed will, to a considerable extent, depend upon the kind of waggons employed, a few examples have been collected from various authorities, and are represented on Plate XLII. The figures on this Plate show three kinds of "end-waggons," those which discharge their load from the back or end; and one example of a "side-waggon," which is emptied over the side. Figs. 1 and 2 are an end and side view of an "end-waggon;" and figs. 3 and 4, end and side views of another; figs. 5 and 6, ditto; figs. 7 and 8, end and side views of a "side-waggon." Between the first two examples the principal difference is in the width and height. The details are also somewhat different, as will be seen on comparison. The narrower and higher waggon, shown in figs. 3 and 4, attains a larger angle when tilted, and this of course discharges its load more readily: on the other hand, the greater breadth in proportion to its length, of the first example, shown in figs. 1 and 2, gives that waggon a corresponding advantage. The broad waggon, however, leaving less space for the workmen to pass, is attended with comparative danger, especially in cases where, for the sake of expedition, a great number of roads are laid down, and the intermediate spaces necessarily contracted. Figs. 5 and 6 represent a kind of waggon which was used on the Brandling Junction Railway, and is more readily emptied than either of the preceding. The body of this waggon, instead of turning upon a hinge, is supported upon two rollers. When the waggon is suddenly stopped at the tip, the momentum of the load carries the body forward, until its centre of gravity gets beyond the support, and the body is instantly, and, as it were, spontaneously tilted. The body is prevented from overrunning by a pair of curved metal stops, which are checked against the front rollers. The "side-waggon," shown in figs. 7 and 8, is supported upon two cross bearers, and hinged to them. It is adapted to tilt on one side only, and is necessarily somewhat higher than the end-waggons are, in order to clear the wheels. All of these waggons are supposed to be fitted with brakes of a simple construction; merely a block of hard wood, shaped to fit a part of the peripheries of the two wheels, and capable of being turned upon a centre by a long handle of iron, which is carried to the front or hind end of the waggon, in order to be acted upon by the hand or foot of the brakesman. The handle moves within an iron slot, and may be pinned into any position by a pin passed through it. The form usually preferred for earth-waggons is nearly square, having a slight taper, or increase of width towards that end of the waggon which is turned downwards in the act of tipping: the under-framing, or "soles," should in all cases, as shown in the figures on Pl. XLII., project beyond the body, so as to leave room for the driver or others to escape to, in case of the sole-ends or buffers being forced violently together.

In some practical notes upon the subject of earth-waggons, published in the 'Civil Engineer and Architect's Journal,' (vol. vi. page 267,) under the signature of O. T., are the following:

"On the Midland Counties Railway, a waggon of a different construction to any of the preceding was used, both the sheaves and joints being dispensed with, the whole body of the waggon being lifted up from the hinder axle in the act of tipping, and the two axles being retained at an equal distance, so that the waggon falls to its original position as soon as the coup is recovered. I have seen wrought iron used for bodies of waggons of this construction, which answers a very good purpose. Several attempts have been made, but invariably without success, to combine the end and side-waggon in one construction, by making the body of the waggon to revolve. Mr. Cuthbert Burnup made one so early as 1829, for the Newcastle and Carlisle Railway."

The best size for waggons is such that they will contain 2½ cubic yards of earth. Wheels 3 feet diameter;—English elm is the best wood. About 3½ cwt. of iron is usually employed in each waggon.

Figures 10, 11, and 12, Plate XLII., exhibit a kind of waggon, which, if constructed of iron, as shown on the Plate, might be advantageously employed in delivering the material into a lighter or other vessel, if a stage be run out for that purpose. This waggon consists merely of a body, or receptacle, mounted on a frame of two side-arms, with stretchers between the wheels on each side. The larger wheels have a substantial axle; the small ones have none. The body, which when filled is nearly equipoised upon the larger axle, is suspended in front by two chains connected with the side-arms. The mere detachment of these chains admits the body to swing over and discharge its load instanter. The sketch shown in Plate XLII. represents only the general appearance of such a waggon; the details are easily supplied. The original idea of such an apparatus was first, it is believed, carried out in a waggon or waggons used during the construction of the London Docks.

Figure 9, Plate XLII., is an isometrical sketch of the "scoop" or "scraper," an implement which has been much used in America. From the account published in the American 'Franklin Journal,' in September, 1841, the following particulars are quoted:

"The scoop may be used with success in all excavations of earth where the slopes do not exceed 1½ to 1, if the material to be taken out yields readily to the plough, and is not required to be moved horizontally more than 100 feet, nor to vertical heights exceeding 15 feet: there are, doubtless, instances where both these limits may be surpassed, and the use of the scoop still be highly economical; but such cases are not general, and the practical scope of the utility of scoops may be regarded as confined to the excavation of canal trunks, and the formation of low road embankments from side trenches, for both of which purposes it is most admirably adapted. This machine is drawn by two horses, managed by a boy, and usually requires the ground to be first ploughed; then, by simply elevating and guiding the handles a little, the driver causes it to load itself, for the horses being in motion, it turns its *clevisses*, and inclining downward, runs under the loose dirt like a plough: the handles being released, the loaded scoop moves upon two iron-shod runners which form the sides and project below the bottom; and finally, after reaching the place of deposit, the handles being smartly elevated, the edge of the scoop, which is armed with iron, takes hold of the bank, and the horses moving on, it overturns and discharges its load: in this overturned position, with the handles resting on the double tree, it returns upside down to the place of excavation, and is there loaded, &c., as before."

Mr. Morris, from whose Report this account is quoted, proceeds to calculate the cost per cubic yard of excavating as performed with the scoop; and allowing 12*s.* 5½*d.* per day for the hire of the scoop (with the horses it is presumed), and the driver, and further, allowing ·54 pence per cubic yard for the preparatory loosening of the soil, he calculates the cost at 4·25 pence for "double scooping;" that is, working to both sides, and 5·5 pence for "side scooping." The difference between the two is, that for the former, the horses describe only a semicircle for each load put in bank; while for the latter, they have to make two turns or a complete circle.

Of late years the plough has been used in this country, and with great advantage, in the preparatory loosening of the surface for excavating. This method was, it is believed, first used in forming the London and Birmingham Railway. In that instance the material was a hard dry marl; and after a few experiments, which led to some alterations of the size and form of the plough for this particular purpose, the plan was found completely successful, and, moreover, it reduced the material in a much more perfect manner for the embanking, and actually dispensed with the labour of several men who were formerly employed to break up the lumps at the foot of the embankment.

DRAINAGE.—In this important department of railway construction, the engineer is called upon to exercise the greatest care and precaution, and is, notwithstanding his most anxious exertions, very liable to find these insufficient for the preservation of his works. The history of all failures of earth-works shows the disasters consequent upon inadequate drainage; while in the majority of instances it must be, at the same time, admitted that no previous calculation could have foreseen, and scarcely any practicable arrangements have averted, the mischiefs produced by the hidden and insidious enemy—water. Wherever water is known or suspected to exist, its immediate source should be traced, and every possible means adopted of diverting it from the slopes and adjacent surfaces.

Figures 6 to 10, on Plate XXXV., already described, show the ordinary kind of water-courses or ditches provided for excavations and embankments. Beneath embankments, every stream that is intersected, and every field-ditch or other natural or artificial water-way, will require a drain or culvert for the safe conveyance of the water away from the work; and these drains or culverts must, as well as all side ditches, be conducted finally into a river or stream of sufficient extent and activity to sustain the full discharge that can be required. The size of the culvert must of course depend on the quantity of water necessary to be provided for. The culverts must necessarily be built in before the embanking is commenced, and should, moreover, be allowed some weeks at least, to become consolidated before being covered in.

The figures on Plate XL. represent in detail a variety of culverts, &c., that have been adopted on various railways.

Fig. 1 is a cross section of an oval brick drain, 3 feet by 2 feet.

Fig. 2 is a section of a circular or barrel brick drain, 2 feet in diameter.

Fig. 3 is a section of the same, through the head and grating.

Figs. 4, 5, 6, and 7, represent a circular brick culvert of 3 feet in diameter: fig. 4 being a longitudinal section; fig. 5 a front elevation; fig. 6 a plan; and fig. 7 a cross section. The mouth of the culvert is formed with slopes, to correspond with the slope of the earth-work above.

Fig. 8 is a cross section of a simple kind of drain composed of stones, which, if large enough, may be laid dry, and yet answer the purpose of a water-way in some cases.

Figs. 9 and 10 are longitudinal section and front view of a circular brick culvert of 2 feet diameter. The face has a slight batter, and is built with footings, but without any expansion at the mouth, as in figs. 4, &c.

Fig. 11 is a section of a drain composed of rough pieces of stone, laid triangularly. Such a drain is frequently formed of chalk, and if carefully constructed, is very cheap and tolerably efficient.

Figs. 12, 13, 14, and 15, show a brick culvert of 4 feet diameter; the section of which is formed of four curves, of which the several radii are shown by dotted lines. This is a favourite and very strong section.

Figs. 16, 17, 18, and 19, exhibit the construction of an open drain, formed simply of two walls of brick-work, the inner sides of which are battering. Two balks of timber, framed together, are laid across these walls, to carry a single line of rails.

Figs. 20, 21, 22, and 23, show a brick culvert of 8 feet width, adapted to discharge obliquely to its length, and constituting a " skew culvert." Fig. 22, the plan, shows the mode adopted of working the parallel lines of brick-work into the skewed face of the culvert; and fig. 23 is a cross section on the square, that is, at right angles with the direction of the culvert.

Fig. 24 shows the section of another oval brick culvert, the upper diameter of which is 2 feet 9 inches, and the lower 2 feet; the sides being right lines and tangents to these two curves. This section has been adopted and approved in some of the metropolitan sewers.

Figs. 25, 26, 27, and 28, represent another brick culvert of 6 feet diameter: the several radii of the curves of the section and the dimension of each part of the work are given.

Figs. 29, 30, 31, and 32, show a culvert of 4 feet diameter, formed with a circular head, a flat curved invert, and the sides with straight lines. It is composed partly of brick and partly of stone; the head and invert and springings being of brick, with stone footings and spandrels.

Figs. 33, 34, and 35, show a circular brick culvert of 2 feet in diameter, and may be described as exactly similar, but of different size, to figs. 9 and 10.

Figs. 36, 37, 38, and 39, show another circular brick culvert of 3 feet diameter, to which the description of figs. 4, 5, 6, and 7, will nearly apply. The face of this culvert is battered.

Figs. 40, 41, 42, and 43, represent a 5-feet brick and stone culvert, exactly similar to that shown in figs. 29 to 32.

Figs. 44, 45, 46, and 47, represent a 6-feet brick and stone culvert of similar construction.

Figs. 48 and 49 show a brick culvert of 10 feet diameter, similar in construction to those already referred to. Fig. 48 is a half elevation and half cross section, showing dimensions of the brick-work; and fig. 49 is a half plan.

Figs. 50 and 51 show a brick and stone culvert of 6 feet diameter, having a brick head-arch and invert, with stone blocking courses and backing. The front is formed with pilasters of ornamental character; against these abut stone walls, the top lines of which incline at an angle similar to that of the embankment above. The courses are laid square with this line of inclination, and the walls are evidently well adapted for their purpose.

Fig. 52 is the cross section of a culvert of exactly similar construction, but of 8 feet diameter, and less height in proportion. The several dimensions for the brick and stone-work are given.

Figs. 53 and 54 are half elevation, half cross section and, plan, of a 4-feet brick and stone culvert, with stone coping, blocking-courses, &c.

Figs. 55, 56, and 57, show a double brick culvert with stone cut-water; each water-way being 6 feet in diameter, with circular heads, curved inverts, and straight-battering sides. The bed of the mouth is dished out slightly, to facilitate the discharge of the water.

Figs. 58 and 59 show a square drain, 1 ft. 6 in. wide, composed of stone blocks.

In cases where, from the costliness of land, or other causes, the sides of a cutting are upheld by retaining walls of brick or stone-work, the open side drains are usually abandoned, and a brick barrel-drain laid along the centre of the excavation, with cross drains dipping into it at intervals. By this arrangement the walls are drained without exposing the footings or incurring any additional depth of brick-work beyond that required for the stability of the walls. The drains here referred to are shown, together with the additional one required under two-arch bridges, on Plate XXXIX. In order to keep the two archways dry, and avoid interfering with the foundations of the pier, the central drain is here branched into two courses. These receive two cross drains, situated one at each end of the bridge; other similar cross drains being, as already stated, repeated at intervals throughout the excavation.

Plate XLI. exhibits a paved double crossing of a line of railway on the same level; and also a metal single crossing, with the drains for the approaches, &c. Fig. 1 is a section, and fig. 2 a plan of the double crossing. Fig. 3 is a transverse section of the single crossing; and figs. 4, 5, 6, and 7, are details of the guard-plates enlarged. A further reference to this Plate will occur under the head " Permanent Way."

With a view to understand the assigned causes of, and applied remedies for, some of the slips and failures that have occurred upon railway earth-works, the following may be quoted:

In November, 1841, Mr. Brunel reported as follows:[29]

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[29] Report of the Officers of the Railway Department, 1842, page 90.

"The Swindon embankment of the Cheltenham and Great Western Railway is about 1¾ miles in length, and averaging about 20 feet in height, nowhere exceeding 24 feet, and was formed originally of clay obtained from side-cutting. The embankment was made of full width, the slopes good, and a wide bank left between the foot of the bank and the side-cutting. In fact, in the setting out or designing of the work, I do not feel that any precaution was omitted, excepting so far as the formation of an embankment of clay by barrow-work under any but the most favourable circumstances may be considered injudicious. Certainly my subsequent experience in works under my own direction, and observation upon others, have convinced me that if an embankment so formed suffers more than any other from the effects of continued wet during its formation, or before it is consolidated, the loose and divided state in which the separate lumps are thrown together from the barrow, instead of being compressed by the fall from the waggon at the tip-head, easily accounts for this; besides the circumstance of the surface being generally unavoidably left in a much more irregular form, and less capable of being drained.

"Unfortunately, during the formation of a great portion of this embankment, the season was excessively wet. Several small slips occurred in the following year, and in repairing these slips the interior of the bank was found to be saturated with water, and in a soft, almost fluid, state. Still the means taken to remedy the slips appeared effectual. Large portions of the slopes of the embankment were burnt, and the masses of burnt clay thus formed, appeared capable of supporting the pressure of the soft clay within. Further precautions were subsequently taken: portions of the side-cutting, where the foundation of the embankment had given way, were filled up, and the embankment made good every where with good dry rubble and sand brought for that purpose. Every thing was done which I considered desirable to insure the permanence of the work. Immediately after the opening of the line, however, whether in consequence of the working, or from other causes, the bank again began to move, the slips being almost exclusively confined to the up or east side. It appeared most prudent to abandon the attempt of keeping up this line for the running of the trains, to bestow all the attention to the down line, and to use the other for the purpose of bringing materials for the maintenance and restoration of the embankment. The work has been proceeded with ever since as vigorously as the circumstances would admit; the whole of the soft material is being removed or forced out; the side-cuttings are being filled up; a dry stone wall built at the foot of the slip; and the embankment almost re-formed of rubble." This wall is 12 feet thick, built at the bottom of the slope to the depth of 10 feet.

In January, 1842, Major-General Pasley reported upon the slip which occurred in that month upon the London and Croydon Railway, near New Cross, as follows:

"The original slope of the sides of the deep cutting where this slip took place was 2 of base to 1 of height, and they had stood for more than two years without any slip of such magnitude as to prevent the passage of the trains through this cutting until lately, when the continued rains have produced this unfavourable effect, which I do not think that any engineer could have anticipated beforehand, for it is only our late experience that has developed the disadvantages of deep cuttings and high embankments in certain kinds of clay, even at very moderate slopes. No blame, therefore, attaches to the original construction of this railway, though the extraordinary slips that have occurred recently will be a lesson to put engineers on their guard for the future in working in such soil. On the east side of the cutting the extreme height was rather more than 100 feet in one part, with 200 feet of slope."[30]

Sir Frederic Smith reported[31] in November, 1841, upon the Sheffield and Manchester Railway, thus: "In the centre, the Newton Green embankment is about 45 feet high; and whether from the nature of the materials, or the unfavourable state of the weather when formed, or the late heavy rains, it would be difficult to determine, but it has subsided to such an extent, that the base has spread out to two or three times its original width. Mr. Locke, observing that any additional materials of the same description only tended to increase the evil, used light sand to regain the required elevation in proportion as the embankment subsided; but finding that this attempt to obtain a steady surface has also proved unavailing, he has recently thrown two lines of large timbers, as longitudinal bearers, across the treacherous ground.— These timbers are 16 inches square, scarfed at their meetings, and the scarf is supported by a template. This again stands on an upright shore. Other shores are placed at intervals of 10 feet apart under the bearers, and the shores standing opposite to each other rest on a cross sleeper of about 16 by 9 inches."

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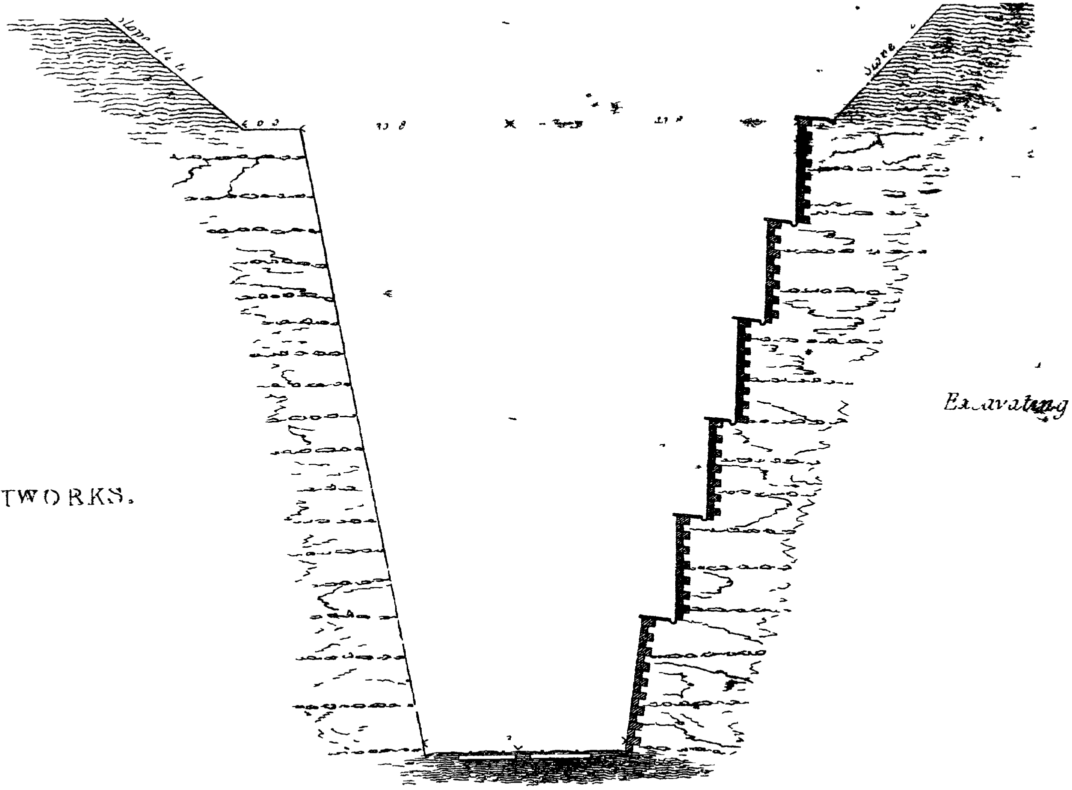
[30] Report of the Officers of the Railway Department, page 92.

[31] Ibid. page 177.

EARTHWORKS.



Excavating in Chalk

Fig 2

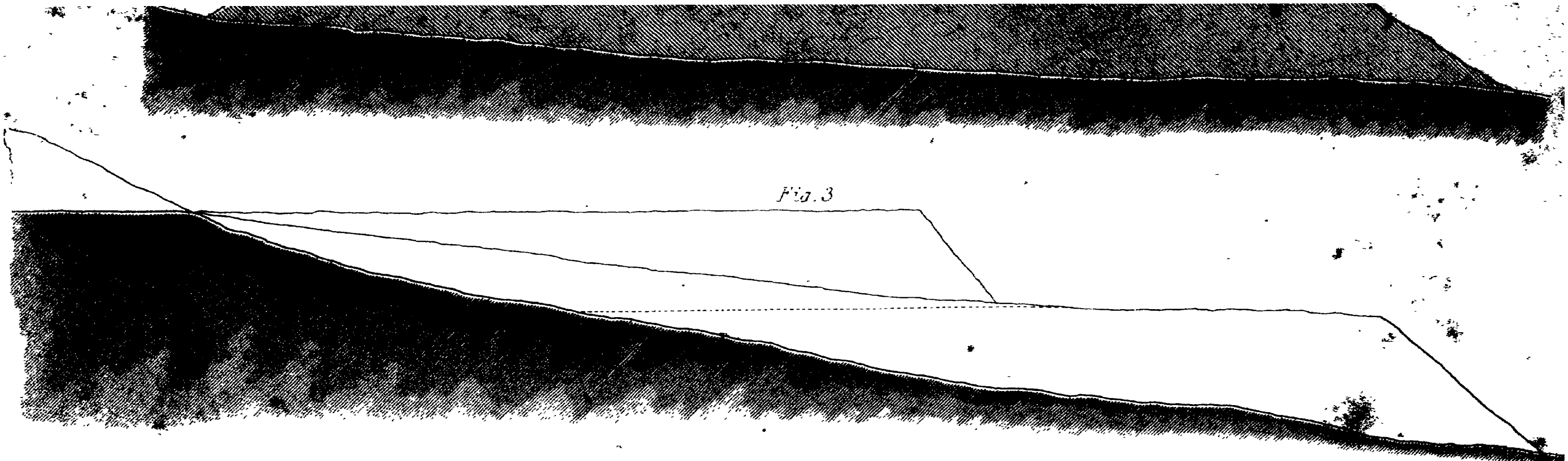


Fig. 3

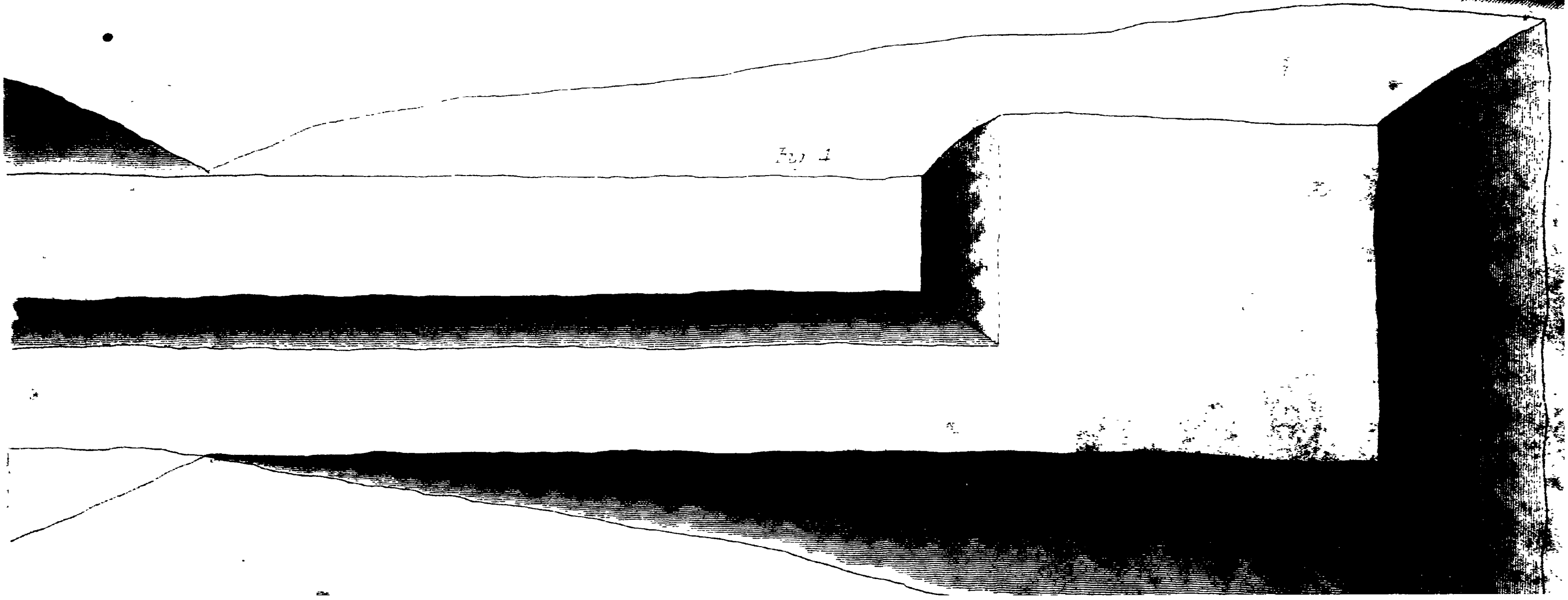
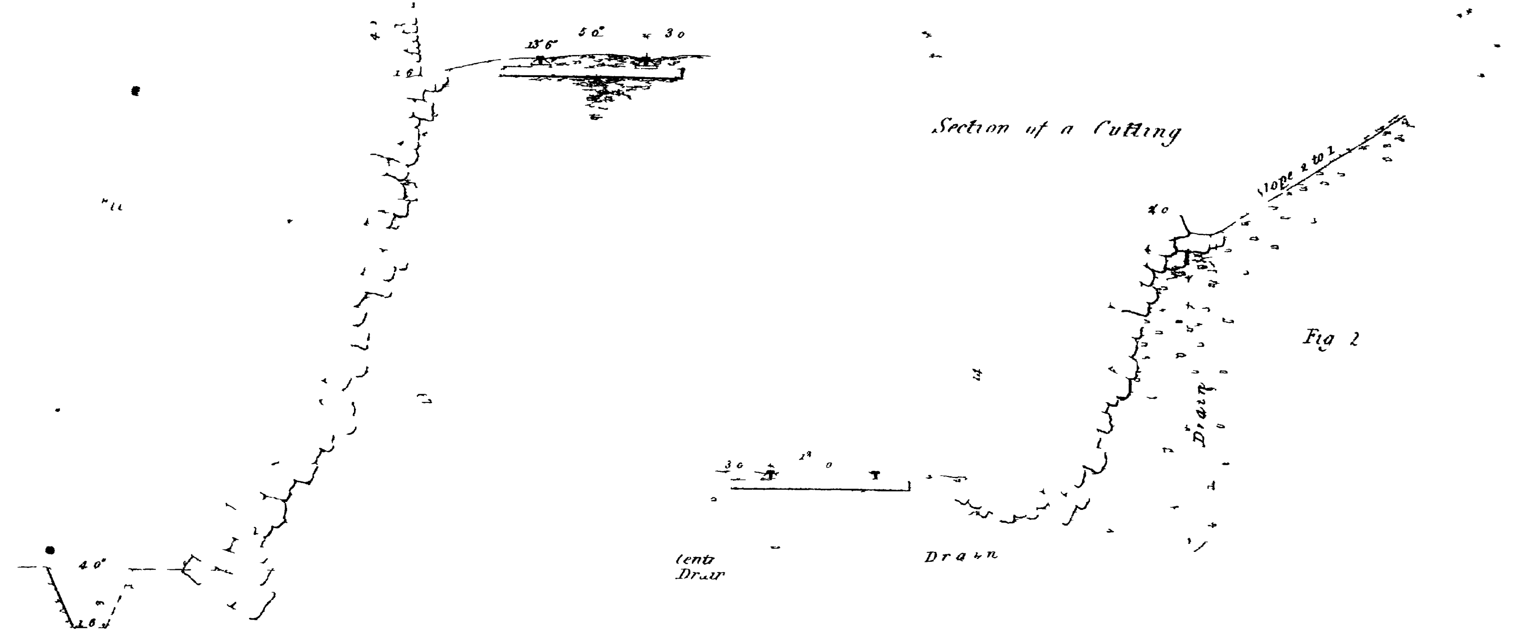


Fig. 4



Section of a Cutting

Fig 2

Bosworth Cutting

Cross Section

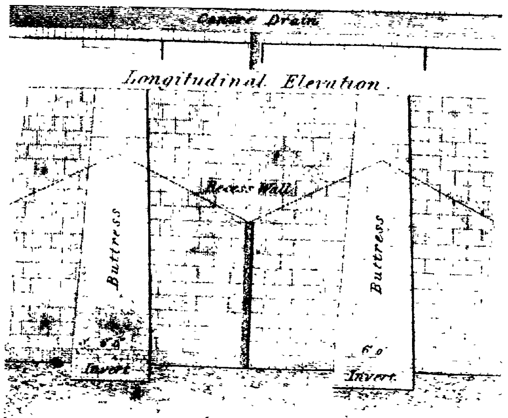
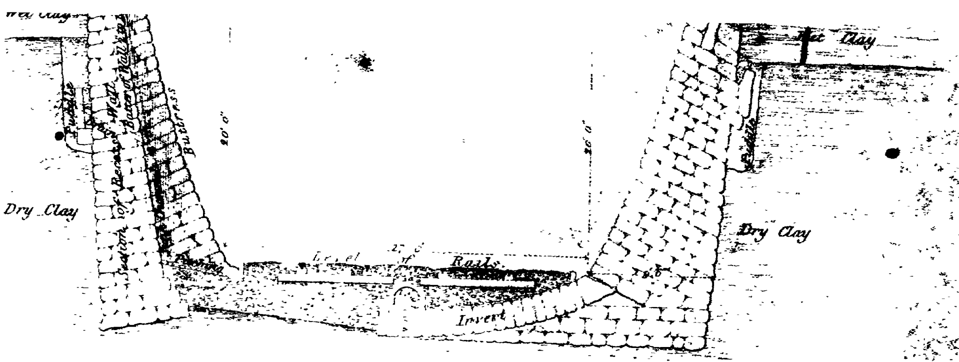
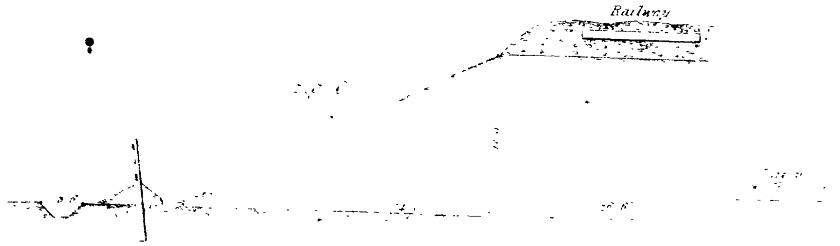


Fig. 5



Section of an Embankment.



Section of Cutting.

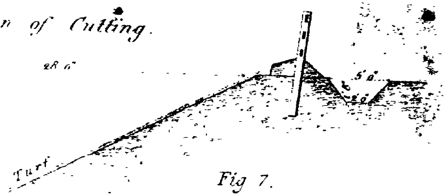


Fig 7.

Section of Ditch & Rail at an Excavation

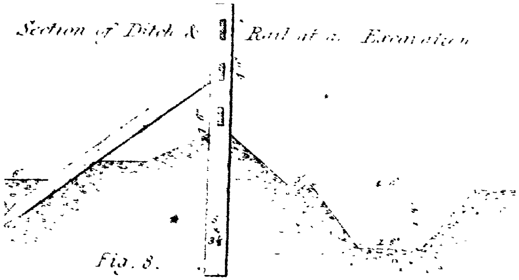


Fig. 8.

Fig. 9.

Section of Ditch & Rail at an Embankment.

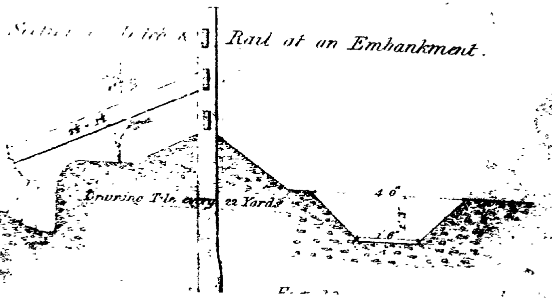


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Fig 1

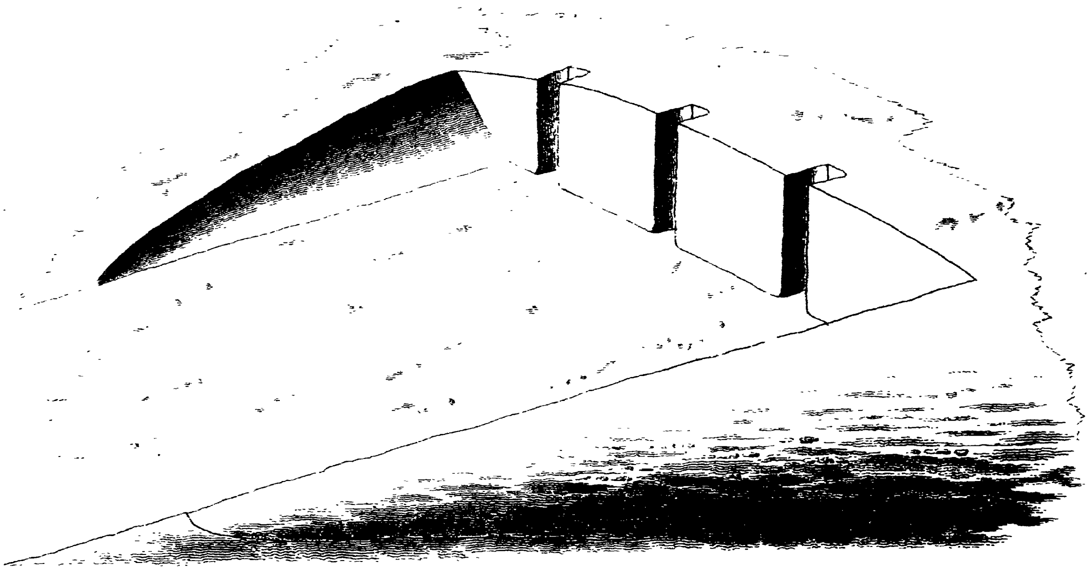
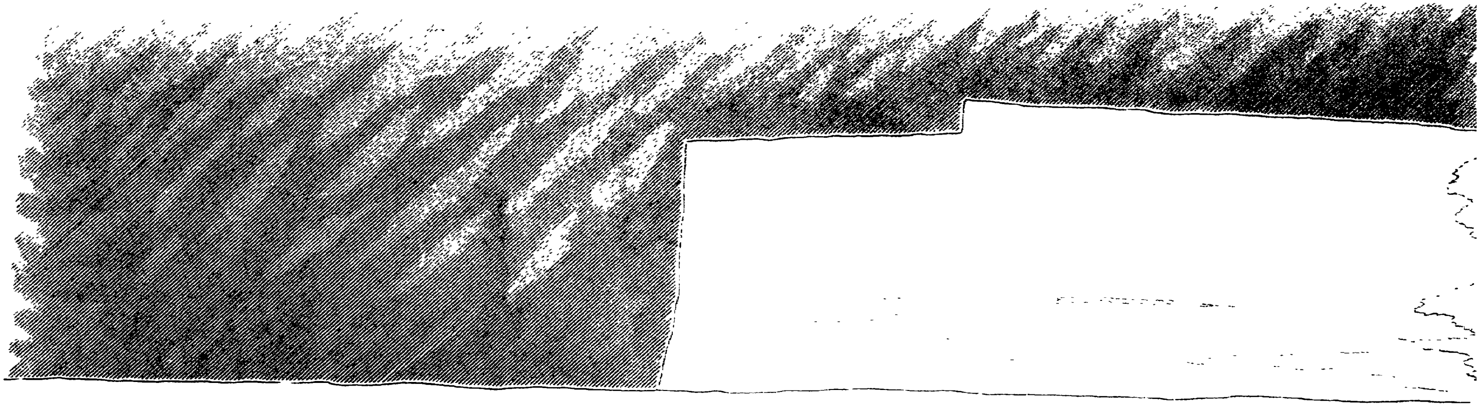
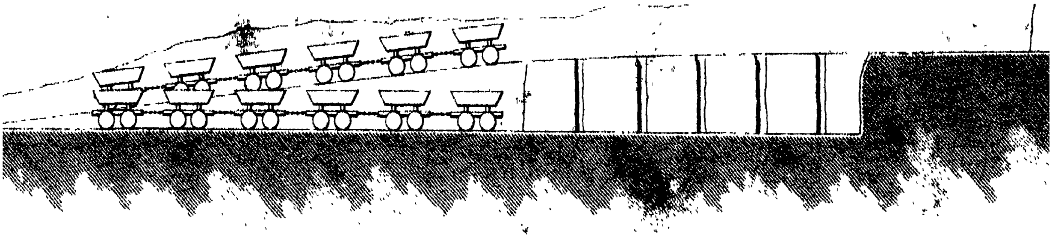
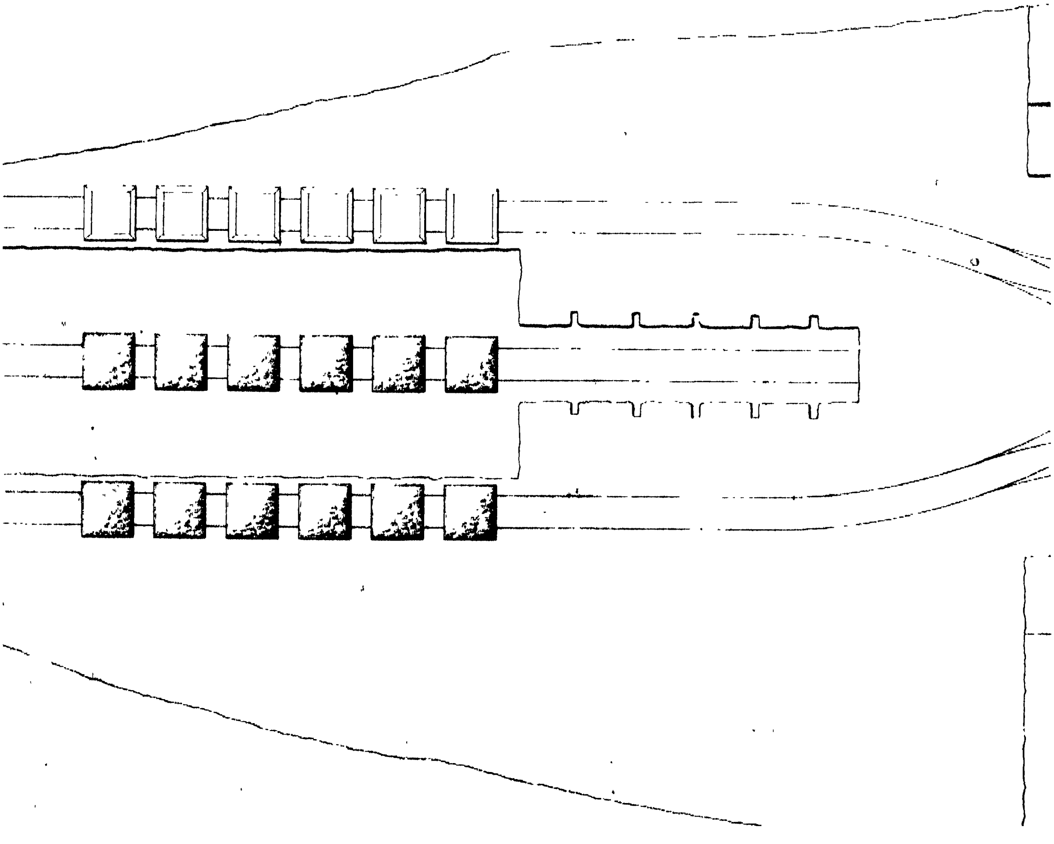


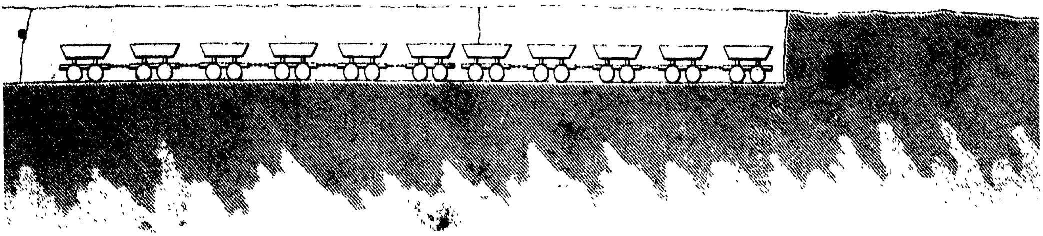
Fig 2.

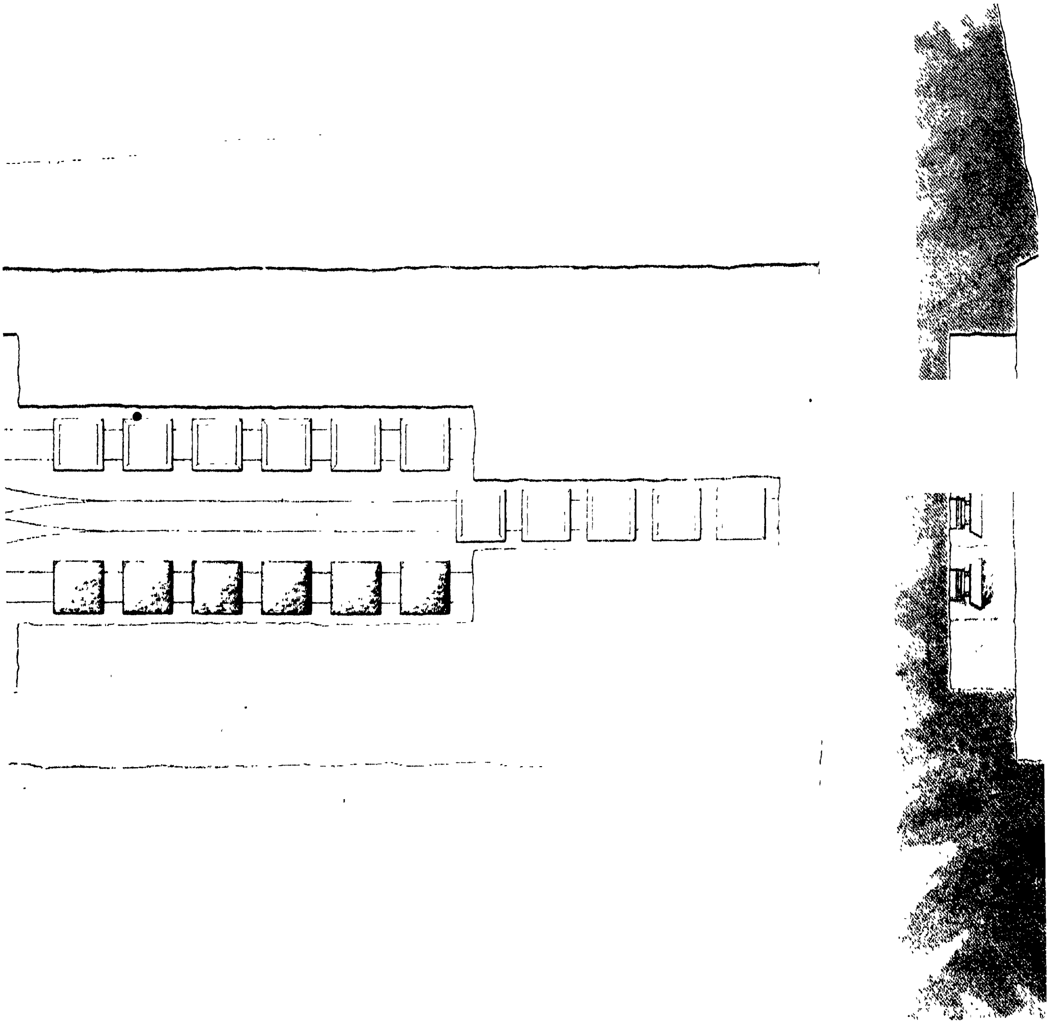


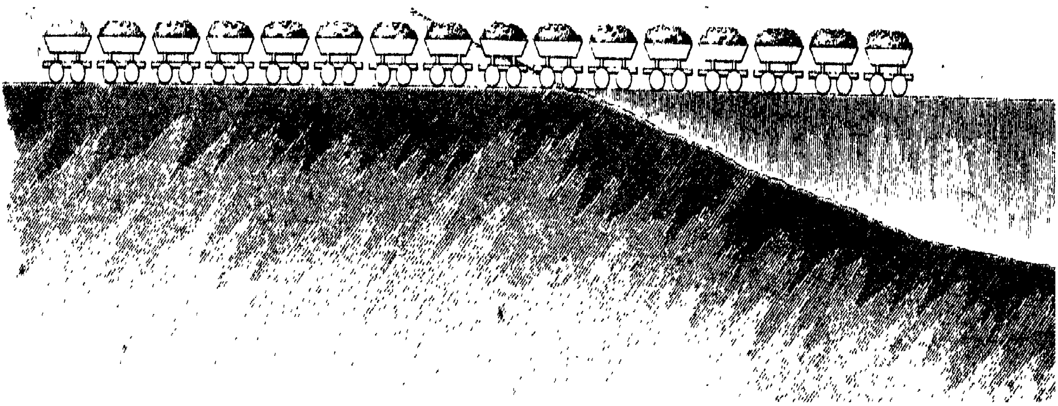


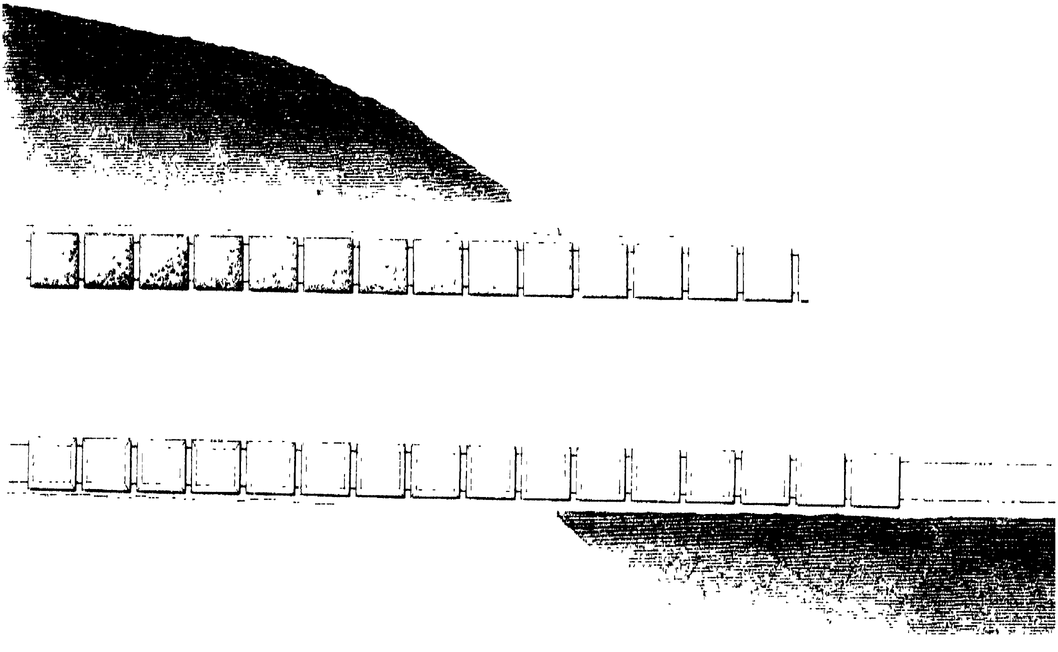


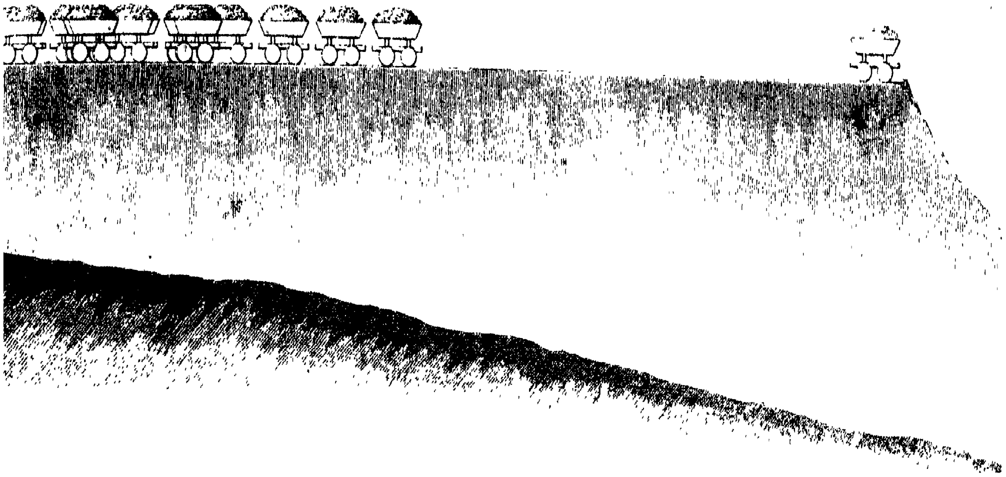
Section.

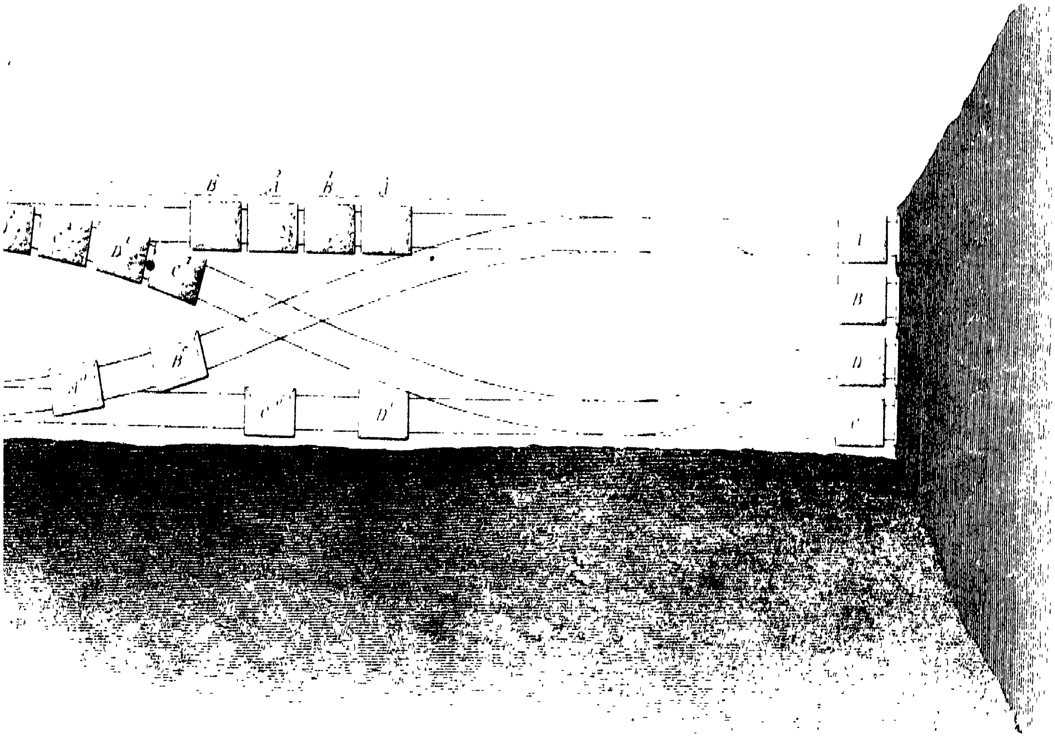


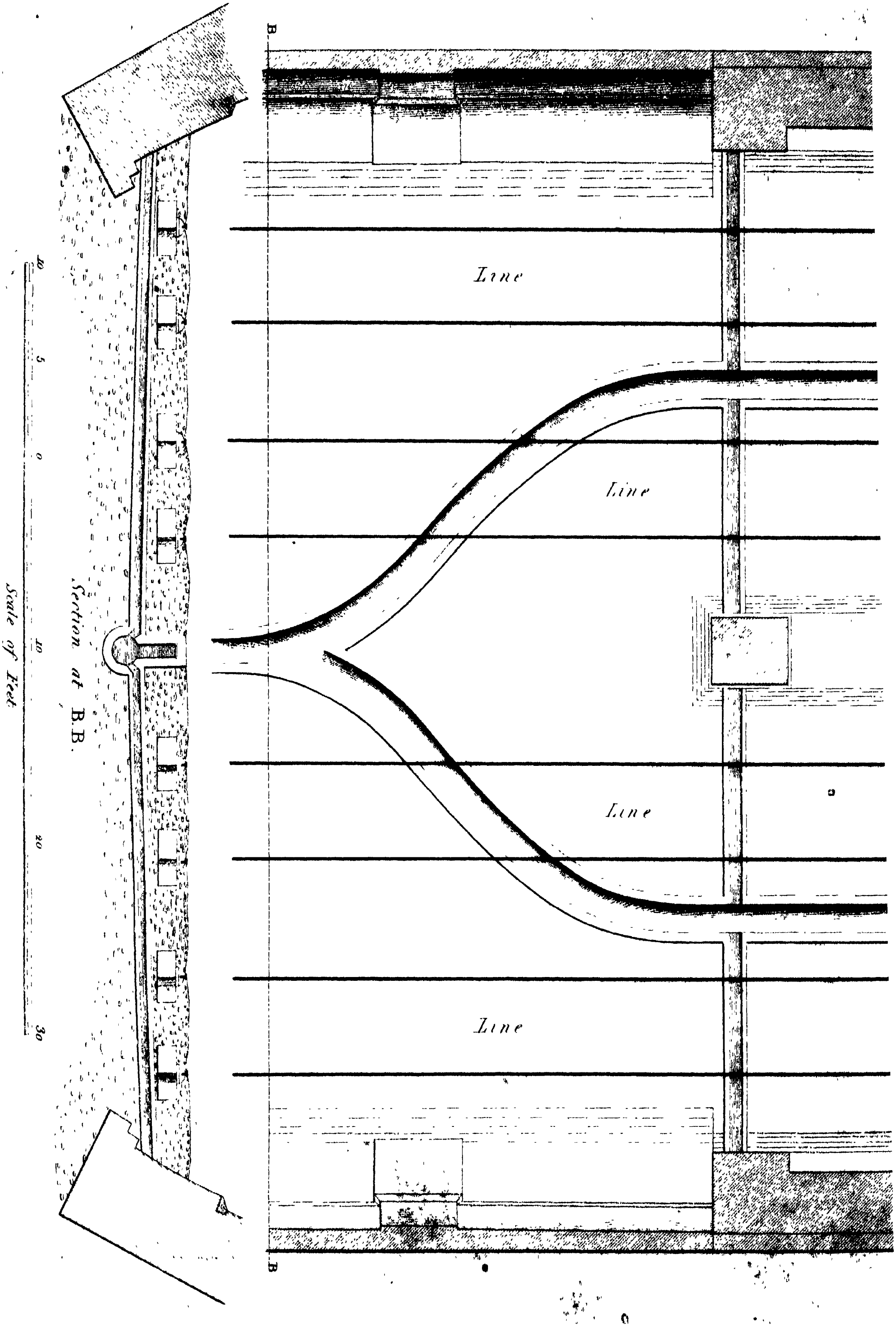


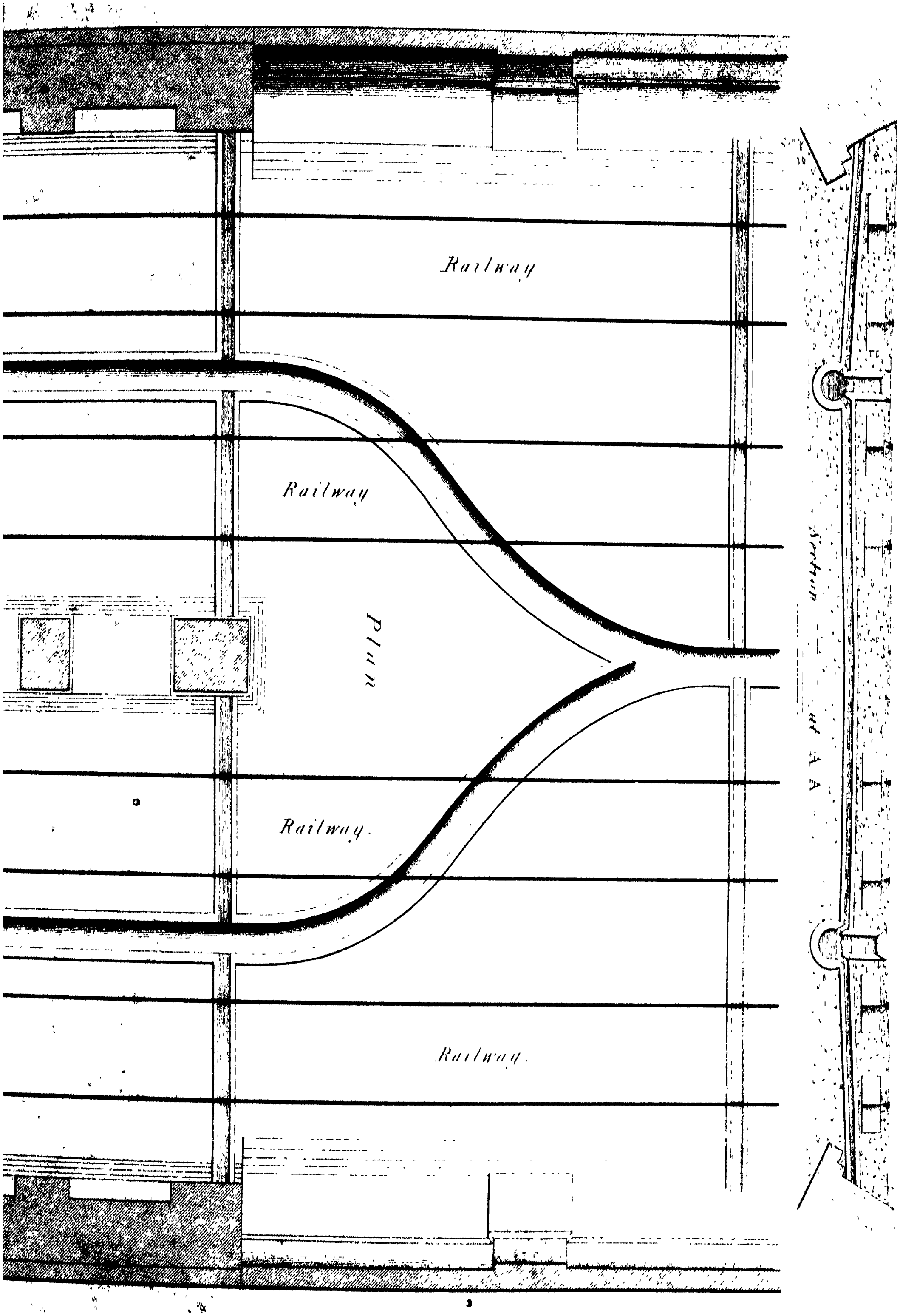







B
A
B
A
D'
C'
B'
A''
C''
D'
A
B
D
C


B
Line
Line
Line
Line
B
Section at B.B.
Scale of Feet
10
5
0
10
20
30


Railway
Railway
Plan
Railway.
Railway.
Section at AA

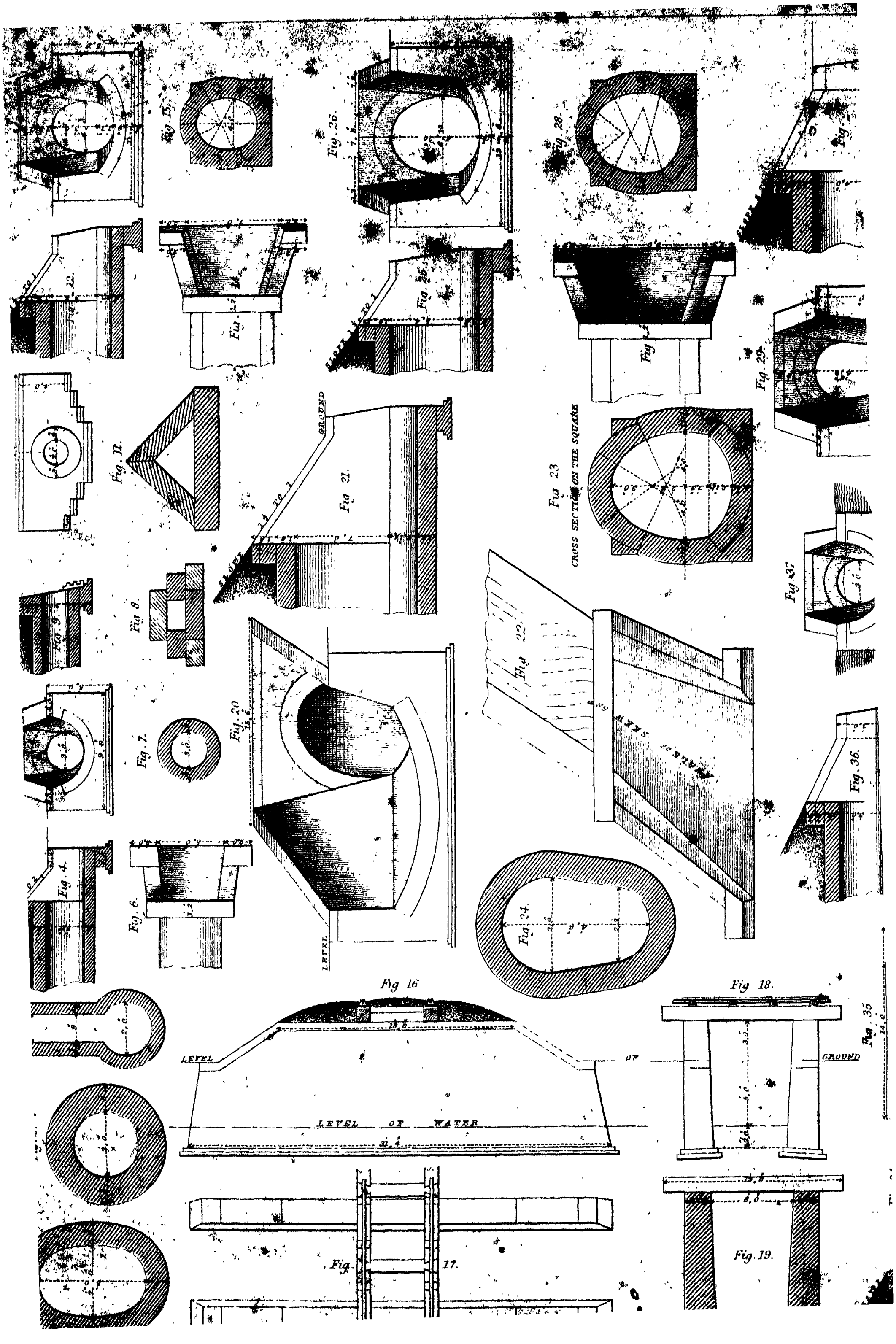


Fig. 4
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Fig. 11
Fig. 12
Fig. 15
Fig. 16
Fig. 17
Fig. 18
Fig. 19
Fig. 20
Fig. 21
Fig. 22
Fig. 23
CROSS SECTION ON THE SQUARE
Fig. 24
Fig. 25
Fig. 26
Fig. 28
Fig. 29
Fig. 35
Fig. 36
Fig. 37
SLOPE 1½ TO 1
GROUND
LEVEL
LEVEL OF GROUND
LEVEL OF WATER
15.6
30.4
15.0
14.0
7.0

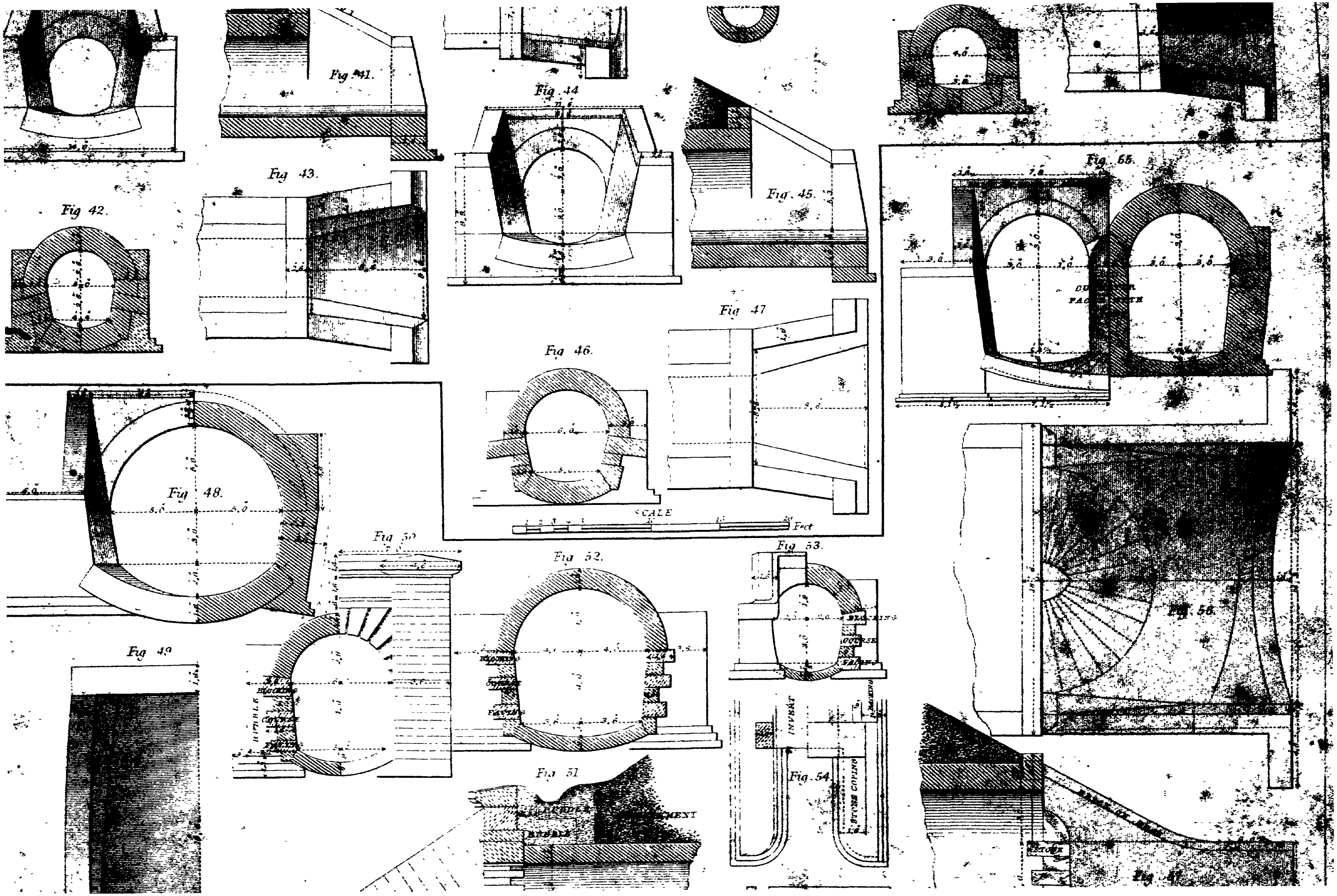


Fig 41.
Fig 42.
Fig 43.
Fig 44
Fig 45.
Fig 46.
Fig 47
Fig 48.
Fig 49
Fig 50
Fig 51
Fig 52.
Fig 53.
Fig 54.
Fig 55.
Fig 56.
SCALE
Feet
BLOCKING
COURSE
FACING
RUBBLE
CEMENT
INVERT
STONE COPING
STONE

PAVED CROSSING.

Admitting Two Carriages to pass.

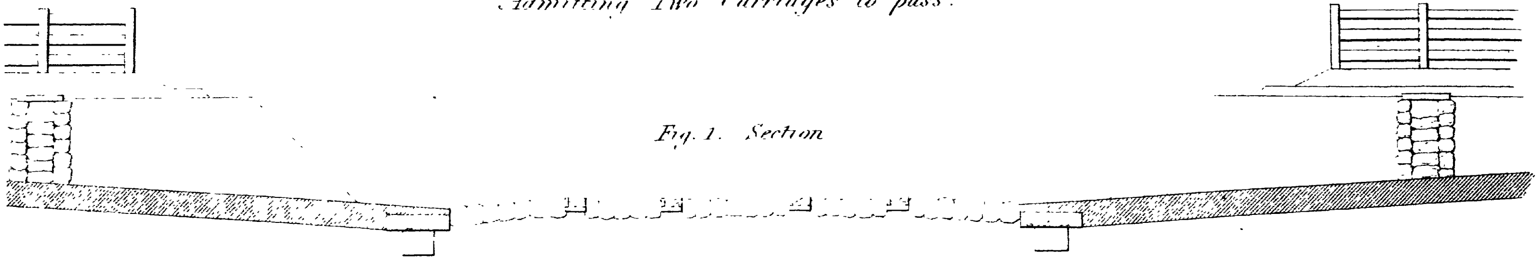


Fig. 1. Section

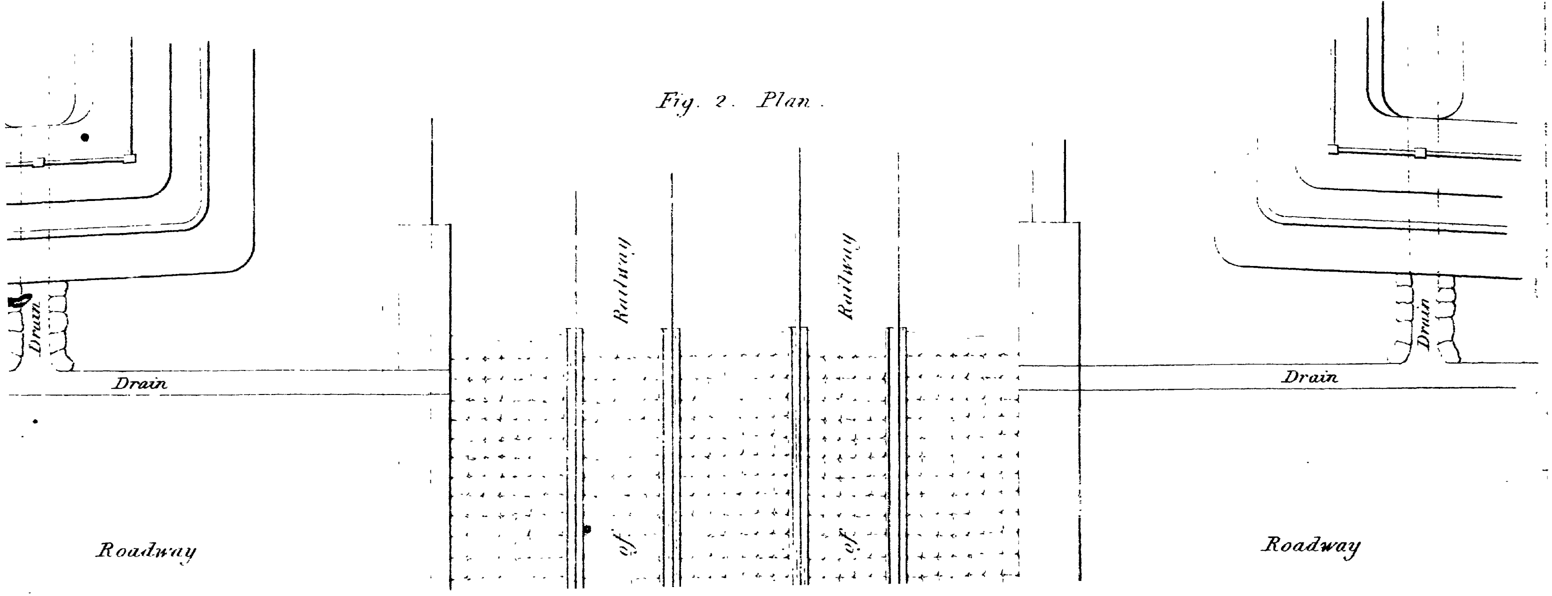
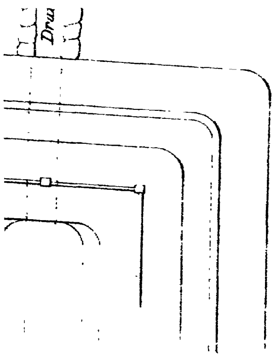
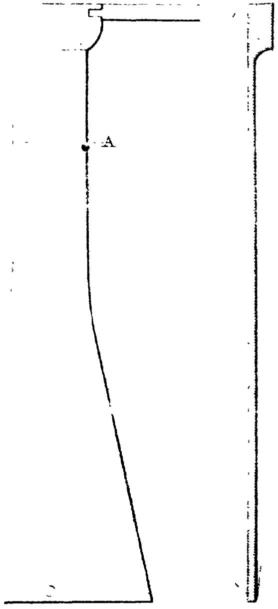


Fig. 2. Plan.



B Plan

Fig 5.
Section at B.B



rd Plate enlarged.

Plan of Metal Crossing
for One Carriage only.

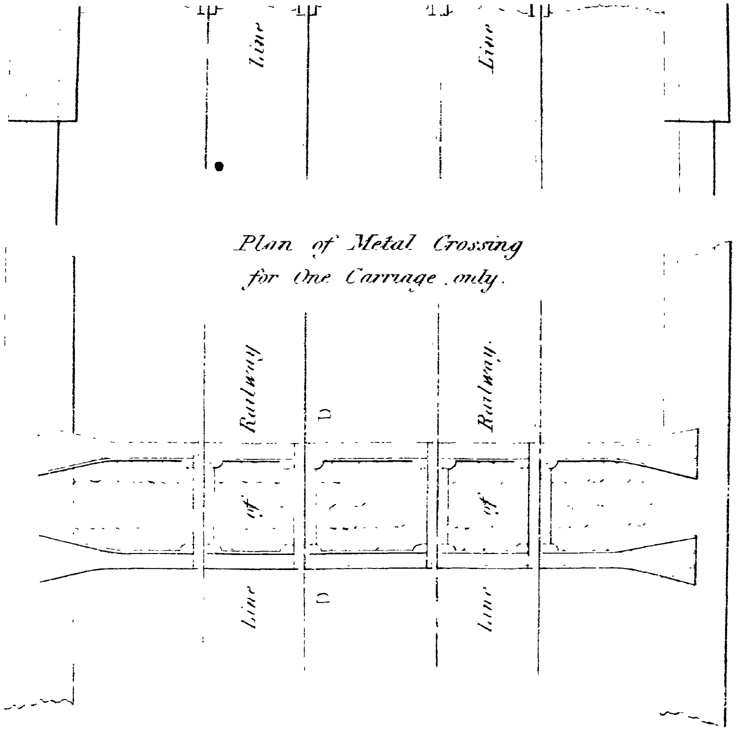
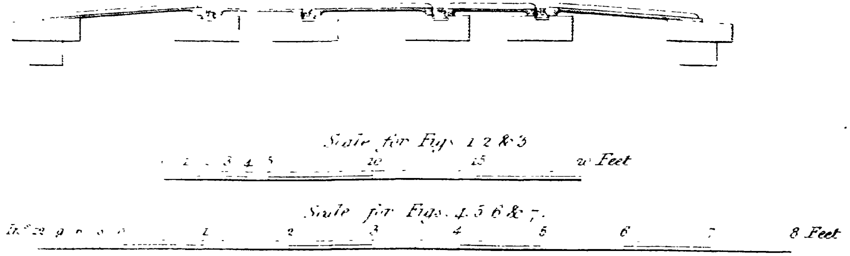


Fig 3 Section



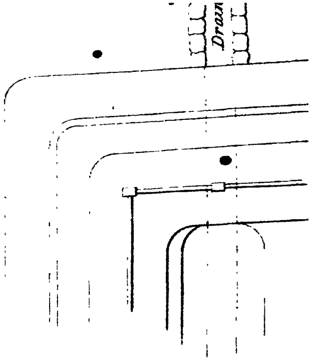


Fig 7 Section at A.A.

Fig. 6. Elevation of Plates at DD

Fig 1

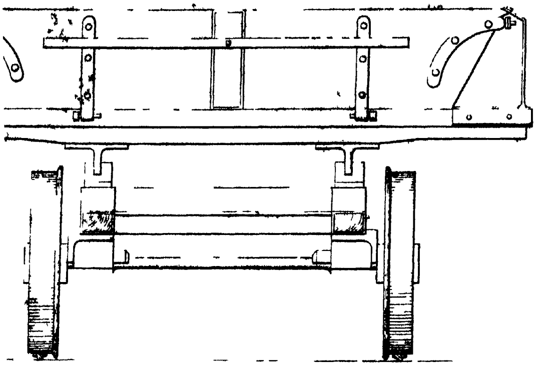


Fig 2

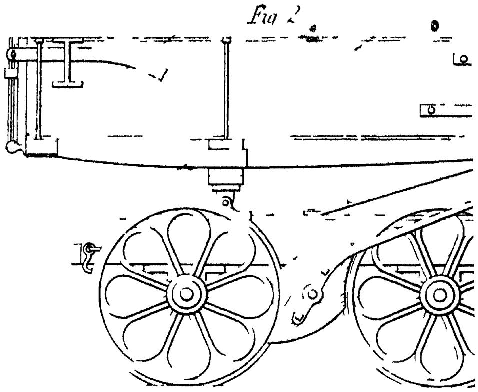


Fig 5

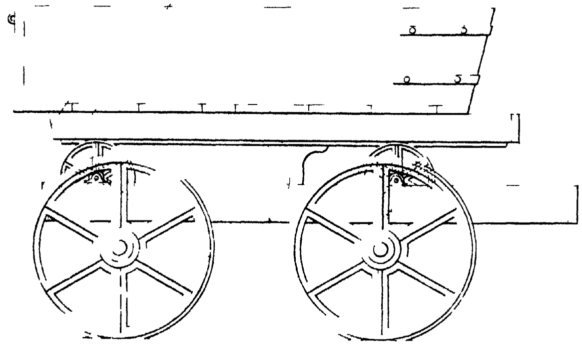


Fig 6

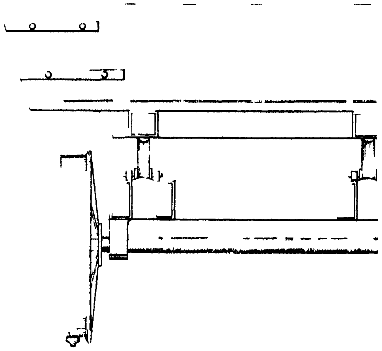


Fig 7

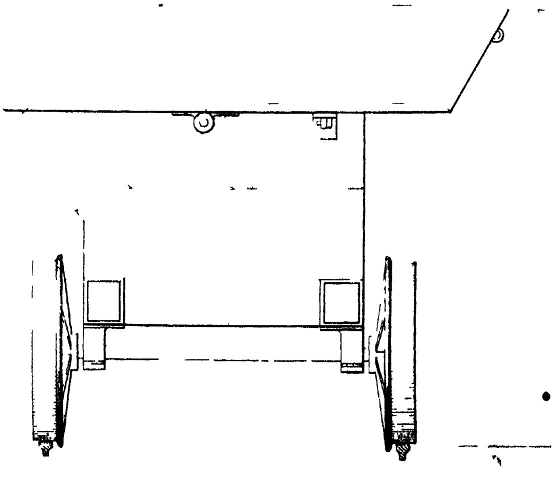


Fig 8

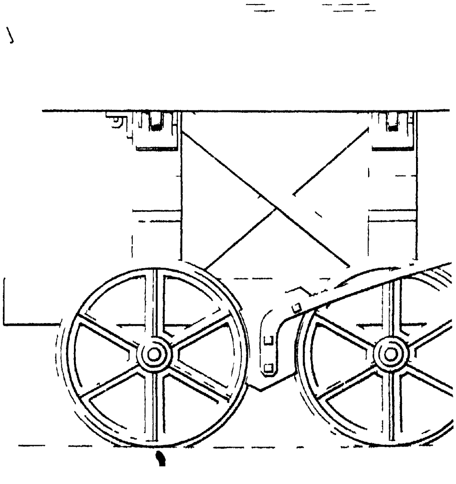


Fig. 3.

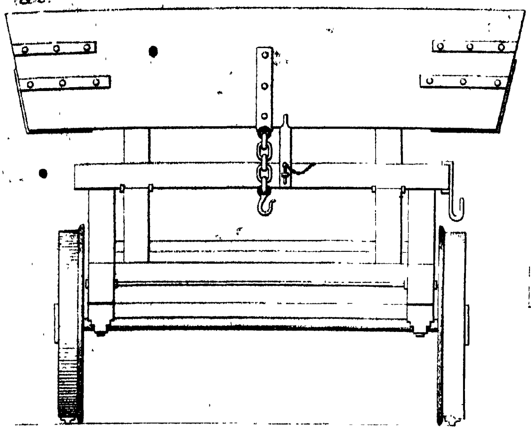


Fig. 4.

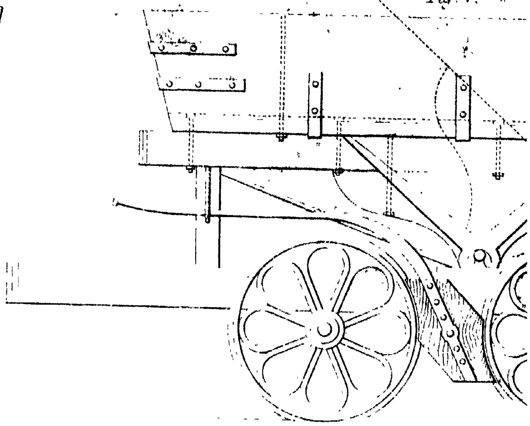


Fig 11

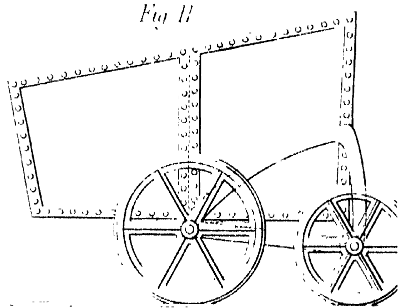


Fig 10

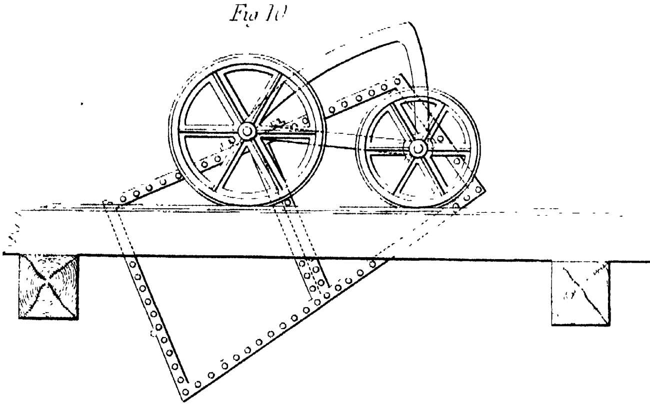


Fig 12

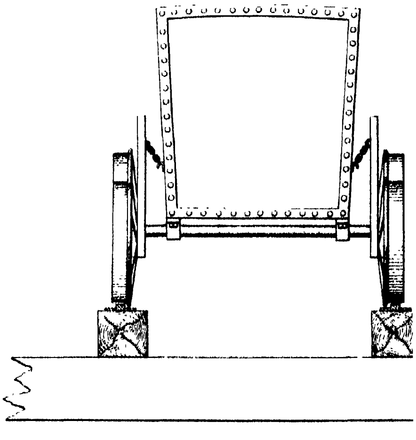
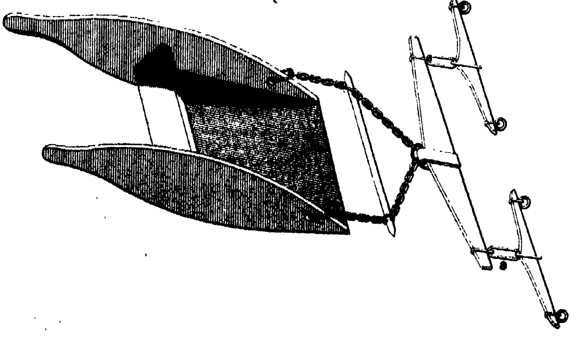


Fig. 9



The following figures, referring to the earth-works on some of the English railways, will conclude this Section, and the present portion of this Paper.

Birmingham and Gloucester.—The earth-works amount to 76,250 cubic yards per mile.

Chester and Birkenhead	Do.	82,451	„
Great North of England	Do.	32,000	„
Lancaster and Preston	Do.	100,000	„
Liverpool and Manchester	Do.	90,000	„
London and Brighton	Do.	156,000	„
London and South Western	Do.	143,434	„
Manchester and Leeds	Do.	100,500	„
London and Birmingham	Do.	142,000	„
Midland Counties	Do.	94,112	„
North Midland	Do.	131,034	„
North Union	Do.	116,120	„
Sheffield and Rotherham	Do.	76,000	„
Stockton and Hartlepool	Do.	41,000	„

G. D. D.

END OF SECTION II.

XV.—*Description of the Mode adopted for Repairing and Supporting the Western Retaining Wall of the London and Birmingham Extension Railway.*

By G. Drysdale Dempsey.

That portion of the London and Birmingham Railway which extends from the station at Camden Town to the terminus at Euston Square, known as the "Extension Line," has been constructed subsequently to the other part of the railway, and executed in cutting of an average depth of 20 feet below the surface of the land through which it passes. For the sake of economy in land and in bridges, &c., this excavation is limited to the width required across the lines of railway, and the sides are retained with brick walls. The width between these walls, it must be remarked, is about twice that required for a double line of rails, having been arranged with a view to provide for the joint use of the London and Birmingham and the Great Western Railways.

This excavation intersects the London clay, the dip of which at that part inclines downwards towards the east. The consequence is, that the wall on the west side is required to sustain constantly an enormous thrust, which is, of course, much increased when the clay becomes swollen by absorbing water from the western environs lying towards Primrose Hill, which are above the level of the top of the cutting. This wall of the excavation, although built of great thickness, with a curvilinear batter, substantial footings, and bedded and backed in good concrete, and withal, carefully built, showed early symptoms of its inability to withstand the pressure acting behind it; and the upper part of the wall, the weakest, becoming displaced to a considerable extent, (in some instances more than 12 inches,) it was deemed necessary to adopt the ready means of a temporary support offered by timber shoring. Meantime, holes of 6 or 8 feet in length, and 3 inches in diameter, were bored through the wall and the backing, and inclining upwards, by the apparatus known as "Watson's Boring Machine;" and the perforated tubes used by the inventor of that machine were then introduced, and fixed into the wall. By this precaution much of the water was prevented from accumulating within the clay; and in some parts the clay appeared to be in some degree drier than it was previously; but in other parts the frequent discharge of water through the wall showed the activity of the mischievous agent, and it became highly necessary to adopt some permanent method of giving support to the failing wall, and preventing any further alteration of its position.

Under the able direction of Robert Stephenson, Esq., the Consulting Engineer to the Company, and R. B. Dockray, Esq., the Resident Engineer, three measures were promptly adopted, which have been found to answer their purpose admirably. These measures were: first, introducing cast iron girders of a large section between the eastern and western walls, so as to serve as abutments for the latter against the former. Second, embedding strong wooden horizontal foot-struts between the footings of the two walls, so as to prevent the lower part of the western wall from yielding forward, when the upper part was strengthened by the cast iron girders. Third, reducing the weight pressing against the western wall by excavating the clay, and constructing spacious vaults with strong walls.

Besides these arrangements, a large side drain was constructed near the western wall, which drain received the water, by means of cross channels formed with drain-tiles, from the clay behind the wall; perforations in the wall being formed for that purpose.

Plates XLIII. and XLIV. are intended to illustrate these several means; Plate XLIII. showing the original construction of the walls, the manner in which the western wall was driven forward by the swollen clay, and the temporary shoring adopted to prevent the entire displacement of the wall. Plate XLIV. exhibits in detail the permanent remedial measures adopted so successfully.

In Plate XLIII. it will be seen that a shoring was applied opposite each pier or pilaster, 20 feet distant, and also midway between them, so that the shores occurred at intervals of 10 feet. In some parts of the wall, where the symptoms were not equally threatening, the intermediate shores against the panels were omitted. The walls were constructed with a bold curvilinear batter, the thickness being reduced by steps in the back. They were founded upon a bed of concrete, and at intervals were backed by the same material, as shown by the vertical line behind the wall on the right side of the cross section, Plate XLIII. The west wall is shown both in its original and its altered position. The shoring consisted of double struts, a foot-strut and an upper one. The upper strut abutted against a blocking piece, bolted upon the foot-strut, both starting from a short pile placed at right angles to the foot-strut. A waling piece was extended throughout the length of the shoring, and served to tie the foot-piles together. The upper ends of both struts were retained by needles, sunk 2 feet into the wall through a 2-inch plank, placed vertically against the wall for that purpose.

Plate XLIV. represents the wall, &c., as reconstructed, and contains a cross section and plan of one bay, with five figures of details of the iron-work.

Each girder consists of five separate castings; two half-arches or haunches, one key-piece, and two abutment plates. The latter have wide projecting caulking-pieces cast on the top and bottom. For these, holes were first cut in the brick-work of the piers; the abutment shoes were then introduced; the two half-girders raised, dropped into the grooves formed for them in the abutment plates, and thus suspended while the key-piece was raised, gradually lowered in between the bearing flanges of the haunches, and bolted together. Before a second girder was fixed, the intermediate braces were fixed. Each of these is cast in two pieces; in fixing them one-half was first connected with the main girder by bolts passing through the bearing flanges of the girders and key-pieces, and the other end temporarily supported while a second main girder was being raised. When the key-piece of this was dropped into its place, the other half-brace was raised and fitted to the previous one by means of the tenon and mortise joint, shown at fig. 5. The bolts were then put in, connecting the key-piece, brace, and girders, and also a half-brace for the next bay.

The foot-struts consist of whole balks of timber, each one nearly half the width of the railway. Between their ends, and near the centre of the line, a short pile is driven, and between this pile and the ends of the struts, stout wedges are driven. The struts are prevented from rising at this point by cross pieces bolted to the top of the piles.

The new side drain is formed with a double course of brick-work over the upper semicircle, and a single one for the lower part. Into this side drain, cross drains conduct any excess of water which may accumulate in the centre drain; and other cross drains are formed, at intervals, leading into the side drain from the foot of the wall.

The new wall is built of extra thickness, and bedded upon concrete. The vaults are built of two bricks in thickness, with arched ends against the clay, and arched heads. Two vaults are constructed in each bay; the distance from centre to centre of division walls being 10 feet; and the clear length of each vault about 16 feet. The clay is excavated in a raking line, forming an angle with the horizon considerably less than that of the repose of the material. The footings of the vault walls are stepped in 6-inch courses a little below the surface of this slope. The walls are perforated with cylindrical apertures at the front and lower part, to afford a continuous passage for any water that may find its way into any of the vaults.

Of the cast iron girders, ninety-six are erected, each set consisting of main girder in two pieces, key-piece, two abutment plates, and two half-braces, weighing about 7 tons. The vaults were constructed and the wall rebuilt only for a part of the length between the ninety-six girders. It should be added, that some time after each of the girders was fixed and had attained its permanent position, the bearings of the abutment plates in and against the walls were carefully completed with Roman cement; and wherever the false shape of the walls made it necessary, wedging-pieces of oak were introduced between the plate and the wall. From careful measurements of the walls, and attention on the part of the founders, these cases were very rare. The deflection (measured vertically between the lower edge of the key-pieces and the level of the surface of the rails) of the permanent position of the girders from their places, as first fixed, was in no case more than $\frac{5}{8}$ths of an inch.

The whole of this work was executed without, in a single instance, interrupting or impeding the constant traffic on the railway, which throughout this excavation is carried on by means of the stationary engines at Camden Town, and a rope; the carriages descending the incline to Euston Square by their own gravity, and at a great velocity. By a faithful adherence to the regulations issued by the Company's engineer; good tackling provided by the contractors, Messrs. Bramah and Cochrane, of the Woodside Works; and constant care and attention on their parts during the erection, they were enabled to complete it without any accident or unfortunate casualty. The only available method of sustaining the immense weight of these girders during fixing was by stretching a beam of timber across the railway, bearing upon the tops of the walls on either side. In order to avoid disturbing the iron railings which surround the walls, bearing-stages of timber were used; these were moved along on both sides of the cutting at once, as the work required it, in order to bring the beam over each pier in succession. The beam used for this purpose was fitted with cast iron shoes at the ends, and two intermediate straining-brackets, (dividing the length of the beam into three parts, nearly of equal lengths,) and trussed with a pair of 1½-inch wrought iron rods.

It is evident that the system of repairs here described must have involved a tremendous expense. In those parts of the cutting where the vaults have been built, and the clay excavated as described, the section is little different from that of a common cutting, the clay lying below its natural position, and all the expensive brick-work and girders added, in order to sustain the depth of made ground covering the vaults, and afford adequate protection to the adjoining parts of the walls. Adding to this the cost of buying or arranging for the overlying land, and other property, it may safely be inferred that, in comparison with this total cost, any width of land required for forming this western side as an open cutting at a flat slope, would have been cheaply purchased at almost any price whatsoever. The fact that all the circumstances of such cases as this can never be clearly foreseen by the most experienced judgment, allows the remarks here made, without in the slightest degree impugning the discretion of the justly celebrated engineer who designed the works of the London and Birmingham Railway.

G. D. D.

London

RETAINING WA

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with

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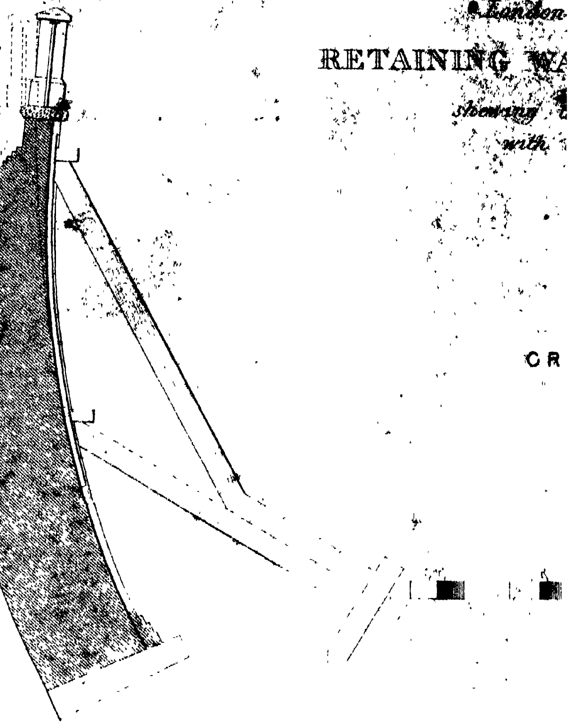
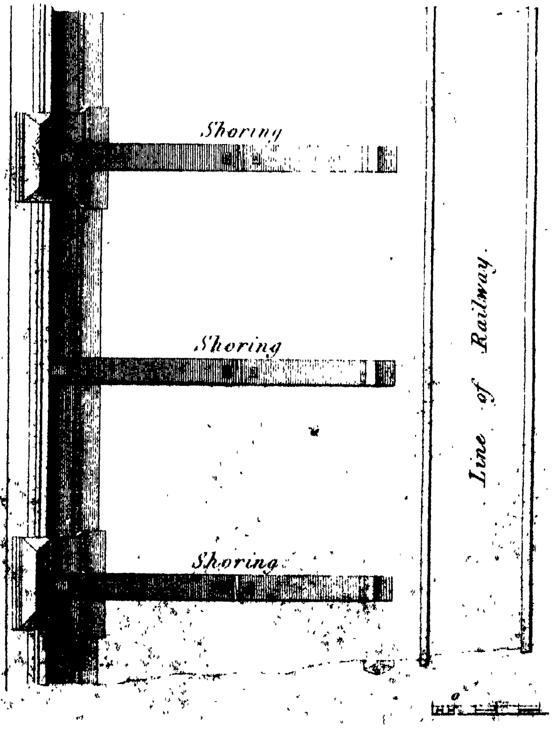


The dotted lines shew the original position of the Wall.



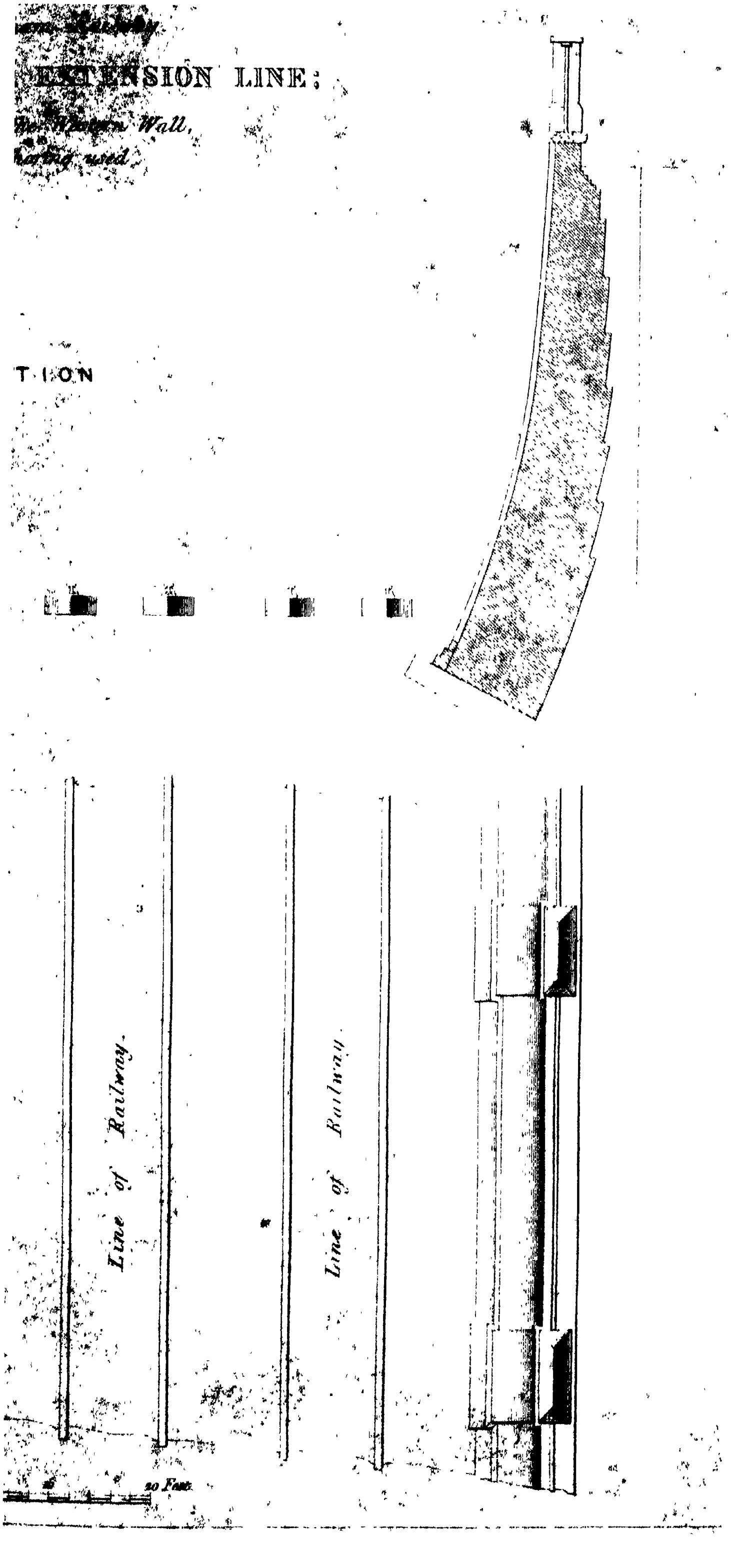
Railway

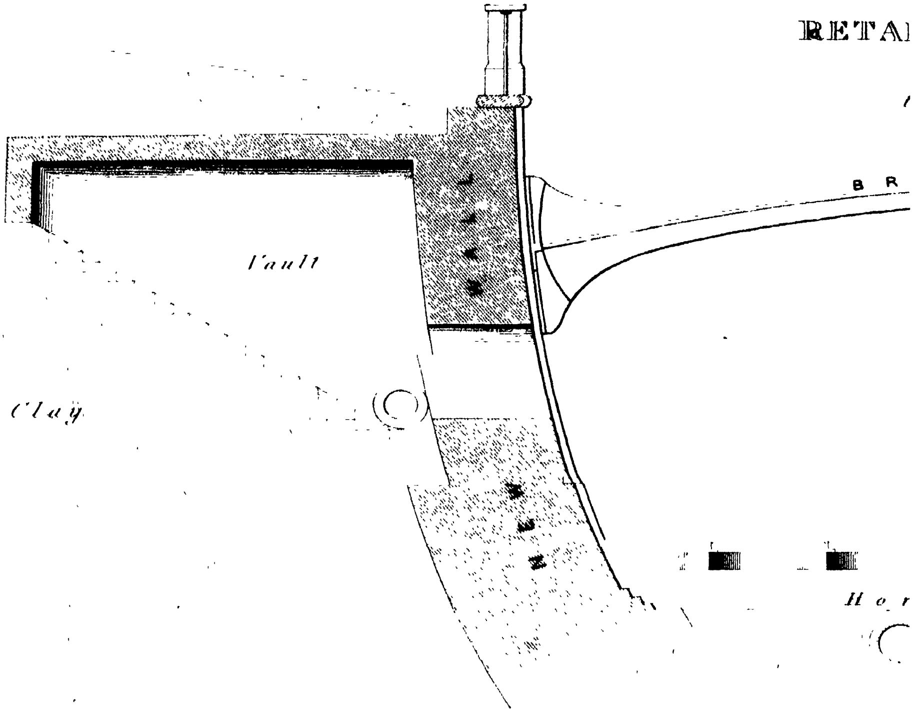
EXTENSION LINE;

Wall,

having used

TION




RETA
Vault
Clay
WALL
NEW
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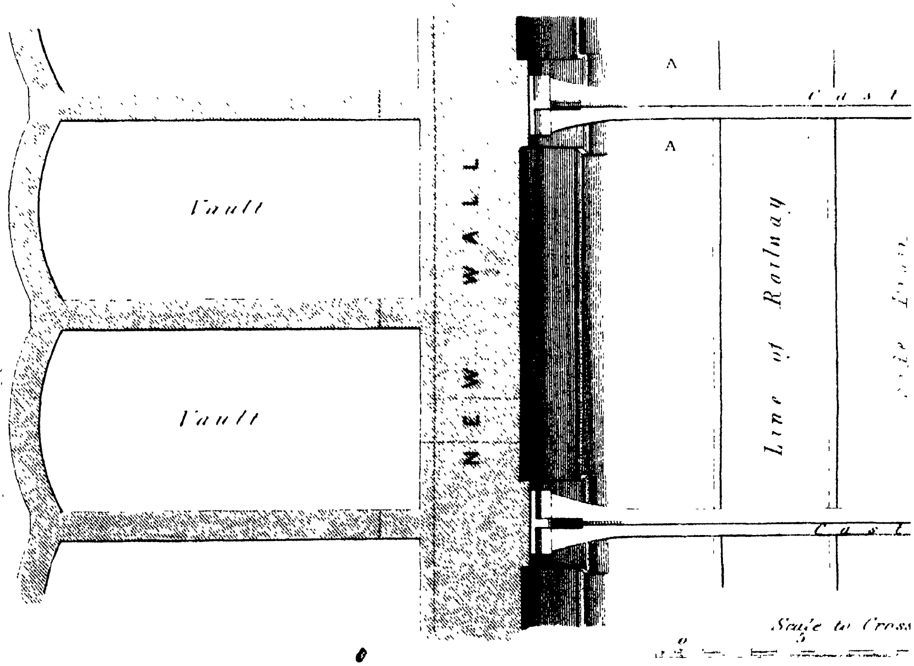
A
C a s t
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Vault
NEW WALL
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C a s t
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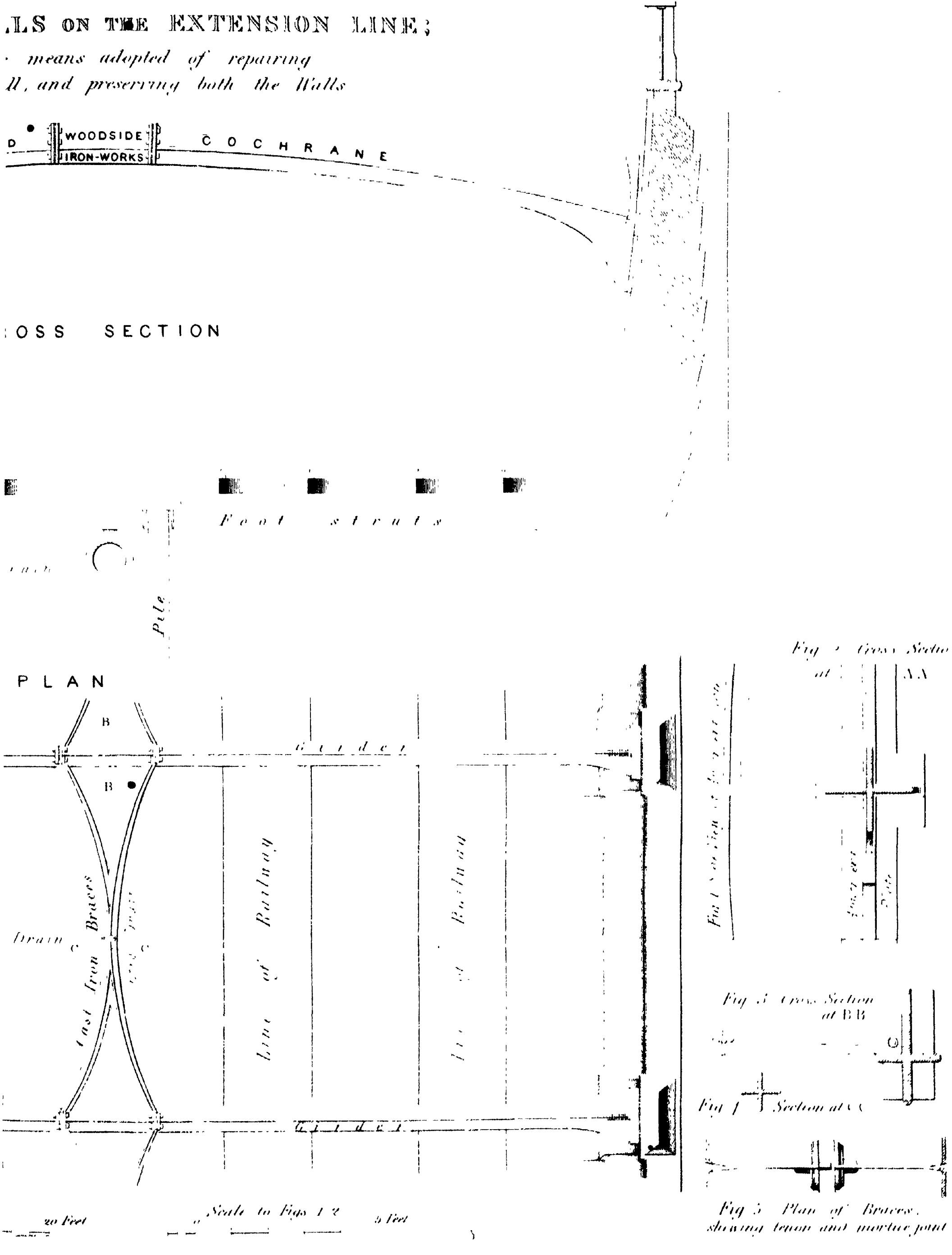
nd Birmingham Railway.

LS ON THE EXTENSION LINE;

means adopted of repairing

ll, and preserving both the Walls



XVI.—*Report on the System of Drainage of Low Lands in Holland, the Mechanical Means employed therein, and the Differences of Cost, &c. By Captain* G. W. Hughes, *Corps of Topographical Engineers, United States' Army. Being an Appendix to one of the Documents accompanying the President's Message.*

Albany, September 30, 1843.

Sir,

While absent in Europe, in the year 1841, I availed myself of a favourable opportunity to visit Holland, for the purpose of examining the hydraulic works, the canals, dikes, and drainage, for which that country is so justly celebrated.

Through the kind intervention of Mr. Bleecker, our representative at the Hague, and of Mr. Falcke, the Netherlands minister to Brussels, I obtained access to manuscript reports and maps which had never been published. I was also indebted to Mr. Goudrian, of the *water staat*, and to Mr. Simons, civil engineer, for much valuable information touching the objects of my investigation, drawn from official documents.

From the sources[1] above enumerated, and from information derived from personal observation, I have written the following Paper, which (although not prepared under specific instructions) I beg leave to submit to you in the form of an official Report, in the hope that it may prove of some practical utility, not only to the corps over which you preside, in the discharge of its multifarious duties, but also in advancing the general interests of the country.

Before proceeding to a consideration of the public works above indicated, it may be advisable, for a better understanding of the subject, to enter upon a

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[1] It is proper to observe, that the greater portion of this Paper *relating to the drainage of the lake of Haarlem,* is nearly a literal translation of the manuscript report by the engineer, Mr. G. Simons; and that, in the general remarks, I have occasionally consulted Murray, and other authorities, for facts, when my own notes were not sufficiently full.

brief description of the remarkable country of whose physical necessities they are the offspring.

The kingdom of Holland (bounded on the west and north by the North Sea, on the east by Hanover and Prussia, and on the south by Belgium) consists of the following provinces, through which the Scheldt, Maas, and the several branches of the Rhine, discharge their waters into the German Ocean, viz.: North Brabant, Zealand, South Holland, North Holland, Utrecht, Guilderland, Overyssel, Friesland, Drenthe, and Groningen, containing a population of nearly 2,800,000 souls.

In traversing that part of Europe, which was significantly called "The Netherlands," and a portion of France, included on the sea coast between the Helder and Dunkirk, the conclusion is forced on the mind of the reflective traveller, that the whole of the "low countries" is alluvion—the wash of the higher regions of Germany, borne down by the Maas and the various tributaries and branches of the Rhine, and deposited from their muddy waters.[2] At an early period, before the skill, industry, and science of man were called into requisition, where now flourish populous cities, rich meadows, and waving fields of corn, the sea disputed the empire with the land, and at least twice in each day asserted its supremacy. Even at so comparatively a recent date as the invasion of Germany by Julius Cæsar, the whole of this region of country was regularly overflowed by the ocean, with the exception of a few scattered mounds, on which a brave, hardy, independent, but sparse population existed, mainly relying for food on the fish left on the sands by the ebbing tides, and preferring a precarious subsistence among their native fens to the luxuries and refinements of Roman life.

The exact process by which the Netherlands have been reclaimed from the sea has not yet been fully described. Natural causes having first produced an alluvial swamp, by a process similar to that which is still in action in different portions of the globe, (more especially in the deltas of the Nile and the Mississippi, under the combined influence of which, and the exertions of man, Egypt and Louisiana have gradually emerged from the dominion of the waters,) a certain degree of art has been employed to erect barriers by which

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[2] This process seems to be still actively going on, as may be seen at the mouths of the rivers Scheldt and Maas, where extensive low, reedy mud-banks, tufted with marine grass, are exposed at tolerably low tides; and there can be no doubt that, with due exertion, many square miles of new land might be added to the territory of Holland.

the influx of the sea was prevented. This first step having been gained, it remained to drain the marsh thus enclosed. This operation was, of course, slow and laborious; for, as the surface of the ground was below the level of the ocean, the water was elevated into artificial channels, through which it might be discharged at low tides. And here, again, Nature interposed and lent her powerful assistance to co-operate with the efforts of man in staying the progress of the sea, and checking its encroachments. For centuries her exertions have been employed in raising and increasing bulwarks to resist tidal inundations.[3] The constant action of the winds on the sandy beach, when exposed at low water, has caused the formation of large mounds, (or "dunes," as they are called,) elevated considerably above the highest tides, rising, in some cases, so high as to conceal from view churches and châteaux. These dunes extend, with but little interruption, like a range of hills of variable height, from Alkmaar, in the neighbourhood of the Helder, to the vicinity of Dunkirk—a distance of about 130 English miles. The wind, blowing fresh from the German Ocean, raises the fine and dry particles of sand from the beach, (where it has been deposited by the waves,) which are drifted, like snow, up the outer faces of the banks or dikes, either adding to their height, or being carried over and behind them, according to the intensity of the moving force. In the latter case, the breadth of the dunes is increased, and they do, indeed, vary from 1 to 3 miles in width.[4] The benefit resulting from this accumulation of sand is not, however, unattended with evil consequences, as there is a continual tendency of the sand to invade the arable lands. To prevent the further encroachments of the sand, and to counteract its evil action, the dunes are every year sown with a species of reedy or bent-grass (the *arundo arenaria*) growing in the vicinity of the sea, which finds in the sands a kind and congenial soil. The roots soon spread, strike deeply into the ground, and so intertwine that the sand is held firmly between them; and, as the growth of the grass is luxuriant, the decomposition of its successive crops at last forms a soil sufficiently rich to produce, it is said, potatoes, and to bear plantations of firs. By this process, the moving sands become fixed and

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[3] The same result may be seen on the Gulf of Mexico, from St. Joseph's, in Florida, to Mobile, in Alabama; and perhaps for a much greater extent on the coast. These sand-banks, or downs, composed of a fine and very white sand, present very much the appearance of immense snow-drifts in more wintry climes.

[4] Professor Van Kampen says they are from a quarter of a league to two leagues wide.

harmless, or, rather, like every thing else in this wonderful and utilitarian country, are rendered tributary to the wants of man. Before attempts had been made to prevent this movement of the sand, it had, in the process of years, penetrated far into the interior; and, quite recently, many hillocks have been removed for the purpose of cultivating the virgin soil beneath, which was found to have lost none of its value by this long entombment.

The efforts of the inhabitants of the country to shut out the waters have been mainly directed to those portions of the coast where the natural dunes do not exist, and to the margins of the rivers and interior lakes.

In the construction of dikes, the first essential is to secure a firm foundation, sufficiently solid to sustain the weighty superstructure to be reared upon it. To effect this object, various expedients are resorted to—such as the compression of the natural soil; the laying a substratum of clay or of fascines; the driving of piles; the filling in of stone; and the formation, in some cases where wood can be readily procured, of grillages or platforms. On this substructure is built the dike proper, consisting of successive strata of earth, clay, and sand, consolidated by ramming, and bound together by straw, rushes, reeds, or fascines. The sea-slope is protected by a species of gabion, or close wicker-work of osier-twigs—the spaces being filled with clay, or puddling, to prevent the percolation of water.

This portion of the work is, of course, liable to rapid decay; but, for the purpose of furnishing the branches with which to renew it economically, and partly with the view of more firmly uniting with their roots the materials of which the ramparts are composed, willow-trees are abundantly cultivated along the dikes. Where these structures are much exposed to the fury of the ocean, they are faced with masonry, and protected at the base by vast mounds of rock, or rows of piles, forming artificial breakwaters. The upper surface is covered with turf, and is, in many places, more than 40 feet above the level of the sea at low tide.

The most wonderful embankments in the world, perhaps, are those of the Helder and of West Kappel, on the island of Walcheren.

The Helder is a fortified town at the northern extreme of North Holland, opposite to the isle of Texel; and, being greatly exposed to the action of the winds and the waves, is enclosed on every side by stupendous dikes.

The author of 'A Journey in North Holland' thus describes it: "The great dike of the Helder, which is nearly 2 leagues in length, is 40 feet broad at the summit, over which there is a very good road. It descends into the sea by a slope of 200 feet, inclining about 40 degrees. The highest tides are far from covering the top; the lowest are equally far from showing the base. At certain distances, enormous buttresses, broad and high in proportion to the rest, and constructed with still greater solidity, project several toises into the sea. This artificial and gigantic coast is entirely composed of blocks of granite, all brought from Norway; and these masses, which look as if it were impossible to move them, are levelled and squared like a pavement. The number of rocks which are seen at one view are sufficient to confound the imagination: how much more, when we think on the quantities buried beneath the waves, to serve as the foundation of such mountains."

This great work stands an enduring monument to the memory of Napoleon, by whose commands it was constructed. He called it his Northern Gibraltar.

The lowest land on the Dutch coast is in the province of Zealand, or "Sealand," as it is called from that circumstance. It consists of nine islands, (separated from one another by the different branches of the Scheldt,) the largest of which is Walcheren, on whose western extremity stands West Kappel. This latter position was defended by one of the most enormous sea-walls in the Netherlands; which was overwhelmed by a violent tempest in 1808, and nearly the whole island, in consequence, submerged. The inundation would have been universal, but for the existence of the secondary dikes running across the island. The extent of the Zealand dikes is said to be at least 300 miles, and to cost, for annual repairs and preservation, about $800,000; while the sum total expended for similar objects, and for the regulation of the water levels throughout Holland, amounts to nearly $3,000,000 per annum.

The interior embankments are nearly as extensive as the sea-dikes; and, at times, as much danger is to be apprehended from the irruptions of the rivers as from the ocean. The one may be compared to a foreign enemy, boldly assailing the frontiers; the other to a secret foe, insidiously undermining the domestic institutions of the country.

The ocean having been shut out from the land by the ramparts already described, and the rivers having been confined within proper bounds, the next question was, to get rid of the downfall water, and the waters which had subsided in the small lakes, whose bottoms were *below* the level of ordinary *low tides.* Embankments seem, in the first instance, to have been formed (the materials for them having been taken from alongside) on a level with the rivers, at certain stages of the tides; and on these embankments canals were *built*, and rendered water-tight by puddling. These canals were provided with lift locks and sluices at their embouchures; by which latter contrivance the surplus water might be discharged when the tides fell below their level. The side ditches, formed by the excavation, would suffice to drain all the lands which would (before the dikes were erected) have been exposed at low water. These side ditches (or *small canals* as they may be called) are frequently intersected by lateral ditches, which answer a threefold purpose: 1st, for drainage; 2nd, for channels of transportation for the small farmers to house their crops, or to send them to the next market-town; and 3rd, as boundary lines, and as substitutes for fences.

The *first class* of canals are intended principally for great commercial purposes, and will be treated of separately. The small canals are often seen passing underneath the larger ones; and two boats may cross each other, at the same moment of time, on different levels.

The *second class* of canals, as we have already shown, are of a mixed character; but their primary object was for the drainage of the country. It must be obvious, however, that no system of ditching alone can free a country of water lying below the level of low tides. To drain the ponds, or small lakes, the waters must be raised sufficiently high to be discharged at low tides. This has been effected mainly by the power of the wind; for, in Holland, even the wind is not allowed to blow without being turned to some *useful* purpose. It is applied not only in drainage, but in grinding grain, tobacco, painters' colours, and rape-seed for oil; in making paper, and in sawing timber. Some idea of the extent to which the wind is employed may be formed from the fact, that, in the vicinity of Saardam, a town of 9000 inhabitants, there are 400 wind-mills—some of them of enormous size.

The morass or lake to be drained is first surrounded by an earthen bank, to cut off the flow of water from higher grounds. Along this dike wind-mills are erected, to elevate the water into a channel so high that it may be eventually discharged into the ocean. It sometimes happens that this cannot be done at one operation, as wind-mills cannot be effectually used to raise water to much more than a five-feet lift; which is, in fact, its maximum of useful effect. If it should become necessary to overcome much more than that height, another set of mills must be established ; and, in some cases, there have been as many as four separate stages formed, each stage having its own set of mills. and a separate canal, from which, in turn, the surplus waters are are expelled.

These canals also serve as enclosures, rendering fences unnecessary. The lands thus reclaimed are called *polders;* and the girdle of wind-mills, which announce at a distance the frontiers of these polders, have been compared to a chain of gigantic sentinels placed to guard the approaches.

"It is easy to conceive the extreme fertility of land managed in this manner. Formed originally of mud, which was itself rich, it is covered almost all the year round with herbs which contribute to its fertility. All the water which might be injurious, is drawn off at pleasure by means of the mills, and a regular gradual irrigation is introduced at the most favourable moment."

Pumps are not often employed in the drainage of land, on account of the great friction which unfits them for that purpose; but, in their stead, are used the Eckhardt wheel, the Archimedean screw, and the scoop-wheel.

By these means have been drained in the province of Holland—

From 1440 to 1600,	23,649	acres of arable land.
From 1600 to 1650,	71,006	„ „ „
From 1650 to 1700,	5,370	„ „ „
From 1700 to 1750,	10,309	„ „ „
From 1750 to 1800,	39,268	„ „ „
From 1800 to 1841,	23,880	„ „ „

Making in all, 173,482 acres previous to the beginning of the draining of Haarlem sea.[5]

The most gigantic work of the kind ever undertaken in this, or any other country, is the draining of the lake of Haarlem, (or Haarlem sea, as it is often

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[5] There is a great deal of very rich land in Louisiana, belonging to the United States, that might be reclaimed at a comparatively low cost. I refer more particularly to an extensive district of country west of the Lafourche, embraced between Thibodeauville, the Attakapas canal, Lake Long, and Bayou Blue. The greater portion of this tract could be drained by ditches and *Artesian wells;* but a small part of it might be kept free from the downfall water and the infiltration from the Lafourche, by means of wind-mills, which, when not wanted for drainage, might be used for other purposes. This would make one of the finest rice regions in the world, and would possess great advantages from the manner in which it might be irrigated, and the water expelled when it was no longer required.

and appropriately called.) On my way to Amsterdam, I crossed an arm of this lake, which, being at the time greatly agitated by the winds, presented the appearance of an angry sea; its waves breaking with great force against the restraining dikes.

This lake was formed, as has been stated in another portion of this Paper, by a frightful irruption towards the close of the 16th century. It is 13½ miles long in the direction of its greatest length, with a maximum breadth of 8½ miles, and covers 44,480 acres of land. It is on an average about 13 feet deep, (the whole of which body of water is to be raised a mean height of 6½ feet,) the bottom being composed of very soft mud—the débris of the higher regions of Germany and Switzerland. The mud is a mixture of silicious earth and clay, and is employed in the manufactory of the small clinker bricks with which the Dutch roads are paved.

The lake of Haarlem forms a part of the great water basin (reservoir, *boezem* in Dutch) of Rynland, a large district containing 249,090 acres of land, exclusive of the basin itself, whose surface now is 56,090. All the rain-water which falls on the 305,180 acres, and which is not exhaled, is gathered or pumped up by wind-mills into the basin, to be discharged at low water—

1st. Into the Y, through the sluices at Spaardam, and at Halfway (*Halfwege*) between Haarlem and Amsterdam.

2nd. Into the river Yssel, near Gouda.

3rd. Into the North Sea, through the sluices at Katwyk.

The lake of Haarlem, containing 44,480 acres, when drained, will reduce the basin of Rynland from 56,090 to 11,610 acres. It will be clear, by the following explanations, that the effect would be pernicious to Rynland, if the reduction were not balanced by improving the old, or creating new means of discharging the superfluous quantity of water; the more so, as the lake itself will be emptied into the basin so reduced.

Table showing the mean level for the different months of the year—1st, of the Y, at Spaardam; 2nd, of the Yssel, near Gouda; 3rd, of the North Sea at Katwyk; 4th, of the basin of Rynland, in English inches, above (a) or beneath (b), the comparative point by which the height of the water is generally calculated in Holland; which point is called Amsterdamsch peil, (Amsterdam mark,) and indicated by the letters A. P. (The Amsterdamsch peil, or A. P., is on a level with the ordinary high water of the Y at Amsterdam.)

	January.		February.		March.		April.		May		June.	
	At high water.	At low water.	At high water.	At low water.	At high water.	At low water.	At high water.	At low water.	At high water.	At low water.	At high water.	At low water.
Mean level of the Y, at Spaardam	(*a*) A. P. 2·66	(*b*) A. P. 9·76	(*a*) A. P. 2·68	(*b*) A. P. 10·13	(*a*) A. P. 4·76	(*b*) A. P. 12·07	(*a*) A. P. 4·98	(*b*) A. P. 11·51	(*a*) A. P. 6·05	(*b*) A. P. 10·55	(*a*) A. P. 6·25	(*b*) A. P. 10·40
Mean level of the Yssel, near Gouda. . . .	35·08	12·83	37·52	13·33	45·28	11·90	43·09	14·53	42·20	17·49	43·05	17·01
Mean level of the North Sea at Katwyk . .	34·60	33·62	34·69	33·25	37·09	31·14	35·83	31·36	35·49	30·39	36·23	27·08
Mean level of the basin of Rynland	(*b*) A. P. 16·75		(*b*) A. P. 16·50		(*b*) A. P. 15·90		(*b*) A. P. 17·17		(*b*) A. P. 19·79		(*b*) A. P. 23·82	

TABLE—(*Continued*).

	July.		August.		September.		October.		November.		December.	
	At high water.	At low water.	At high water.	At low water.	At high water.	At low water.	At high water.	At low water.	At high water.	At low water.	At high water.	At low water.
Mean level of the Y, at Spaardam	(*a*) A. P. 6·17	(*b*) A. P. 10·17	(*a*) A. P. 6·36	(*b*) A. P. 10·10	(*a*) A. P. 8·20	(*b*) A. P. 8·52	(*a*) A. P. 8·95	(*b*) A. P. 9·05	(*a*) A. P. 11·31	(*b*) A. P. 7·66	(*a*) A. P. 8·71	(*b*) A. P. 10·80
Mean level of the Yssel, near Gouda. . . .	44·05	14·11	42·97	13·80	40·81	14·10	40·63	13·87	42·31	6·82	43·82	5·65
Mean level of the North Sea at Katwyk . .	36·50	25·05	36·44	25·11	34 98	23·90	36·37	22·66	38·13	23·04	38·24	26·15
Mean level of the basin of Rynland	(*b*) A. P. 26·43		(*b*) A. P. 26·38		(*b*) A. P. 23·43		(*b*) A. P. 22·69		(*b*) A. P. 18·25		(*b*) A. P. 15·57	

From an inspection of this Table, it appears that the only regular evacuation is through the sluices at Katwyk; nevertheless, a great, and perhaps a greater, quantity of water is discharged into the Y through the sluices at Spaardam and Halfway, which were, with the less important evacuation at Gouda, the only means till 1807, when the sluices at Katwyk were constructed.

It is not difficult to account for the great quantity of water discharged into the Y, although its mean ebb be higher than the mean level of the Rynland basin. The south-west is the most prevailing wind; it lowers the waters of the Y before the sluices, and elevates, at the same time, behind them, the waters of the basin, whose level is often thus raised above such extraordinary ebb of the Y. This circumstance was of the more importance, as the conducting canals to the sluices at Katwyk were not of great capacity, although quite sufficient to answer their purpose in the present condition of Rynland. It is clear that the draining of the lake will greatly lessen the effect of the wind in raising the waters behind the sluices at Spaardam and Halfway, and that it will diminish, in the same proportion, the evacuation through those sluices.

A large basin, such as that of Rynland now is, has, moreover, a great advantage. The waters from the lower lands, as the greatest part of Rynland are, must be pumped up by wind-mills. The larger that basin is, the less will its level be raised by the waters discharged into it; and this not only diminishes the height to which those waters must be lifted, and so augments in the same proportion the efficacy of the wind-mills, but the result is, likewise, that the evacuation is possible; which is not always the case in other districts, with smaller basins, the level of which is not to be raised beyond certain limits.

The first object, then, in draining the lake of Haarlem, must be to secure Rynland against all evil consequences. To this end, a new canal of great capacity[6] has been made from the Lee to the canal of Katwyk, to which the waters of Rynland were formerly conducted through the narrow and winding Rynsburgervliet. The canal of Katwyk itself has been widened to nearly 171 feet;[7] and in the same proportion the capacity will be

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[6] Length of the canal . . 4235 metres = 13,895·0 English feet.
Width of the canal at A. P. 40 do. = 131·2 do.
Width of the canal at bottom 31·2 do. = 102·4 do.
Depth of the canal . . 2·2 do. = 7·2 do.

[7] Present width of the canal at A. P. 52 metres = 170·6 English feet.
Present width of the canal at bottom 42·2 do. = 141·7 do.
Present depth of the canal . . 2·2 do. = 7·2 do.

augmented of the interior sluices, whilst the capacity of the exterior ones is considered large enough to answer the purpose after the intended change. With a view to the same object, (the protection of Rynland,) a double-acting steam engine, of more than two hundred horse-power, will be erected at Spaardam, adapted to scoop-wheels of 20 feet diameter, by which the water from the basin may be discharged into the Y, whenever the ordinary evacuation through the sluices fails.

Besides the security of Rynland, there was also to be taken into consideration another object, perhaps of no less importance—the inland navigation. The lake of Haarlem being surrounded by numerous canals, situated between large towns and rich villages, in the very heart of the most populous, opulent, and mercantile province of the kingdom, it is evident that it must be of great utility to the inland commerce and navigation; the importance of which will appear from the fact, that 20,000 vessels are crossing the lake every year. The draining would, therefore, be most injurious to the intercourse of the interior, if this were not provided for by an ample canal, dug around the lake, deep enough for the passage of the largest vessels now crossing the lake. Along the banks of the surrounding canal (*ringvaart*) there is to be made a road, or path, for the purpose of towing the vessels by horses, whenever the wind is not favourable.

These remarks were deemed necessary, not only to account for all the expenses, but also to explain the reasons why, after so many other and great works of the same kind had been successfully executed, the draining of the Haarlem lake was so long deferred—the first project for that purpose having been proposed as early as 1632.

The canal around the lake already referred to will form a part of the Rynland basin, as the lake of Haarlem now does. The reduced size of that basin will thus be augmented by that canal, 131 feet wide at A. P., 73 feet at bottom, 10 feet deep from A. P.[8] The length of the canal being nearly 34 English miles, its surface at A. P. will be more than 540 acres.

The first thing to be done in this, as in all other cases where lands beneath the surface of the surrounding waters are to be drained, is to construct a dike around the whole extent, so that the lands may be protected against the action of those waters. When the grounds on which the dike is to be raised, and the

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[8] The lowest level of the Rynland basin, and, consequently, of the surrounding canal which is to form a part of it, being not even 2½ feet beneath A. P., there will always remain a depth of water of more than 7½ feet, which is quite sufficient for the largest vessels now crossing the lake.

materials of which it is to be made, are bad, (that is, light, porous, and watery,) as is generally the case in Holland, the dike must be not only higher than the highest level of the surrounding waters, but it must be very massive, at the same time, in order that the subjacent grounds, and the materials of the dike itself, may be duly compressed and perfectly united together in one firm and solid mass, so as to prevent the infiltration of the exterior waters. Whenever the ground is extremely bad, and the dike not large enough, this infiltration may be very injurious, and become permanent, as is the case with some drained lands; but in the first years after the draining, a greater or less degree of filtration always takes place, even when the dike is built with the greatest care, as it requires some time before it is sufficiently settled and compressed to resist the percolation of water through it. These are the reasons why the dike for the draining of Haarlem lake will be higher than the level of the surrounding waters may seem to require. Its dimensions are as follows:—Its top is 7 English feet 10·49 inches (2·40 metres) above Amsterdam mark, (Amsterdam peil, A. P.)[9] The inner (the side towards the lake) slope is five times the height; therefore 39 feet 4·45 inches (12 metres) at A. P.; the outer, sloping towards the surrounding canal, is 6 feet 6·74 inches (2 metres) from the top to the height of 6 feet 6·74 inches above A. P., and from there twice the height; therefore, 13 feet 1·48 inch (4 metres) at A. P. The breadth of the dike at A. P. is 59 feet (18 metres).

Two-thirds of the surrounding canal is already dug, and the same length of dike has been built, chiefly of the earth excavated from the canal. The most expensive part of the dike would have been at the east side of the lake, where large and deep pools are situated near the lake, and only separated from it by a narrow tract of very porous land almost floating on the water, and presenting, therefore, the very worst possible foundation for an embankment. But more than seventy years ago a dike was raised on this side of the lake, at enormous expense, to prevent the threatened junction of the Haarlem lake with the adjacent pools, which would have been most destructive not only to the neighbouring lands and villages, especially to Aalsmeer, but even to the whole

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[9] The highest mean level of the surrounding waters (of Rynland basin), indicated in the Table, is 15·57 inches, A. P.; but in extraordinary cases, this level rises sometimes to 20 inches, A. P. The top of the dike will, therefore, be more than 8½ feet above the highest level of the surrounding waters; but the dike will be somewhat lowered by the compression (*inkinkling*) already mentioned.

province of Holland.[10] This dike, stretching from Oude-wetering to Nieuwemeer, a length of nearly 10 English miles, is a very substantial and solid one, although not so high as the dike now in progress; but, with comparatively small cost, it may be made of the same height, the materials for which are provided by the excavation of the canal on this side.

Between the dike and the surrounding canal, a road is to be made, 19 feet 8 inches (6 metres) broad. On the other side of the canal, at a distance of more than 13 feet (4 metres), there is to be a small dike, to separate the works of the Haarlem lake from the adjacent lands, and to protect them against the waters of the canal.

In this, as in all other similar cases, the power employed in draining should be proportioned to the force necessary to keep the lands constantly dry after the draining. The greatest quantity of rain fallen in a month was 6·524 inches more than the evaporation, according to ninety-eight years of observations at Halfway (*Halfwege*), between Haarlem and Amsterdam; consequently in the neighbourhood of the lake. It is, therefore, highly improbable that the quantity of water to be discharged in a month will ever exceed a depth of 8 inches, allowing even 1·476 inch for infiltration.[11]

The lake of Haarlem contains 44,480 acres, or 1,937,548,800 square feet. On this surface 8 inches of depth make a mass of 1,291,699,200 cubic feet of water, or 1,291,699,200 × 62½ = 80,731,200,000 ℔s.—a cubic foot of water weighing nearly 62½ ℔s. The level of the drains to be made within the drained lake, or intended polder, will never be more than 16 feet below the surface of the surrounding canal into which the water is to be discharged; consequently, the lands will be kept dry, even under the most unfavourable circumstances, by a power capable of raising 80,731,200,000 ℔s. 16 feet, or 1,291,699,200,000 ℔s. 1 foot in a month. Allowing five days for cleaning and repairing machinery, there remain twenty-five days in a month for working the steam engines

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[10] The sheet of water now known under the general name of Haarlem lake, was formed by the irruption and junction of different lakes. Three villages (Vyflingen, Nieumerhoek, and Ryk) were swallowed up by the waves at different times; and even greater destruction was imminent, when the dike at the east side of the lake was raised, in 1767, by order of the States of Holland. Since that time the borders have been preserved at immense costs, (30,000 florins, or 12,000 dollars annually,) paid by the district of Rynland, with the assistance from Holland or the General Government.

[11] This estimate is founded on unfavourable examples, and it is not probable that the infiltration will often be as great as stated in the text.

by which the lake is to be emptied; the horse-power must, therefore, be $\frac{1,291,699,200,000}{33,000 \times 60 \times 24 \times 25} = 1087.$[12]

Although this power may be quite sufficient, it is nevertheless prudent, in a work of such importance as the one in question, to use one greater than that indicated by calculations founded, at best, upon uncertain data. For this reason, it has been determined to employ six engines of 200 horse-power each. As to the description of engines to be thus employed, they will be single-acting pumping engines, which, as it is well known, perform the greatest duty, and are, therefore, the most economical.

There is, besides, another advantage in using pumps: the water may be raised by them 16 feet at one lift, whereas it cannot conveniently be raised to that height at less than three lifts by scoop-wheels, or two lifts by Archimedean screws, which are the two sorts of hydraulic engines generally and almost solely used in Holland. The kind of pumps to be used is not yet fixed upon.

Six steam engines will be erected: two at Lutke-Meer, two at Zuyder Spaarne, and two at Kager-Meer, as the most convenient places for the discharging of the water.

The surface of the lake being 1,937,548,000 square feet, and its depth 13 feet, it contains 25,188,134,400 cubic feet of water. This mass must be raised to the mean height of 6½ feet; or, by reduction, 25,188,134,400 × 6½ = 163,722,873,600 cubic feet = 10,232,679,600,000 ℔s. to be raised 1 foot.

To this quantity must be added the filtration water and the rain likely to fall during the draining. According to the alleged observations made at Halfway, between Haarlem and Amsterdam, the average quantity of rain surpassing the quantity of evaporation is, during winter, (from September to March,) 9 inches; and during summer, (from April to August,) the quantity of evaporation sur-

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[12] This power is much greater than is generally used in polders drained by wind-mills, the costs of the erection of which, for extraordinary cases, would be too great; the more so, as the additional provision of wind-mills would even be of little use, the wind often failing when it is most required.

It is a general practice, when low lands are to be kept dry, to erect one wind-mill of the largest size (the sweeps of which are from 80 to 90 feet) for every 1250 acres, and 5-feet lift. Now it has been proved, by numerous observations, that the whole annual effect of such a wind-mill does not exceed 695,220,000 cubic feet of water raised 1 foot; therefore, the average effect in a month will be 57,935,000 cubic feet raised to the same height. This effect is not a third of what would be required to discharge 8 inches of depth; making, on a surface of 1250 acres (or 54,450,000 square feet), 36,300,000 cubic feet to be raised 5 feet, equal to 181,500,000 cubic feet to be raised 1 foot.

passes the quantity of rain by 6 inches. There remain, therefore, annually, 3 inches of rain not exhaled. But, as it often happens in wet years that this quantity is much greater, it will be more safe to suppose, during the draining, the double; and, therefore, 6 inches a year, or, on an average, ½ an inch per month. The filtration during the same period has already been estimated at 1½ inch; which, together with half an inch of rain, make 2 inches per month.

Taking this for granted, it will appear that the lake may be emptied in 8 months by a 1200 horse-power. The rain and filtration water will be, in 8 months, $1,937,548,800 \times \frac{16}{12} = 2,583,398,400$ cubic feet, which must be lifted to the mean height of 6½ feet; thus, $6\frac{1}{2} \times 2,583,398,400 = 16,792,089,600$ cubic feet; or $16,792,089,600 \times 62\frac{1}{2} = 1,049,505,600,000$ ℔s. to be raised 1 foot. This quantity, added to the aforesaid 10,232,679,600,000 ℔s., makes the whole mass 11,282,185,200,000 ℔s. to be raised 1 foot. A 1200 horse-power will raise to the same height in 8 months, or 200 days, (supposing, as before, twenty-five working days per month,) $33,000 \times 60 \times 24 \times 200 \times 1200 = 11,404,800,000,000$ ℔s.

But it is evident that, in the beginning, at low lifts of a few inches, the steam engines will not act with their whole power, nor perform so great a duty as they will do afterwards at higher lifts. For this reason, it has been thought better to suppose that fourteen months will be required to empty the lake, and to calculate the necessary quantity of fuel as if the steam engines were to be working, during that period, with their whole power.

For the annual draining, the average quantity of water to be discharged may be thus calculated:—

	Inches.	
Rain in winter	9	
Infiltration during seven months (from Sept. to March)	10½	
		19½ inches.
Infiltration in summer (from April to August)	7½	
Evaporation in summer	3	
		4½ inches.
Total		24 inches.[13]

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[13] It is clear that it will be sometimes necessary, or at least useful, to discharge in summer the heavy rain falling on the lands; and that this should be added to the quantity computed. But it has been remarked in Note 11, that the filtration, although it may be in the beginning so great as stated, will assuredly be much less, if any, at a later period. The whole average quantity of water, calculated to be discharged annually, is even much greater than can be deduced from examples of similar cases. In Note 12 it has been stated: 1st, that generally one wind-mill is erected for every

This mass of water will, therefore, be 1,937,548,800 × 2 = 3,875,097,600 cubic feet, to be raised 16 feet; or, by reduction, 62,001,561,600 cubic feet is = 3,875,097,600,000 lbs. to be raised 1 foot.

As 33,000 × 60 × 24 × 1200 × 68 is = 3,877,632,000,000, the 1200 horse-power will raise that mass in 68 days; which, consequently, may be taken for the average number of days that the engines must annually be in operation.

After the draining, a number of ditches will be dug through the drained lands, (this is called *rockarden*, which means a division into regular compartments,) that they may be divided into convenient portions, and that the water falling on them may be collected, and conducted to the discharging steam engines.

Having thus briefly described the works, we will now proceed to give an approximate estimate of the costs:

	Florins.
The canal from the Lee to the canal of Katwyk has been made for . .	140,000
The canal of Katwyk has been widened for	72,000
Two stone bridges over it have been lengthened for	34,500
Three wooden bridges over the canal from the Lee	37,900
It is calculated that the interior sluices of Katwyk canal will be widened for	70,000
The steam engine to be erected at Spaardam will probably cost, with the buildings and hydraulic machinery	240,000
It is quite uncertain how many days this steam engine must be worked during the draining of the Haarlem lake, but, as nearly as can be conjectured, these costs will not exceed	25,600
The sluice to be made at Spaardam is rated at	85,000
Total	705,000

(282,000 dollars—a dollar being nearly 2½ florins.)

1250 acres, (54,450,000 square feet,) and 5-feet lift; 2nd, that the annual effect of a first-class wind-mill does not exceed 695,220,000 cubic feet of water lifted one foot. Now, it is a general observation, that even less than half this effect is sufficient to keep the lands dry in ordinary cases; and that, therefore, the usual number of wind-mills might be reduced to the half, were it not necessary that nearly the whole quantity of superfluous water should be discharged in a few months. This being granted, we have only to divide the half of 695,220,000 (or 347,610,000) by 54,450,000 × 5, and multiply the quantity by 12, to find the average annual charge of water in inches. As $\frac{347,610,000 \times 12}{54,450,000 \times 5}$ is $= 15\frac{1}{3}$ nearly, it follows that the annual quantity of water is not more than 15⅓ inches, instead of 24, as was supposed. If it were not that too favourable calculations might lead to disappointments, the average annual number of working days for the steam engines might be reduced from 68 to 42, or even less, $\left(\frac{68 \times 15\frac{1}{3}}{24} = 41{\cdot}2.\right)$

Such will be the approximate costs of the works intended to secure Rynland.

The works for facilitating the navigation have been rated at 300,000 fl. ($120,000.) Hitherto only 50,500 fl. ($20,200) have been expended, viz.: 38,600 fl. for a road along Zuyder and Noveder-spaarme, and 11,900 fl. for sixteen wooden bridges necessary for the passage of the track-horses.

	Florins.
The costs of such parts of the dike and surrounding canal as are completed amount to	1,114,200
What remains to be made may be rated at	450,000
The present communications between the lake and the adjacent waters must be left open, till the dike, canal, and all the works for Rynland navigation are finished. The subsequent filling up of such channels will cost nearly	175,000
For covering the dike with sods, and other items, the costs may be rated at	110,800
Total of the costs for the dike and surrounding canal	1,850,000

or $740,000.

The digging of the ditches after the draining, (*verkavelinger*,) and the other operations necessary to make the lands fit for cultivation, may be estimated at 2,000,000 fl. ($800,000.)

It has been found necessary, for the carrying on of these works, to appropriate some lands not belonging to the Government, the costs of which cannot yet be fixed, but it is presumed that they will be about 500,000 fl. ($200,000.)

It is well known that Amsterdam can be defended against the most formidable enemy, by inundation of the surrounding lands, by which, in 1672, the republic was enabled to withstand the formidable attack of Louis XIV. The draining of the Haarlem lake would, it was feared, have rendered Amsterdam less capable of defence in case of war; but, to obviate this objection, it is proposed to substitute such works as will make the inundation of the surrounding country even more easy and effective. The costs of these proposed works are calculated at 300,000 fl. ($120,000.)

It may be interesting and instructive to enter into a more detailed estimate of the costs for working the steam engines and discharging the water, as it has been a question much debated in Holland whether steam engines or wind-mills would be the least expensive in the draining of land; many Dutch engineers being, even now, in favour of the latter.

Six single-acting pumping steam engines, of 200 horse-power each, constructed on the Cornish principle, are intended to be employed. By the experiments and observations which have long been made by others, and, more recently, by some members of the committee for Haarlem lake, sent to England for that purpose by the Dutch Government, it is ascertained that the quantity of fuel for such steam engines, per horse power, does not exceed 2½ lbs. of good coals per hour. The price of these coals, delivered on the spot, is in Holland 6·5 florins the 1000 lbs.

		Florins.
According to the estimate, the lake will be emptied in 14 months or 350 days, by the proposed steam power. The costs of coals will, therefore, be $\frac{1200 \times 24 \times 350 \times 2\frac{1}{2} \times 6\cdot5}{1000} =$		163,800
For tallow, oil, and hemp, cost may be calculated at 40 fl. per week and steam engine; consequently, for six engines in 14 months . .		14,640
Persons to be employed, per engine and year:		
1 engineer	fl. 1,500	
4 firemen	2,000	
3 assistants	1,000	
Total	4,500	
Consequently, for six engineers, &c., in 14 months . . .		31,500
The price of each steam engine, with boilers, may be rated at	70,000	
And the engine-house and hydraulic machinery at . .	150,000	
	220,000	
Which make, for six engines		1,320,000
Cost of repairs, 5000 florins per engine per annum: thus, for six engines in 14 months		35,000
Total		1,564,940

or nearly 1,565,000 fl. ($626,000.)

Recapitulation of costs.

	Florins.		Dollars.
Security of Rynland	705,000	equal to	282,000
Navigation	300,000		120,000
Dike, and surrounding canal	1,850,000		740,000
Digging of ditches, cost	2,000,000		800,000
Purchase of land	500,000		200,000
Defence of Amsterdam	300,000		120,000
Steam engines and water pumping	1,565,000		626,000
To be added for repair of dike, cost during the draining, overseers of the works, and incidental expenses .	280,000		112,000
Total costs . .	7,500,000		3,000,000

With the foregoing estimate of costs, let us now compare the cost of draining by wind-mills.

According to general practice, one wind-mill is required for every 1250 acres, and 5-feet lift. (Note 12.) The lake of Haarlem contains 44,480 acres, and its waters must be raised 16 feet for annual drainings. If, therefore, it were to be drained by wind-mills, the requisite number would be $\frac{44,480 \times 16}{1250 \times 5} = 114$. It has been proved by many experiments, that scoop-wheels and Archimedean screws are the best hydraulic engines at present known, whenever wind-mills are to be used. In the present instance, screws would be most appropriate, as by them the water may be raised 16 feet at two lifts, whereas scoop-wheels would require three lifts.

If, therefore, the lake were to be drained by wind-mills, half only of the intended number would be used in the beginning, (57 upper wind-mills—*boven molens*,) till half of the lake were emptied. Arrived at this point, the 57 under wind-mills (*onder molens*) would be used, to raise the inferior waters to a *low* or *intermedial* basin, whence they would be lifted by the upper wind-mills, in order to be discharged into the surrounding canal; consequently, half the contents of the lake would be lifted, by the 57 upper mills, to the average height of 3¼ feet.[14] The remaining waters would be lifted, by the 57 under mills, to the same average height of 3¼ feet; but as these under mills would discharge the water into the low basin, whence it would be lifted again by the 57 upper mills to the constant height of 6½ feet, we have to calculate the time required to empty the lake by 114 wind-mills, as if the water of the first half were to be raised 3¼ feet, and the water of the other half 6½ feet, by 57 wind-mills.

The lake contains 25,188,134,400 cubic feet. Half this mass to be raised 3¼ feet is equal to 40,930,718,400 cubic feet to be raised 1 foot. This may be done by 57 wind-mills in eighteen months, supposing the same quantity of rain and filtration water as before—namely, 2 inches per month, which must be lifted at the same time. Two inches on the surface of the lake (1,937,548,800 square feet) make 322,924,800 cubic feet; therefore, in 18 months, 5,812,646,400 cubic feet to be raised 3¼ feet, or 18,891,100,800 cubic feet to be raised 1 foot. This quantity, added to the first half of the

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[14] The whole depth of the lake being 13 feet, the superior waters are to be lifted from 6½ feet; therefore, to the mean height of 3¼ feet.

lake, forms a mass of 59,821,819,200 cubic feet to be lifted 1 foot. The average performance of a wind-mill in a month being 57,935,000 cubic feet of water lifted 1 foot, (Note 12,) the effect of 57 wind-mills in eighteen months will be 57 × 57,935,000 × 18 = 59,441,310,000 cubic feet raised 1 foot; which quantity is nearly equal to the mass to be raised. The other half of the lake's contents, to be raised 6½ feet, forms a mass equal to 81,861,436,800 cubic feet to be raised 1 foot. Allowing always 2 inches for rain and filtration, the 57 wind-mills will raise this mass, together with the rain and filtration, in 68 months. The effect, namely, of these wind-mills, in 68 months, is equal to 224,556,060,000 cubic feet of water raised 1 foot. The 2 inches of rain and filtration make, in 68 months, a quantity of 21,958,886,400 cubic feet to be raised 6½ feet, or 142,732,761,600 cubic feet to be raised 1 foot; which, with the water of the last half of the lake, makes a mass of 224,594,198,400 cubic feet—nearly equal to the computed effect of the mills.

With the supposed quantity of rain and filtration, the draining of Haarlem lake with 114 wind-mills would, therefore, require 68+18=86 months, or more than seven years. This period, long as it may appear, is nevertheless not longer than has been required in some cases of draining land by wind-mills. But to give the most evident proofs of the advantage of draining with steam power, we will take the ordinary cases for wind-mills, and compare the results with the unfavourable suppositions already made in the case of the steam engines.

According to the remarks in Note 13, the ordinary quantity of rain and filtration may be rated at 15 inches, or 1¼ inch per month. This supposition will reduce the time for draining the first half of the lake to 15½ months, and for draining the other half to 41 months, making in all 56½ months. The 1¼ inch makes in 15½ months, on the surface of the lake, 3,128,334,000 cubic feet to be lifted 3¼ feet, or 10,167,085,500 cubic feet to be raised 1 foot; and if to this we add half the contents of the lake, the whole mass will become 51,097,803,900 cubic feet to be lifted 1 foot. The 57 wind-mills would raise to that height 51,185,572,500 cubic feet in 15½ months. In 41 months, the 1¼ inch of rain and filtration per month makes 8,274,948,000 cubic feet to be raised 6½ feet, or 51,787,162,000 cubic feet to be raised 1 foot; to which, if we add the mass of water still remaining in the lake, the quantity will be 135,648,598,800 cubic feet to be raised 1 foot. The performance of the 57 wind-mills in 41 months is 135,394,095,000 cubic feet of water raised 1 foot, and therefore nearly equal to the mass to be lifted.

Founding an estimate on the last supposition, the costs of emptying the lake by wind-mills may be thus computed:

	Florins.
Construction of 57 upper wind-mills, at 26,000 fl. each	1,482,000
Repair of the mills and salary of the millers, at 750 fl. a year per mill: thus, for 57 mills in 56½ months	201,281
Construction of 57 under wind-mills	1,482,000
Repair of mills, and salary of the millers in 41 months . . .	146,062
	3,331,343

Amounting, in all, to about	3,331,000 fl. =	$ 1,333,400
The application of steam power would cost, as has been estimated	1,565,000 =	626,000
Difference in favour of the steam . .	1,766,000 fl. =	$ 706,400

Great as this difference may appear, it must still be augmented by more than 1,000,000 fl. for the difference of the interests; making, in favour of the use of steam, a profit of nearly 2,800,000 fl., or $ 1,120,000.

For the annual draining, one engine will be employed for each pair of steam engines; making, in all, three engineers, at a salary of 1200 fl. each. Three firemen and two assistants will suffice for each engine. The salaries of the firemen are rated at 300 fl., and of the assistants at 150 fl. each. The necessary fuel per horse-power and hour is rated at 3 lbs. of coals, instead of 2½ lbs., as there will be more frequent interruption.

As 68 is the computed average number of working days for the annual draining, the costs may be thus calculated:

	Florins.
Fuel $\frac{3 \times 24 \times 68 \times 1200 \times 6\frac{1}{2}}{1000}$	39,394 [15]
Tallow, oil, and hemp, cost 400 fl. per steam engine	2,400
Three engineers	3,600
Eighteen firemen	5,400
Twelve assistants	1,800
Repair, 2500 fl. per steam engine	15,000
Total	67,594

or nearly 68,000 fl. ($27,200.)

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[15] It has been remarked in Note 13, that the probable average number of working days will be less than forty-two. Taking this number, the costs for fuel might be reduced to 24,332 fl.; and, consequently, the total costs to less than 53,000 fl. ($21,200).

The application of wind-mills would cost, annually—

Repair of mills and salary of the millers, 650 fl. per mill, for 114 wind-mills . . . . 74,100 fl. = $29,640

The annual costs of the draining system, even on the most advantageous terms, will be 6000 fl. ($2400) less than the costs would be if the Haarlem lake were to be drained by wind-mills.

The important duty of preserving and repairing the dikes, guarding against the danger of irruptions, and regulating the water levels, is confided to a peculiar organization, called the *water staat*—a corps of engineers possessing much knowledge of hydraulics, and practical skill in matters appertaining to their profession.

The winter being the season of greatest danger, the officers of the *water staat* are, during that period, stationed along the dikes, and furnished with the means of strengthening them whenever there is reason to fear they may yield to the furious onslaught of the waves.

A concurrence of adverse circumstances may at any time cause the destruction of an entire province, and even threaten the very existence of the kingdom.

If the prevalence of south-west winds, forcing the waters of the Atlantic, round the north of Scotland, towards the German Ocean, should be suddenly followed by hurricanes from the north-west, (which often takes place in the winter,) the sea will be driven violently southward through the British Channel; but this body of water, greatly augmented and piled up, as it were, by the causes already mentioned, cannot find a ready outlet through the narrow straits of Dover, and is, in consequence, thrown back on the coast of Holland.

If this should happen at or near the period of high tide, the danger becomes imminent: the alarm bell is sounded, and the levy *en masse* of the population takes place, as if to repel a hostile invader. If the tides should continue to rise much above their usual altitude, the top of the dike is raised with such materials as may be at hand; if its surface is abraded, mats, previously prepared for the purpose, of straw, rushes, or willow twigs, and even sail-cloth, are laid on the outside, to prevent the washing of the banks, and to stop the leaks. But if the enemy still gathers strength, and the defences are obviously too weak to resist the assault much longer, a semicircular bulwark (enclosing the yielding front) is hastily thrown up in the rear, to present a new barrier to further encroachments. If the outer rampart should be carried, the temporary dike cannot be expected to hold out for any great length of time; and the only hope of escape is to be looked for in the falling of the tide and the abatement of the storm.

Notwithstanding the numerous precautions observed to avoid inundations, the winds and waves have often triumphed over the efforts of genius and science, prostrated the barriers which the labour of man had in vain erected to stay their course, and swept madly over whole provinces, as with the besom of destruction, involving the hapless population in one common ruin. Such accidents, unfortunately, have not been of rare occurrence. Nearly the whole of what is now called the Zuyder Zee, covering a surface of 1200 square miles, was dry land, and habitable, down to the latter part of the 13th century; such was also the case with the land now covered by Haarlem lake, which was formed by a sweeping irruption of the waters towards the close of the 16th century. In 1421, Dort was separated from the main, and is to this day an island. In this neighbourhood may still be seen the traces and the evidence of that terrible catastrophe. It is said that upwards of seventy villages and 100,000 people were destroyed by this inundation; and the country has never recovered its former condition. The ravages of the deluge are most conspicuous to the south-west of Dort, where an extensive tract of land, called the Biesbosch, is now a marsh, unfitted for any agricultural purpose.

Of all the provinces of Holland, Friesland seems to have been the greatest sufferer. Murray, for the purpose of showing the uncertain tenure by which the Dutch hold their lands, makes the following extract from Gauthier's 'Voyageur dans les Pays-Bas,' a book I have not had an opportunity to consult:

> "Friesland was inundated in 533, 792, 806, 839, 1164, 1170, 1210, 1221, 1230, 1237, (this year the island Vlieland, or Lakeland, was formed,) 1248, 1249, 1250, (the consequence of this inundation was a pestilence which destroyed several thousand persons,) 1277, (this year the gulf of Dollart was formed,) 1287, (in this year the Zuyder Zee assumed its present extent and shape, and 80,000 persons lost their lives in the inundation,) 1336, 1400, 1421, 1429, 1516, 1524, (three inundations in this year,) 1530, 1532, 1559, 1570. On November 1st, 1570, an inundation occurred which covered even the heights called Wierem, and cut off 100,000 persons, 30,000 of whom were Frieslanders. From this year the inundations are less frequent, as an improved method of constructing the dikes was then introduced by the Spanish Governor Rolles, who at the

same time passed a law that they should be kept up by the owners of the lands. Those recorded since 1570, were in 1610, 1675, 1717, 1776, and February 5, 1825."

If an unusual rise of the ocean waters, or of the Zuyder Zee, should take place soon after long-continued rains, or at the time of ice floods in the rivers, following severe winters, the most disastrous consequences are likely to ensue, from the rivers breaking through their artificial banks and overflowing the surrounding country. Such an event happened in the spring of 1809. The preceding winter had been remarkably cold, and ice had been formed of extraordinary thickness. Almost at the same time that the thaw occurred on the Upper Rhine, a furious gale from the north-west elevated the surface of the Zuyder Zee some feet above the highest spring tides. The immediate effect of this was, of course, to dam up the interior waters, and the destruction of the river-dikes followed. The loss of life and property by this casualty was enormous.

In the winter of 1825, Amsterdam itself was threatened with a similar calamity; and it is said that, if the tide had continued to rise for fifteen minutes longer on the 5th of February of that year, this proud and rich city, with its two hundred thousand inhabitants, would probably have been overwhelmed and swallowed up by the waters of the Zuyder Zee. As it was, the city suffered great pecuniary loss.

The kingdom of Holland is intersected in all directions with canals, which are, in fact, the highways of this country; all heavy burdens being transported by water, and the roads, of which there are but few in comparison, serving for light carriages. These roads commonly run along the margins of the canals, often occupying the embankments on which the canals are built. They are paved with small clinker-bricks, set up on edge close together, and are almost as smooth as a floor.

As has been said before, the canals are often elevated above the level of the surrounding country, and serve as recipients of the downfall water of the polders, which is pumped up into them. They are usually 60 feet broad at the water-line, and 6 feet deep, and are nearly level throughout. Wherever it has been found necessary to construct locks or sluices, (and they are generally combined,) the foundations always rest on platforms, sustained by numerous piles; as it would be manifestly impracticable to build in any other manner, owing to the soft and pulpy nature of the ground.

The ship-canals, or those intended for the accommodation of the foreign trade, are of much larger dimensions than those above mentioned, which are calculated only for domestic commerce, and to connect together all the more important towns and villages of the country.

The great North of Holland canal, and the canal of Katwyk, are of the largest size, and demand a more particular description.

The natural approach to Amsterdam, from the German Ocean, is through the Zuyder Zee, by a tedious and dangerous navigation among the narrow channels, sand-banks, and shoals, with which that gulf abounds. Ships were formerly detained by these obstructions, and by contrary winds, sometimes for weeks, in making the voyage between the Texel and Amsterdam; and large vessels were compelled to tranship a portion of their cargoes, and to resort to the use of camels, in order that they might pass the bar at the mouth of the river Y.

To avoid all these difficulties,[16] the North of Holland canal was constructed. It was begun in 1819, and finished in 1825, at a cost of more than $4,000,000. It commences on the Y, opposite Amsterdam, and, after traversing the whole length of the peninsula of North Holland, (a low, marshy, barren region,) terminates at the port of Nieuwe Diep, a large artificial harbour formed by means of projecting jetties, built of earth, fascines, and stones. This harbour is intended to afford protection to vessels navigating the great canal, and to the Dutch navy, of which it is the principal dépôt and dockyard.

The entrance sluice of this canal is situated on the river Y, opposite the city of Amsterdam, and is of the following dimensions:

Depth of the gates above the sills	22 feet	2 inches	A. P.
Width of the gates in the clear	50 „	9 „	
Length of the whole lock	297 „	4 „	
Length of the lock between the gates	214 „	0 „	

The usual high water at Amsterdam—A. P.[17]

The usual height of the water in Waterland,[18] 3 feet 7 inches A. P. There-

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[16] It may be well worthy of consideration, whether the same means may not be resorted to, with advantage, to avoid the bars at the mouth of the Mississippi, which, at present, interpose such serious obstacles to the navigation of the river and to the commerce of New Orleans.

[17] A. P.—(Amsterdamsch peil—Amsterdam mark)—an assumed point by which the height of the water all over Holland is calculated.

[18] *Waterland,* a district of North Holland. That part of the canal which is locked up between the sluices at Buiksloot and at Purmerend is known by the appellation of Boerem of Waterland, and differs in level from the other parts of the canal, as is shown in the text.

fore, when a vessel passes through the sluice at high water, it sinks to a level of 3 feet 7 inches below A. P.

About one and a half English mile from the entrance of the canal is the village of Buiksloot, where the canal passes through the sea-dike by means of a sluice with double flood-gates, and of the following dimensions:

Depth	22 feet 2 inches A. P.
Width	50 „ 9 „
The whole length of the lock	79 „ 7 „

After passing the sluice at Buiksloot, you enter *Waterland*, where the level of the canal is 3 feet 7 inches lower than between Buiksloot and the entrance. This height of the water is continued to Purmerend, a distance of about 9 miles (English).

At Purmerend is another sluice of the following dimensions:

Width	50 feet 9 inches.
Depth	22 „ 2 „
The length of the whole lock	263 „ 0 „
The length of the lock between the gates . .	214 „ 6 „

After passing through this sluice, you enter the North Holland *voerem*, or level, which is 1 foot 7 inches higher than the canal between Buiksloot and Purmerend, and so below A. P. 2 feet.

Near 30 miles from Purmerend, and 15 from Alkmaar, the North Holland canal passes through the Zippesea dike (which protects this part of the country from the inroads of the North Sea) by means of a sluice, separating this part of the canal from the waters of the Koegras, and of the naval arsenal at the Nieuwe Diep, which are generally at the same level with the water of the canal.

This sluice consists of two separate single sluices, joined in such a manner as to form a lock-sluice. Both these sluices are of the following dimensions:

Width	50 feet 9 inches.
Depth on the gate sills	22 „ 0 „ A. P.
Length of the whole lock	80 „ 5 „

Immediately on passing this last sluice, you enter the Koegras canal, leading to the naval arsenal, Nieuwe Diep, a distance of full 7 miles.

To carry merchantmen out of the canal into the Nieuwe Diep, there is a sluice which is only 45 feet 6 inches wide between the gates, which, not being sufficient for large size merchant ships and men-of-war, these ships pass through the sluice belonging to the dockyard, and so enter the harbour of the Nieuwe Diep.

The whole length of the canal is 52 English miles. It is 30 feet wide at bottom, 111 feet at the surface line, and 18 feet 6 inches deep, in reference to the usual water-mark.

The locks and sluices on this canal (and, indeed, the most of buildings in Holland) are erected on piles.[19] Models of these works have been made on

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[19] The houses in Rotterdam and Amsterdam, being all founded on piles, (which are not always driven into the firm soil,) present a very curious appearance, as but few of them have retained a vertical position, in consequence of the unequal compression of the foundation. The result is, that they lean in all directions; and a rigid police is observed, to prevent accidents. In New Orleans, where large platforms, made of different layers of inch-thick boards, projecting some distance beyond the walls of the houses, are resorted to, no difficulty is found in procuring foundations for even the largest structures,—such as the late St. Charles Theatre, and the St. Charles Exchange Hotel.

In 1822, the large Corn Exchange, or warehouse, in Amsterdam, actually disappeared, bodily, in the mud, in consequence of the piles giving way. This building, at the time of the accident, contained upwards of 70,000 cwt. of grain. All heavy burdens in that city are transported on sledges, for fear the rolling of heavy wheels may disturb the foundations of the houses. Many of the hackney coaches are of the same construction; and the runners are greased, to make them run the smoother. The driver generally carries in one hand a rag dipped in oil, and fastened to a string, which he contrives to throw occasionally underneath the runners, to diminish the friction.

Notwithstanding the immense number of piles which are annually employed in Holland in the preparation of foundations for houses and hydraulic structures, the contrivances for driving them are of the rudest and most primitive kind. I have often watched the operation, with a mixed feeling of wonder and merriment, when recalling to mind the simple but beautiful machinery used in my own country for the same purpose, which, with the aid of a horse, and less than one-fourth the number of men, would probably drive ten times the number of piles in the same period. But, even in England, till two years since, when an American steam pile-driver was set to work to prepare the foundations for the Hungerford Market Bridge over the Thames at London, they had no great reason to pride themselves over their Dutch neighbours in this respect.

The Dutch pile-driving machine (if machine it may be called) consists of two uprights, along which the hammer moves vertically, sustained in place by three legs, or tripod braces, forming the outline of a triangular pyramid; at the apex of which is a wheel, or large pulley, over which passes a large rope—one end being fastened to the hammer, and the other end passing through a ring, to which several smaller ropes are tied. By means of these small ropes, the hammer is raised about 6 feet, and is then permitted to fall again. I repeatedly saw them driving piles in this manner, with one man as captain, or boss; two to regulate the pile with crowbars, keeping it in a vertical position; three to steady it with ropes; and twenty to raise the hammer, which is done by a very large scales, and with extraordinary exactness and minuteness, exhibiting each individual portion of the structure, and the precise position of each pile. In case of failure, or of a threatened giving way of any part of these works, the models are consulted for the purpose of ascertaining what portion of the structure may need repair. These models are preserved in the office of the *water staat* at Amsterdam, and are well worthy a careful inspection, as they give a much better idea of the plan of these buildings than any drawings or written description can convey.

GREAT CANAL THROUGH THE ISLAND OF VOORNE, IN THE PROVINCE OF SOUTH HOLLAND.

For large merchantmen, the navigation from Rotterdam to the sea was attended with many difficulties, arising partly from the strong currents and contrary winds, and partly from the shallowness of water on the bar at the mouth of the Maas, below Brielle; in consequence of which, it often became necessary to break bulk, and resort to lighters, (by which much valuable time was lost, amounting often to several weeks;) or else to pursue the southern and circuitous route, by the way of Dort and Helvoetsluys, which offers at all times a sufficient depth of water for the very largest ships. For the purpose of avoiding this necessary *détour*, a canal has been dug through the isle of Voorne, opening a regular and direct communication between Rotterdam and Helvoetsluys, through which last Indiamen and first-rate frigates may reach the former port in a single day from the mouth of the Maas.

This canal passes in a straight line through the isle of Voorne; beginning on the River Maas, between the villages of Hunvliet and Zwartervaal, and ending in the Haringvliet, near Helvoetsluys, where it forms a small angle.

common pull, at the word of command. The iron hammer, according to the estimate of 50 pounds to each man, must have weighed about 1000 pounds. The piles which they were driving were about 6 inches diameter at the large end, and about 20 feet long. But the piles used under the large ship-locks are of Norway pine, 2 feet 5 inches in diameter at the large end, and many of them 50 feet long.

Their dredging-machines also struck me as being very clumsy and inefficient. They were all worked by hand; and I could not ascertain that they had ever resorted to the agency of steam for this purpose.

Although the hydraulic works of Holland are most gigantic in their dimensions, and are exceedingly well built, it must be confessed that an American will learn but little by a visit there, as it regards labour-saving machinery; and this want of mechanical assistance must render the Dutch works very expensive, as manual labour is by no means cheap.

At both the extremities of the canal are sluices or guard-locks; the water in the canal (usual height) being upon a level with low water at Helvoetsluys, or in the Haringvliet, which is 3 feet A. P. These sluices, or locks, are also provided with contrivances by which the flood-tide may be used in clearing out the canal.

Both sluices are nearly of the same construction and dimensions; that at the Maas extremity has a drawbridge over it.

Each of the sluices (or, rather, guard-locks) consists of two separate sluices, having each two flood and two ebb-gates, by means of which vessels can always pass, whether the water within the lock be higher or lower than without.

The usual height of the water in the canal is upon a level with the low water at Helvoetsluys; the whole, however, is so regulated, that at every flood water may be let into the canal, and, if required, during the whole of the flood-tide.

The difference of the water's height between ebb and flood is 6 feet; and with this difference, the usual height of the water in the canal may every flood be wholly or partly increased.

In the outer ebb-gates of each sluice are port-holes for the purpose of draining off the water of the canal when it becomes necessary to diminish its depth.

There are four floating bridges in the canal, so constructed as to allow vessels to pass at any height of the water, and causing no stoppage to carriages.

The dimensions of the canal, at is usual height, (which is the low-water mark at Helvoetsluys,) are as follows:

Width of the sluices	45	feet	6	inches.
Depth of the gate sills at low water	17	„	3	„
Each guard-lock sluice (as stated before) consists of two sluices, each of which is in length (for the whole lock) . . .	106	„	0	„
The inner and outer single sluices are at a distance from each other of	130	„	0	„
The lock between the gates	236	„	0	„
The floating bridges open	48	„	0	„
The depth of the canal below low water is	16	„	4	„
Breadth at the bottom	35	„	9	„
Breadth at the surface (low water depth)	110	„	6	„

The whole length of the canal, which has dikes on both sides, is about 6 miles (English).

The canal is provided with a towing-path on each side, 13 feet wide, for the purpose of tracking vessels through the canal.

The surplus waters of the adjacent lands are drawn off through four self-acting sluice-gates of 10-feet openings, fitted up with vanne-gates which close spontaneously when the water of the canal is at a higher level than the ditches. Water-wiers have also been constructed through the lateral dikes, for the purpose of irrigating the meadows in seasons of protracted droughts.

This work was begun in the year 1827, and finished in 1830.

The Rhine, after descending into Holland, throws off various branches to seek the ocean, as the Waal, the Linghe, the Leck, the Yssel, &c.—many of them important rivers ; whilst the most insignificant of them all is the only one retaining its original and time-honoured name. It passes through Leyden, (the Lugdunum Batavorum of the Romans,) and is discharged into the German Sea at Katwyk, about seven miles from that town. The debouche of the Rhine, on the coast, was so blocked up by a barrier of drifted sand, thrown up by a violent tempest in 1840, that the waters could only filter their way to the sea, and all navigation was, of course, stopped.

The consequence was, that a large district of country was overflowed and converted into a sickly marsh. For the purpose of opening a new channel, to discharge the waters of the river, and for the better drainage of the low grounds, (called Rynland,) the canal of Katwyk was constructed—a work, although of short extent, that may, from the boldness of design, the success of its execution, and the difficulties encountered, be ranked among the grandest and most important of the hydraulic structures of which Holland is so justly proud.

The first projêt for this canal was suggested in 1404, but it was not till 1571 that a serious attempt was made to carry it into execution; but when commenced, it was prosecuted with so much vigour, that, on the 1st of April of the following year, the last coffer-dam having been cut, and the sluices opened, (in the presence of the authorities and an immense crowd of by-standers,) the interior waters, which had been so long pent up, were seen to rush violently into the German Ocean. In consequence, however, of the civil troubles and the foreign wars, the canal was interrupted before it had been entirely completed, and again disappeared beneath the drifting sands, where it remained buried till the year 1802, about which time this project was again agitated, and the execution of it finally ordered by the legislature of the Batavian Republic in the month of May, 1804. The works, begun in August, 1804, were finished in 1807, under the superintendence of M. Conrad, a distinguished French engineer.

The canal is about 4 miles long, 49 feet wide at bottom, 52 feet at surface, and 6 feet 3 inches in depth,[20] (mean.) The water is withheld by means of an inner and an outer flood-gate and a sluice bridge.

The outer flood-gate, on the sea-shore, has five sluices of 12 feet 6 inches opening each; presenting thus to the flowing of the water a thoroughfare of 62 feet 6 inches. The length of the aperture walls, measured on the middle line, is 63 feet 5 inches. The sluice floors are 17 feet 3 inches below the highest tides.

Each sluice is provided with a pair of tide-gates, a strong flood-gate, and a turning door (*porte tournante*) for clearing the sluice.

The tide-gates (*portes de flot*) are not as high as the highest tides, but rest against a staying girder, above which the water is restrained by a heavy arch of brick-work, against which the most furious tempests have beaten without effect.

At 1462 feet 6 inches back from the first flood-gate, is the second flood-gate, just within the dunes. This flood-gate has three sluices, each of 18 feet opening, making in all a total width of 54 feet. The length of aperture walls is 96 feet. The sluice floors are 17 feet 3 inches below the highest tides.

A sluice bridge, (*pont écluse*,) provided with three sluices of 20-feet openings, arranged with floating doors, (*portes flottantes*,) can, if necessary, be used as a third withholder during extraordinary high tides.

The junction of the terminus of this work with the sea has been effected by means of jetties formed of fascines, (secured in position by piles driven into the sands,) on which heavy masonry has been laid. The fascines prevent the underwash; and the masonry, formed of huge stones, or rather rocks, is sufficiently strong to resist the force of the waves. These piers are 625 feet long, leaving between them a basin 320 feet wide.

The difference in level between the inner water and the ebb-tide being usually only about 16 inches, it was feared, in the beginning of the undertaking, that the outer channel would be liable to fill up with sand; to prevent which, by creating a greater scour, a steam engine was established with the view of

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[20] Since the commencement of the drainage of the lake of Haarlem, the dimensions of the canal have been greatly increased.

raising the water within the gates to a higher than its natural level. Time, however, having shown that the flowing out of the water at low tides was sufficient to keep the basin free from the accretion of shingle, the engine was sold many years ago.

When the flood-tide commences, the gates of which we have spoken are closed, to prevent the entrance of the sea. At extraordinary high tides the exterior water rises about 17 feet, pressing against the gates, and is several feet above the inner waters.

When the tide is on the ebb, the gates are opened by means of machinery; and the accumulated waters, which had been withheld during the flood, are allowed to flow out, carrying with them the sand which may have been brought in by the rising tides.

The water discharged by the sluices has been estimated at 100,000 cubic feet per second; but, when strong westerly winds prevail, and the tides do not subside to their ordinary level, it is impossible to open the gates, and no discharge can take place.

The use of sluices, for the purpose of keeping harbours and the mouths of canals and rivers free from silt, has long been quite common in many parts of Europe—more particularly in Holland, Belgium, and France. They are often also resorted to for the same object in England, where they were frequently recommended by Mr. Smeaton.

The canal of Middleburgh, in Zealand, by which large East Indiamen are carried up, is kept open wholly by sluices. Turning gates, enclosed in folding gates, are used at the Briel, and also at Helvoetsluys. The sluice at Helvoet is 48 feet wide. The gates of this sluice that Smeaton mentions were built in 1722; and he says they were in good order when he saw them, and that they had been originally exceedingly well constructed and very strong. He speaks of the sluice having been emptied by the turning gates alone in fifteen minutes; but he does not state its contents, except relatively to that of Dover.

The port of Ostend, in Belgium, and the canal to Bruges, are kept open by large and well-conducted sluices, which I examined with great care in June, 1841. They had been rebuilt and enlarged by Napoleon.

The outfall channel, from Dunkirk to the sea, is maintained wholly by sluices, the effect of which, in the time of Queen Anne, was so great, as to clear out a passage by which large ships of war were enabled to enter that port. The sluices were the subject of frequent and angry controversies between the

Governments of France and England; and the great sluice of Mardick was finally demolished by treaty, but has, I believe, been since rebuilt. (See Smeaton's Reports on Dover Harbour and the Drainage of the North Level Fens.)

In a Paper published in the first bulletin of the National Institute, I have given a description of the method employed in keeping the new Bute ship-dock at Cardiff open, by employing the surplus water of the river Taaf.

I have embraced in this Paper the following cross-section and specification of the mode of preparing foundations for railroads in Holland, where the nature of the ground may require it, as I believe it may be used to great advantage in many situations in the United States.

DUTCH RAILWAY FROM AMSTERDAM TO UTRECHT.

Description of the fascine causeway, or foundation of the embankment, at places where the ground is soft and pulpy.

The fascine foundation (*rysbedding*) is to be formed by an under and upper frame-work of hurdles, (*wiepen, saucisson,*) 0·4 metre thick, with a packing of fascines (*rysbessen*) between them. Including the second layer of hurdles of the under frame, as hereinafter described, and the first layer of hurdles of the upper frame, the mean depth of the packing ought to be 0·5 metre = 1 ft. 7½ inches English. The hurdles to be of a uniform texture of straight sticks, strongly connected together by no less than eight twig bindings for every metre in length. The hurdles of the first layer of the under frame to be placed lengthwise, in the direction of the axis of the way, one metre apart between the centres; and those of the second layer placed at right angles across the first, also one metre apart. The cross hurdles to be of a uniform texture, and the joints in the lengthway hurdles to be placed checkerwise, or to break joints. The hurdles of both layers to be tied together at every crossing by strong twig bindings. Upon the under frame, which must be well filled up with sand to the level of the upper side of the hurdles, are to be laid down the first course of fascines; then two transverse layers, crossing the first at right angles; and upon this a fourth layer—like the first, at right angles across the axis of the way, but having the larger ends of the fascines turned to the other side. In this, as in the other layers, the fascines are to be laid down in such a manner that the larger end of the one outreaches one metre that of the fascine lying underneath. They are to be well rammed together, so as to allow no room between them. Finally, the fascine packing must be so arranged as to give it a depth in the middle of 0·6 metre, (2 feet,) and at the sides of 0·4 metre, (1 foot 4 inches,) and must be made as will be directed by the engineer. The upper frame, of the same construction as the under frame, to be placed exactly vertically above it, and so that the under layer of hurdles, which falls in the fourth layer of fascines, is at right angles across, and the upper hurdles in the same direction as the axis or centre line of the way: through each crossing, and between two succeeding intersections, stakes (piquets) are also to be driven, passing also through the hurdles of the under frame: finally, between each of the lengthway hurdles, and parallel to them, to be twisted upon stakes 0·3 or 0·4 metre apart, a weft or tangle (*tuin*) of hoop-wood, which, after being well pushed down, remains 0·15 metre above the fascine packing. When fascine foundations are thus furnished, they must be filled up with sand precisely to the level of the upper side of the hurdles or tangles, so as to leave no room or spaces between the fascines. The further construction of the embankment will be done with thin coats of earth, spread as may be directed.

If, at some places, it may be thought requisite to give the fascine foundation more depth, there will be placed upon the above-described substructure, of the mean depth of 0·5 metre, further layers of fascines, one across another, and filled up with sand, but without further frame-works; while, at places where a less depth is sufficient, a single layer of fascines will be laid down, instead of the two transverse middle layers; and instead of frame-works, a single row of hurdles may be used, according to the nature of the ground and of the local circumstances.

DESCRIPTION OF THE MATERIALS.

Fascines (*rysbessen*) to be made of sound and clean willow-wood of not less than three years' growth, or of oak brushwood of not less than five or six years' growth; the wood to be straight and cut green in the last season, to be firmly bound by two bindings, and well tightened. The length of the fascines to be 3½ to 4½ metres, the larger end being half a metre in circumference.

Hoop-wood (*gaarden*) of straight and flexible water-willow, not less than 2 metres long and 0·055 to 0·085 metre thick.

Stakes (*palen*) to be 1·3 metre long, and in the middle of 0·1 metre in circumference.

Hurdles (*wiepen*, *saucisson*,) 0·4 metre in circumference, made of the largest and straightest sticks out of the fascines, well tightened and bound together.

NOTE.—The metre, or Dutch ell, is 39½ inches English, (nearly.)

I have the honour to be, Colonel, your obedient servant,

GEO. W. HUGHES,
Capt. Top. Eng. U. S. Army.

Col. J. J. ABERT,
Chief Corps of Topographical Engineers.

APPENDIX.

I.—*Addenda to the Account of the Operations at the Round Down Cliff, Dover, inserted in the sixth volume.*

FROM LIEUT. HUTCHINSON, R. E., TO CAPT. DENISON.

SIR,

In my account of the great mining operations at Round Down Cliff, Dover, in January, 1843, inserted in the 6th volume of the 'Professional Papers,' there were some omissions which I regret, but which must be ascribed to extreme haste on my part, because my Report and the drawings which accompanied it were not prepared until the time of year when the volume is usually published, and I then only contemplated giving a correct statement of the execution of those interesting operations: I therefore request that you will publish the following additions to my former Paper.

In the first place, I should have stated the circumstances which led to my having been employed on this service. This was owing to Major-General Pasley, who was referred to by Mr. Cubitt for some officer or person who understood the method of firing mines by the voltaic battery, of which neither he himself nor the assistant engineers of the South Eastern Railway had any experience; though they had previously fired several experimental mines with success by Bickford's safety fuses, a method incapable of producing simultaneous explosions.

The General accordingly recommended me for the service, as having been employed under him for two previous summers on the demolition of the *Royal George* at Spithead. This, added to my being stationed at the time at Dover, the proposed scene of action, led to the consent of the Master-General of the Ordnance being asked and obtained for my undertaking the executive charge of the operation, my commanding officer, Lieut.-Colonel Rice Jones, kindly allowing me to do so, though not without considerable personal inconvenience to himself.

I also wish to notice some particulars with reference to the original plan of the operations which did not appear in my Report, and of which indeed I was partly in ignorance at the time I wrote it.

Mr. Cubitt had requested Major-General Pasley by letter to come to Dover, to inspect the preparations for the mines, and to favour him with his opinion and advice: a consultation accordingly took place between them on the 10th November, 1842, at which I was present, when the General strongly recommended that three mines should be fired in preference to two. It appears, however, as I have since been informed by General Pasley, that in the same letter Mr. Cubitt had mentioned that three mines were intended, though the preparations for two only were at that time made;[1] so that the General's recommendation and approval of the three, served principally to confirm Mr. Cubitt in the plans which had already been formed by himself and his assistants.

On my subsequently taking charge of the work, the lines of least resistance originally proposed (as being the results of former experience in firing numerous blasts in the chalk cliff) were adhered to during the execution; the centre charge being varied for reasons stated in my Report, and the chambers of the two extreme mines moved a little further from the centre, which had been previously suggested by Major-General Pasley, but by no means to so great an extent as he had proposed to Mr. Cubitt, who objected to it at the time, on what certainly appeared to the General to be a sound reason; namely, that the entire demolition of Round Down Cliff was not the only object, but that in effecting it, it was desirable that the whole of the chalk of which it was composed, should be thrown down directly in front towards the sea, and not laterally, which might give unnecessary trouble by burying portions of the proposed railway line east and west of the cliff, that did not require any alteration of their then level, under masses of chalk that would have to be removed afterwards.

I must further notice the kindness of Captain Montgomery Williams, formerly Adjutant of the Royal Engineer Establishment, who afforded me the benefit of his own experience in the application of the voltaic battery to mining purposes, and who, before he quitted Chatham, caused numerous experiments to be tried by Serjeant-Major Jones, in reference to the proposed operations at Round Down Cliff, in order to ascertain whether three mines might be fired simultaneously by one battery and one set of wires only; and he considered the result of these experiments so satisfactory that he strongly recommended it to me; but as Serjeant-Major Jones, whose skill in mining operations is well known to the corps, worked with wires only 500 feet in length, and as the experiments carried on at Dover, in which I was assisted by Mr. Wright and Mr. Hodges, Resident and Assistant Engineers of the South Eastern Railway, were tried with wires of twice the above length, found absolutely necessary at Round Down Cliff, and were not satisfactory, I thought it most prudent to adhere to the plan suggested by Major-General Pasley, of using three separate batteries, each having its own conducting apparatus; one for each charge to be fired simultaneously by three operators, by word of command, in the manner described in my Report. This method succeeded perfectly, as is well known, but I should myself have preferred the other, had our experiments at

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[1] As the preparations for the third mine were not commenced until more than a month afterwards, it was natural for me to conclude, that this was an addition to the original plan, either suggested or definitively decided upon at the above interview, which was the impression upon my mind at the time.

Dover been more encouraging; and I shall further remark, that afterwards, when again employed at Spithead under Major-General Pasley in the summer of 1843, numerous attempts made by us to fire several charges simultaneously against the remains of the wreck of the *Royal George* by means of one very powerful voltaic battery, having a branch to each charge from a main conducting apparatus, invariably failed; for when the voltaic circuit was completed, successive reports were always heard, with perceptible intervals of several seconds between each, and when we tried to fire more than four charges by this method, the whole of them did not explode.[2] This must, however, be ascribed in some measure to the circumstance of their having been subaqueous instead of subterraneous explosions; for the conducting power of water is so well known, that the least moisture penetrating to the wire through its exterior coating, a circumstance very possible to happen from the great pressure at the depth of 13 fathoms, would considerably weaken the power of the electric fluid, and might cause the successive reports which we heard. In our previous experiments for these explosions, made with bursting charges in air, with the same power of batteries and arrangement of conducting apparatus, we found the whole of the charges to explode invariably as one report.

Taking every thing into consideration, if the work with which I was intrusted at Round Down Cliff had to be done over again, I should not be inclined to make any alteration in the mode of firing.

I would here observe that the conducting apparatus of each of our three mines at Dover was the same in principle as that adopted in the works at Spithead, though from its being a land operation, the same precautions were not necessary in preparing and securing the bursting charges as would there be required; and the detail of construction of those small charges was therefore somewhat varied. The principal difference was that of using two bursting charges for each of the mines, an arrangement which was adopted on account of the large masses of powder to be ignited, and the oblong form in which it was distributed.

I will conclude this letter with noticing an ingenious machine afterwards contrived by Mr. Hodges, Assistant Engineer to the South Eastern Railway, for the purpose of forming simultaneous contact of several distinct wires. It consists of a frame or stand, containing mercury in cups. One set of wires leading from the poles of the batteries are attached to short pieces of stout copper wire, let into each cup, and surrounded by the mercury. The other set of wires to be connected with the poles are attached to stout pieces let into a cross or arm of wood suspended immediately above the cups, and moving on a hinge fixed to the frame: this arm, when let down, will cause all the wires attached to it to enter the mercury cups below at the same instant, the distances between the wires being equal to those from centre to centre of each cup. In this way

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[2] See the 'United Service Magazine' for September, 1843, (page 136,) containing an accurate account of the operations against the wreck of the *Royal George*, during the first part of the summer of that year.

as perfect a contact will be formed between the disconnected ends of the pole and wire, when both are immersed in the same cup of mercury, as if these ends touched each other; and thus the simultaneous explosion of a number of mines may be made by one operator after all the connections of the wires (a very troublesome operation, and one requiring great care) are completed.

This method would answer very well for firing a large number of mines or blasts, as would frequently be required in quarrying for bringing down a long face of earth or rock, and where it might be inconvenient to have more than one operator; or where the saving of wire is an object, and the battery has to be placed near the mine, the machine may then be made self-acting,[3] so as to complete the circuit a certain time after the person in charge of it has made the arrangements and got out of danger. For either of these objects this machine will be found very useful.

But for an operation on so great a scale as the Dover mines, where the number to be fired simultaneously was only three, I think the plan of three *careful* and *experienced* operators to be just as good as the use of mercury in the manner I have described.

I am, Sir, your most obedient servant,

G. R. Hutchinson,

1st January, 1844.

Lieutenant, Royal Engineers.

[3] P.S. This arrangement was actually adopted in firing 16 mines simultaneously (containing in all about 12,000 lbs. of powder) on the 18th April, 1843, for bringing down a portion of the Abbott's Cliff, near Dover, during the progress of the South Eastern Railway Works. The arm of the machine, to which one set of wires was connected, was suspended by a piece of string to a vertical standard fixed behind the frame, so that on being disengaged it would immediately fall on to the cups below; the arm was also weighted, to insure its falling with sufficient force. A short piece of portfire was fastened to the string. The connections and arrangements at the batteries being completed, the portfire was lighted by Mr. Hodges, who had then a short time to make his escape, the batteries and machine being very close to the mines. The string was burnt asunder as soon as the flame of the portfire reached it; the arm of the machine, with the wires attached to it, being then disconnected from the standard to which it had been previously held, fell, causing the wires to enter the mercury cups, and the explosion of the mines immediately ensued.

G. R. H.

II.—*On the Means of Preventing Damp in Walls.*

I CANNOT do better than reprint and circulate this Paper, published by the Commissioners on the Fine Arts, on the means of preventing damp in walls. W. D.

IN buildings erected without due precautions, in humid situations, it is found that the damp rises through the masonry by capillary attraction. The external coatings of the walls are thus affected to a considerable height: not only paintings are destroyed, but the plastering itself becomes detached. In Venice, where the foundations of so many houses are partly immersed in water, it has been remarked that the plastering is frequently loose, even above the level of the first story:[1] the presence of damp at a still greater height, in a less pronounced form, may therefore be inferred. It is probably owing to the action of moisture thus communicated, that paintings in the open air have decayed so generally in Venice; for it has been already observed that the sea air, which is sometimes assigned as the cause of this decay, has had no such effect on external painted decorations in Genoa, the foundations of the houses being there dry.

It is to be observed, that in Italy, the use of puzzolana in mortar, and, above all, the warmth and dryness of the air in summer, tend to arrest or repel the progress of damp; so that its consequences, even in exposed situations, are less rapidly destructive than in northern climates. These correcting causes, insufficient as they sometimes prove, may account for the absence of any precautions in Italian and in ancient Roman buildings to check the ascent of moisture in walls. The ancients sometimes took effectual means to exclude damp *laterally* by means of double walls, but, except by placing charcoal or other dry materials under pavements and foundations,[2] they seem to have taken no care to intercept the progress of moisture in a *vertical* direction. The method recommended by Vitruvius,[3] of excluding damp by double walls, was occasionally adopted in Roman edifices in this country; for example, in the Roman villa, at Woodchester, in Gloucestershire,[4] and in

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[1] Mr. Wilson's notes. Mr. C. H. Wilson, Professor of Ornamental Design in the Royal Edinburgh Institution, was, in the course of the last year, employed by Her Majesty's Commissioners on the Fine Arts to proceed to the Continent, to collect information relating to the objects of the Commission. Having been furnished with the necessary instructions, he left England in August, and returned towards the end of January last. The result of his investigations will appear or be referred to.

[2] Vitruvius, De Architect., lib. 3, c. 3; lib. 7, c. 1, and c. 4. Compare Leon Battista Alberti, lib. 3, c. 5, and c. 16.

[3] Lib. 7, c. 4.

[4] Lysons' 'Roman Antiquities of Woodchester,' p. 7.

that of Mansfield-Woodhouse, in Nottinghamshire.[5] These precautions may account for the comparative preservation of paintings on the internal surface of the walls of houses so constructed.

Modern architects on this side the Alps, compelled by the effects of a humid climate and soil, have gone to the root of the evil. M. Von Klenze, of Munich, having remarked the occasional ravages of damp on the external and even internal walls of many Italian buildings, and the consequent decay of the paintings executed upon them, devised an effectual remedy, which is now constantly adopted in Munich. At the third course of bricks (the material usually employed in Munich), above the surface of the ground, the whole horizontal surface of the wall is covered with a thin sheet of lead;[6] the building then proceeds as usual. "The soil at Munich," Mr. Wilson observes, "is gravel, and no particular precautions are taken to protect the lowest floor or pavement from the damp of the ground. The pavement of the Basilica is laid on the soil, a thick layer of gravel only being spread underneath. In the ground-floor rooms of the *Residenz* or royal palace, I observed no dwarf walls, which in our own country would have been considered indispensable to carry the sleeper-joists for flooring, and to insure due ventilation. In so important a building as the Munich Basilica we should have vaulted the whole space, as a necessary protection from damp."[7] The dry gravel bed within the foundations is, however, considered sufficient to protect the ground-floors in Munich; and the possible ascent of moisture by the walls is at all events guarded against by the sheet of lead. M. Hittorff, of Paris, being consulted as to the durability of lead so employed,[8] was of opinion, from numerous instances of its use, though for different purposes, in ancient edifices and in ancient sculpture, that it may be considered sufficiently durable. Mr. Barry has, however, remarked, from the well-known instances of the decay of leaden pipes, that sheets of lead would, after a long series of years, but imperfectly answer the end proposed.

In the Appendix to the first Report mention was made of a contrivance adopted by M. Polonceau, to intercept the ascent of humidity in buildings, by a layer of asphalte on the horizontal surface of the walls, immediately above the surface of the ground. Some doubt having been thrown on the fitness of this material for such a purpose, a further communication on the subject was published in the 'Revue Générale de l'Architecture' for February, 1842. The following is a translation:

"The Number of the 'Revue' for November last contains a letter from a correspondent, who, in consequence of an unsatisfactory trial, doubts the efficacy of the method pro-

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[5] Archæologia, v. 8, p. 366. Where there is not sufficient space for a double wall, Vitruvius suggests the application of hollow tiles, covered on the inside with pitch. A figure given by Perrault (translation of Vitruvius), after Rusconi, explains this contrivance. On the subject of double walls, see also a communication by Messrs. Smith (Scotland) in the 'Transactions of the Royal Institute of British Architects,' vol. i. p. 60.

[6] Mr. Wilson's notes.

[7] Ibid.

[8] Ibid.

posed by M. Polonceau for preventing the damp of the soil from rising in the walls of buildings.[9]

"Although M. Polonceau's answer appears to me sufficient to re-assure your correspondent, I may be permitted, in support of the method referred to, to state the result of a similar experiment made under circumstances eminently calculated to exhibit the action of moisture near the foundation of walls.

"In 1839 I superintended the construction of a house of three stories on the Lac d'Enghien. The foundation of the building is constantly in water, about 19½ inches, below the level of the ground-floor. The entire horizontal surface of the external and internal walls was covered, at the level of the internal ground-floor, with a layer of Seyssel asphalte, less than half an inch thick, over which coarse sand was spread.

"Since the above date no trace of damp has shown itself round the walls of the lower story, which are for the most part painted in oil of a grey stone colour. It is well known that the least moisture produces round spots, darker or lighter, on walls so painted. Yet the pavement of the floor, resting on the soil itself, is only about 2½ inches above the external surface of the soil, and only 19½ at the utmost above that of the sheet of water.

"The layer of asphalte having been broken and removed, for the purpose of inserting the sills of two doors, spots indicating the presence of damp have been since remarked at the base of the door-posts.

"The porter's lodge is built on a higher level, with similar materials, but, being less exposed to damp, the walls were not defended with asphalte; the foundations do not descend to the water-level, and the ground-floor is boarded; yet the lower parts of the walls are spotted with damp. This affords decisive evidence that the preservative in the first-mentioned case is the asphalte.

"I confess I was not without fears as to the compressibility of the asphalte, when softened by the great heats of summer, although I am inclined to believe that walls of 20 inches thick never attain the temperature of the atmosphere, especially at the base, on account of the proximity of the soil, and the alternation of temperature by day and night. I thought it, however, possible that the layer of asphalte might spread under the pressure of the walls, and protrude beyond the external joint, but it has not protruded a millemetre.[10]

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[9] The experiment referred to was made in building a theatre of anatomy on the site of the Cemetery "De Clamart," in Paris. The asphalte was applied in too liquid a state, and flowed out at the joints in consequence of the pressure of the mass of wall above it. M. Polonceau, in his answer, ('Revue,' vol. ii. p. 589,) explains that the asphalte employed by him is not apt to escape, even in summer, and under the greatest pressure, and that it is nevertheless elastic at a temperature of four or five degrees below zero. He further observes, that it differs from the asphalte sometimes employed for pavements, inasmuch as it contains no lime. He adds, that one-fourth of an inch is quite thick enough for the layer, and that coarse dry sand should be well spread over it.

[10] A millemetre is about the 26th part of an inch.

"I had even supposed that the unctuous nature of the asphalte might, in case of an unequal settlement of the foundations, occasion a partial slip of the materials. To obviate this, rows of flints, as large as the fist, had been encrusted midway in the thickness of the masonry, and parallel with the axis of each wall, forming a sort of key (*engrenage*) between the foundation and superstructure. The asphalte, it is to be remembered, entirely covered these flints.

"It may, perhaps, be objected that a trial of two years, and the pressure resulting from a mass of masonry ten metres (about 32½ feet) in height, are insufficient to demonstrate the infallibility of the proposed method: be it so; but another example may be referred to, which, though by an opposite result, tends to support the above statement.

"Another house was built at the same period, on the same soil, at the distance of about 33 feet from the one above mentioned. The area of the ground-floor of this second house is 2 feet 1½ inches above the level of the garden, and rests on sleeper-joists separated from the soil by an empty space of about 2 feet 7 inches in height, which is ventilated by numerous air-holes. Before this floor was laid, the horizontal surface of the foundation walls had been covered with a layer of Roman cement about an inch thick. Notwithstanding all these precautions the damp has ascended the walls as high as 3 feet and some inches above the level of the flooring.[11]

"Thus, of these two examples in the immediate neighbourhood of each other, and on the same soil, the building which was most exposed to the action of damp has been the best preserved from it, owing to the layer of asphalte.

"It should however be stated, that the walls of the house where the asphalte was used are constructed, up to the basement-flooring, with a somewhat solid stone (*meulière*), and with a mortar composed of hydraulic lime, whilst those of the other house are built of lumps of gypsum, cemented with the same material even in the foundation. It is well known that constructions in stucco absorb moisture, even before saltpetre shows itself, much more easily than constructions in mortar. I have seen an instance where the damp has risen 4 or 5 feet in a few days in a slightly-built enclosure cemented with stucco, the base of the wall being in water.

"There is, therefore, every reason to conclude that the method tried and warranted by M. Polonceau is safe. It is even preferable to the mode last referred to on the ground of economy, since the layer of asphalte proposed by him is only 5 millemetres (less than a quarter of an inch) thick.

"I regret that that skilful engineer has not given the cost of the superficial metre of his composition. With regard to that which I have used, it costs the same as the composition for pavements,—that is to say, from seven to eight francs the superficial metre (square of 39⅓ inches).

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[11] A similar instance of the inefficacy of cement for the purpose in question is recorded in the 'Transactions of the Institute of British Architects,' vol. i. p. 59.

"To prevent damp from penetrating the walls of ground-floors, it is usual to paint their perpendicular surfaces, to line them with wood-work, or with plates of metal. These methods, it is true, prevent in some degree the evaporation of moisture in the apartments; but, far from hindering the ascent of humidity from the soil, they, on the contrary, promote it. Oil-paint, applied to the external surfaces of walls, is a certain means of rendering the rooms of the ground-floor uninhabitable. The damp, with which the base of the walls is saturated during winter, being no longer allowed to evaporate on the outside by the action of the sun and the warm dry air of summer, is driven inwards. If, again, wainscot or zinc linings, or coats of paint, be opposed to it internally, the damp, rotting or oxydizing such protections in its progress, may ascend to the first story, especially if the walls are cemented with stucco. I have seen examples in the country of walls thus treated, in which the damp ascended every winter to the height of about 27 inches above the level of the ground. A coating of zinc, 1 metre (39⅓ inches) in height, was, in one case, applied to remedy the evil; the following year the damp rose to 30 centimetres (about 13 inches) above the zinc: the zinc lining was raised 50 centimetres (19½ inches) higher, and the following spring the moisture had passed even this new protection by 20 or 30 centimetres. These facts and observations warrant the conclusion, that the only means of preventing moisture from penetrating the walls of the ground-floor consists in interposing between two courses of masonry, and at the level of the internal ground, an elastic and but moderately compressible substance, which shall be impermeable, incorruptible, and insoluble: such are, bitumen properly prepared, lead, tin, &c.

"As before observed, oil-paint on the outside of houses in almost every case is rather injurious (as regards the point in question) than otherwise. It does not expel the damp from within; on the contrary, it drives it back. It does not even preserve stucco coatings, for after the application of the paint a sort of chemical decomposition takes place in them. On every part exposed to the rain, the wet, lodging in the numerous minute fissures which take place in a few years in the pellicle of paint, dissolves the plaster, producing channels which rapidly increase, and give the surface a worm-eaten appearance. To remedy this evil, it would be necessary to re-paint the walls every two or three years, which would be a serious expense.

"The application of paint on flimsy surfaces of stucco has undoubtedly a specious appearance, but nothing can be adduced in favour of its employment on façades of stone."

The writer proceeds to express his regret that the masculine character of the barriers of Paris, and, among others, the Barrière d'Italie, and that of St. Denis, should be thus travestied. The last-named instance, he observes, notwithstanding the remedy, exhibits spots of damp several yards in extent, even on the upper story.

"The only coating and preservative," he continues, "which should be allowed on the surface of stone walls, is that which, by its unalterable transparency, is calculated to preserve the grain, the colour, and the *mat*, or absence of shine, in the stone. Of all known methods, encaustic painting appears to me the only one calculated to accomplish these objects, when it shall have undergone in its preparation and application all the improvements of which it is susceptible. But in order that the employment of a hydrofuge of whatever kind on the perpendicular surfaces of walls be effectual, it is indispensable in the first instance to prevent the moisture of the soil from ascending through the walls, and then to devise means of drying the masonry completely before the application of the hydrofuge on the vertical surfaces."[12]

In Italy, paintings on ceilings and on the upper parts of walls have been damaged, and in some cases obliterated, by the moisture penetrating from above; but in a well-constructed edifice, duly inspected from time to time, the danger from this cause is so remote that it can hardly be necessary to call attention to it. The infiltration of water from pipes was, however, the means of destroying a painted ceiling in the Louvre at no distant period.[13] The possibility of such accidents might suggest precautions; for example, coatings of asphalte in the upper portions of walls, and over ornamented ceilings. The injurious effect of flues behind paintings—an evil of an opposite kind—has been already adverted to, (1st Rep. p. 30.) The best means of intercepting the heat would be to leave an empty space (with holes opening into the room to insure a circulation of air) between the flue and the back of the bricks or tiles on which the painting is executed.

It remains to consider the precautions which may be more immediately necessary for the preservation of paintings from damp behind them, whether such paintings are executed on the surface of the wall itself, or whether they are applied to it subsequently to their completion.

First, with regard to fresco:—The appearance of damp and of saltpetre may be prevented either by a space between the solid masonry and the surface (composed of thin bricks or tiles), which is to receive the mortar and intonaco for the painting;[14] or by a hydrofuge composition, or coating impervious to damp. In the latter case it may still be desirable to add a surface of tiles upon or without the hydrofuge, in order to form a proper ground for the mortar, and to assist in absorbing and retaining the moisture, which is freely applied to the surface before and during the execution of the fresco.[15] For the less absorbent or retentive of moisture the ground is, the quicker the fresco will dry, and consequently the greater will be the inconvenience of the execution.[16] Where the mortar and intonaco are thinly spread on a surface of stone, as sometimes happens, for example, in the under church at Assisi,[17] very little absorption can take place; but

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[12] (Signed) " H. Janniard, Architect."

[13] The case is afterwards particularized.

[14] See the descriptions of the practice of fresco-painting in the First Report.

[15] Ibid.

[16] A ground for fresco can hardly be *too* absorbent, since it is always possible, by continued moistening, to saturate it at last.

[17] Mr. Wilson's notes. An accurate inspection of the earlier Italian mural paintings, in various

the difficulty which such a case might present to the painter need not be encountered unnecessarily. It may however be assumed, that a coat of mortar, of the usual thickness, spread on any surface to which it will firmly adhere, would always constitute a sufficiently absorbent ground, as frescos can be executed without inconvenience on lath. It is remarkable that the best preserved fresco in the Campo Santo at Pisa (Orgagna's *Trionfo della Morte*) is executed on lath.[18]

The practice of applying the mortar and intonaco on a pitched ground, without tiles, is said to be common in Lombardy. The dome of St. Celso, in Milan, painted by Appiani, was thus prepared. The hydrofuge is composed of pitch and sand thrown roughly on the solid wall; to this the superadded mortar adheres so firmly, that in breaking walls thus faced, a fracture never takes place at the junction of the two.[19] But supposing thin bricks or tiles to be employed, they might be encrusted or embedded in a similar hydrofuge ground, which would effectually exclude all damp and saltpetre from the solid wall. The surface of the tiles would require to be roughened on both sides, and this could be best done before the clay is baked, in order to insure the firm adherence of the softer substances.[20]

Saltpetre, it may be objected, might still come to the surface, even from one course of bricks or tiles. The general precaution taken at Munich is to use bricks that have been well burnt, at the same time, and in an equal degree. When, after all, saltpetre shows itself, it may be removed by repeated washings. It remains to observe, that at Munich no hydrofuge is applied behind the superficial course of bricks, or behind the mortar; such precautions are considered superfluous; and, provided the progress of damp in a vertical direction be entirely intercepted, they may perhaps be considered unnecessary in any case.

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states of preservation, has shown that they were begun in fresco and finished in tempera. (See Pietro Estense Selvatico, Sulla Capellina degli Scrovegni nell' Arena di Padova e sui Freschi di Giotto in essa dipinti, Padova, 1836; also, Agricola, Alcune Osservazioni Artistiche, &c., Roma, 1839; compare Cennini, Trattato della Pittura, p. 58—64, and the First Report, p. 38.) The observations referred to are confirmed by Mr. Wilson's investigations; and he justly concludes, that the practice may have been in the first instance an unavoidable consequence of painting on thin intonacos, spread on stone, which could not remain moist long enough for the completion of a portion of fresco of any extent. The method of finishing in tempera may have been afterwards retained, even where unnecessary, from habit; but in the best age of art, when proper fresco-grounds were employed, tempera was looked upon as a remedy, allowable only in cases of accident or unusual difficulty.

[18] Communication from M. Orsel.

[19] Communication from M. Aglio.

[20] The tiles and flues found in the remains of the Roman villa at Woodchester were thus toothed. Lysons, *ib.* Vitruvius (lib. 7, c. 4) recommends giving tiles a coat of lime and water before the application of the mortar, to insure the adherence of the latter.

Some distinguished French chemists have of late years directed their attention to the means of excluding damp from the internal surface of walls not protected above the foundation in the mode before described. The following is a translation of some observations on the subject by MM. D'Arcet and Thénard.[21] The experiments made by them were begun in 1813, when M. Gros undertook to paint the cupola of the church of St. Geneviève (then called the Pantheon).

"The surface of the cupola had been previously prepared like a primed cloth: after the stone had received a coat of strong size, a ground of white lead and drying oil had been superadded.

"Fearing that this priming was not sufficiently firm, M. Gros came to consult us. We did not hesitate to say that it was far from safe. The moisture might in time, we observed, act on the size, and a painting executed on such a ground would consequently change. We soon came to the conclusion that it would be necessary first to saturate the stone as deeply as possible with an unctuous substance, liquified by heat, and which, solidifying as it cooled, would stop up the pores of the stone. We were strengthened in this view by the authority of the ancients, who sometimes passed melted wax over the surface of walls which they intended to paint, and we were induced to try a coating of wax and linseed oil, rendered drying by litharge. After some experiments on stones, similar to those of the cupola, we were led to prefer a composition consisting of one part wax and three parts of oil, boiled with one-tenth of its weight of litharge. The absorption took place readily by means of heat, and the liquid penetrated the stone to the depth of from a quarter to half an inch. The composition, as it cooled, acquired solidity, and in six weeks or two months became hard.

"Having made these experiments, we proposed to adopt the same means on the cupola, and the operation was to be conducted as follows:

"The surface was first to be scraped, so as to entirely remove the preparation of paint and size, and lay the wall bare; then, by means of a portable furnace, the whole superficies was to be heated, portion by portion (about a square yard at a time), and the mastic[22] or composition was to be applied, at a temperature of 100 degrees, with large brushes. The first application being absorbed, a second was to be added, and so on until the stone should cease to absorb. To promote the absorption, the stone was to be warmed repeatedly, according to its porousness. In every case the heat ought to be as great as possible, but not so great as to carbonize the oil. At length, the stone being saturated to a certain depth with the mastic, and the surface being smooth and dry, it was to receive a coat of white lead mixed with oil, and on this preparation the painting was to be executed.

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[21] 'De l'Emploi des corps gras comme hydrofuge dans la peinture sur pierre et sur plâtre, &c., par MM. D'Arcet et Thénard.' Paris, 1828.

[22] The word "mastic" is sometimes used both by French and English writers as a general term for cements and coatings.

"Our plan was adopted and put in execution; and thus M. Gros was enabled to produce a new masterwork, which could undergo no change except that which light and air might occasion.

"Drops of water, like dew, which covered the whole surface of the cupola every morning, at first alarmed the artist. We knew, however, that there was nothing to fear from this;[23] the drops appeared and disappeared without the slightest bad consequence, and a trial of fifteen years has now dissipated all apprehension."

A letter is then inserted from Baron Gros, certifying that in the course of more than fifteen years his work had undergone no change. The memoir goes on to state that the four pendentives in the same church, painted by Gérard, were prepared in a similar manner. In this case the stone was so hard that the composition could not be made to penetrate more than one-eighth of an inch. The result was, however, quite satisfactory. The painting by Gros was first begun, as before stated, in 1813: having been recently examined with a view to its state of preservation, it has been pronounced to be in a sound and apparently unchanged condition.[24]

For ordinary purposes, resin might be substituted for wax: the ingredients then are, one part of lithargirized oil to two or three parts of resin. This composition has been employed with effect, with the aid of heat, to protect internal walls from damp. A remarkable instance of its successful application, related in the same memoir, is here added.

"Two rooms on the basement story at the Sorbonne happen to be several feet lower on the east and south sides, than the ground level of the neighbouring houses. The walls of the two rooms on those sides are impregnated with saltpetre. Some years since it was thought advisable to coat them with stucco, in the hope of driving the saltpetre to the outside; but it penetrated the stucco, and re-appeared on its surface, producing so much damp that the plaster began to be decomposed, and the place became uninhabitable even in summer. Our method was tried in these rooms in the following manner:—A mastic was composed, consisting of one part linseed oil, boiled with one-tenth of its weight of litharge, and two parts of resin. The latter was melted in the lithargirized oil in a cast iron vessel, the fire being duly regulated. The substances tumefied considerably at first, but the fusion once completed, this effect ceased: the composition was suffered to cool, to be again heated for use. The tumefaction which takes place requires that the resin should be dissolved in the oil by degrees, otherwise it will overflow. The walls being very damp, it was necessary to dry them by means of a portable furnace. That which we made use of was about 1 foot 8 inches wide by 1 foot

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[23] It could only have been a condensation of moisture from the interior.

[24] Mr. Wilson's notes. A writer in the 'Revue de l'Architecture' (who is a strenuous advocate for fresco and encaustic) states that this work by Gros has undergone some change in parts; but this, if true, may be from the nature of the colours used, and is not necessarily to be attributed to the failure of the ground.

4 inches high, so that we could dry a surface of 6 or 7 square feet at a time. The furnace was provided with two rings on the upper anterior corners, serving to hang it on a horizontal iron rod, about 5 feet 4 inches long. The ends of this rod rested in racks in the edges of two perpendicular boards, about 5 feet asunder, bound together by two braces, one above and one below. These boards, which, with their connecting braces, formed a portable frame-work, were nearly as high as the rooms (about 10 feet 8 inches): they were placed at a due distance from the wall. The furnace[25] was provided at the back with two handles, by means of which it was easily shifted on the iron rod from which it was suspended.

"From this description, the details of the operation itself may be easily conceived. The apparatus was stationed opposite a given portion of the wall, till that portion had received the mastic. The composition, thus successively applied, formed eight horizontal bands, each as high as the furnace, and extending in length to the extent of the wall. The workmen began by drying the plaster thoroughly.[26] It was afterwards again heated, portion by portion, to enable the mastic to penetrate it, as in the case before described. The upper part of the wall was completed first. When a given portion of the wall was sufficiently heated, the furnace was pushed along the rod from which it hung to the next portion in the same line; and while the second portion was being heated, the composition was applied to the first. But if the wall did not absorb sufficiently well, the furnace was re-shifted to its first position, and placed at the requisite distance from the surface. Upon this, air-bubbles were rapidly disengaged, and the absorption took place in a very short time. The mastic was applied without intermission till the plaster ceased to absorb. Five thick layers were absorbed; the sixth was only partially so, and formed a slight glaze on the surface, which after a time became very hard. The upper band or portion having been covered, the rod and furnace were lowered about 1 foot 8 inches, and the remainder of the wall, in successive bands, was treated in like manner. The cost, without reckoning time and labour, was 16 sous the square metre (about 7*d.* the square yard): it would be less on stone, because there would be less absorption, and therefore less consumption of the ingredients.

"The stucco became hard in a short time: it is now difficult to make an impression on it with the nail of the finger. In two spots it had been too much heated: these portions were re-plastered. Where saltpetre is very abundant, the composition penetrates with difficulty, and is apt to fall off in scales: in this case also it would be necessary to renew the stucco. The operation always succeeds perfectly on new and dry stucco.

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[25] The furnace, heater, or cauterium, was made like a common barred grate, except that it was furnished with a half-closed lid to protect the ceiling from the heat. A similar furnace may be applied by means of a pole fastened to the back, instead of being suspended from a rod.

[26] The authors state that 120° are about the maximum of heat which plaster will bear; at 145° it became decomposed.

"Another, and perhaps the best mode, where walls are much impregnated with saltpetre, is to remove the plaster, to re-face the surface of the stone with the peck, to stop the joints well, and then cover the whole with the composition: the surface may then be cloth-papered."

A similar mode of rendering pavements dry is also described; and the authors recommend saturating stucco on ceilings with wax and lithargirized oil, as a preparation for oil-painting. The composition, it is observed, penetrates so deeply into stucco, that no damp from the body of the wall or roof can decompose it: it becomes so hard at last that broken stone-work has been made good by adapting the stucco to the forms or mouldings first, and then saturating it. The writers proceed to state, that a ceiling in the Salle des Antiques, in the Louvre, painted by Barthélemy in 1801, was destroyed in 1820 by the infiltration of water from a room above: they observe that, had the stucco of this ceiling been prepared in the mode before described, the painting would still have existed. "The above methods," they add, "may be employed to expel damp from ground-floors, and from cells of prisons; to make cisterns and reservoirs water-tight; to render vases of plaster fit to contain fluids; and, among various other uses, to preserve corn for any length of time in subterraneous chambers." [27]

In preparing a wall for encaustic painting, the surface of the stone is first heated in the mode above described, and is then saturated as deeply as possible with wax, dissolved either in the volatile oil of wax, in that of lavender, or in highly rectified spirits of turpentine. This subject will be re-considered under the head of Encaustic Painting.

To recapitulate: should it be thought desirable to prevent the possible egress of damp from a brick wall upon which a fresco is to be painted, the surface of the bricks may be well covered with a hydrofuge. The composition might be melted in the mode above described, or it might be applied in some body; in the latter case its surface should be so roughened as to afford a sufficient hold for mortar; if, again, the mortar alone should be thought not sufficiently absorbent, tiles, which might be made to adhere perfectly to the hydrofuge, might be interposed between it and the ground on which the fresco is to be executed.

On a surface of stone, for example, on the walls of Westminster Hall, even assuming that the ashlar in its present state affords a sufficient tooth for mortar, the little absorption that could take place might possibly render the execution of fresco inconvenient. This point could be easily determined by making experiments on stone of a similar quality. That used for the new buildings closely resembles the ashlar of Westminster Hall.

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[27] See, on this subject, 'Note sur la Construction et l'Emploi des Silos dans le Nord de la France, par M. D'Arcet, membre de l'Institut, &c. Inséré au Recueil de la Société Polytechnique,' Avril, 1841. In these chambers for preserving corn, the grain is dried, and even the insects which may lurk in it are killed, by an ingenious contrivance. An explanatory engraving accompanies the description. The ingredients of a variety of hydrofuge compositions are given in the same Memoir, p. 4.

Should such a material prove unfit, it would be necessary to fasten tiles against the wall; and this it appears could be effectually done by various cements: thus prepared, the surface would be sufficiently absorbent.

In the preparation of an ashlar wall for encaustic or oil-painting, no difficulty presents itself. The surface of the stone should be heated and saturated as deeply as possible with a composition similar to those above described, the joints of the stones being well stopped. The cement sometimes used for this purpose in Paris is the "cément de Dihl," composed of the outer scales of fire-bricks pounded, and mixed with oil.[28]

The "grounds" for oil-painting, applicable to walls, and the means of executing the work without the inconvenience of painting on the wall itself, from first to last, will be considered in another Paper.

C. L. Eastlake, *Secretary.*

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[28] M. D'Arcet ('Note sur la Construction et l'Emploi des Silos,' p. 3) says that the ingredients have been published by him. It has been observed that, as the cément de Dihl, employed to stop the joints, cannot absorb the mastic during the progress above described in the same manner as the stone itself absorbs it, the surface of the painting sometimes shows the lines of the joints, producing a partial change of tint. This might be obviated by merely stopping the joints with stucco, and relying on the mastic to give it a hydrofuge quality, together with the stone, by which means the surface would be homogeneous, while the operation would, at the same time, impart sufficient hardness to the stucco. When the joints are close there can be still less difficulty. The firm adhesion of various hydrofuge cements to mortar or tiles may render them preferable in every case where it is desirable to intercept damp behind paintings executed on walls. Some of these cements are here enumerated. The mixture of oil and lime, recommended by Vitruvius (lib. 7, c. 4) as a cement well calculated to exclude damp from pavements, has been often introduced as a novelty by the moderns. Hamelin's mastic is said to be thus composed (Gwilt's 'Encyclopædia of Architecture,' p. 509). The mastic de Loriot, said by the last-named authority to be the same, is, according to Biston ('Manuel du Chaufournier,' Paris, 1828), merely a compound of lime and pounded tiles or flints, without oil. The fanciful ingredients of the Maltha of the ancients, "res omnium tenacissima et duritiam lapidis antecedens," are given by Pliny (lib. 36, c. 24). Various compounds, under the same name, are used by the Italians; such as lime slaked in bullock's blood, the whole being mixed with pounded tiles and iron filings (Biston, *ib.*) The mastic de Vauban is composed of finely pounded tiles, lime, and linseed oil (Biston, *ib.*) The mastic de Tunis, which is employed to line the cisterns in that kingdom, and is said to be the same as that used in the ancient cisterns of Carthage, is composed of wood-ashes, lime, and fine sand; its peculiar quality is the result of constant manipulation and beating for several days, while oil and water are thrown upon the ingredients in small quantities alternately. The mastic à la litharge (see 'Chimie de Thénard,' v. 2), and the mastic de Corbel, are also composed partly of oil, (*ib.*) A cement composed of lime, linseed oil, white lead, and sand, is recommended by Merimée ('De la Peinture à l'Huile,' p. 247). Many of these adhere firmly to the smoothest surfaces; the recently patented "stucco paint cement" of Messrs. Johns and Co. adheres to glass.

III.—*Experiments on an Open Cast Iron Girder.*

Figures 1 and 2, in the sketch below, show the section and elevation of a cast iron open girder, which was intended to act as a bressummer between the columns which supported an iron sheet roof of 40 feet span. These columns were 20 feet apart from centre to centre, and the principals of the roof being 6 feet 8 inches apart, two of them were of course supported by the iron girder at the points *a* and *b*.

The maximum weight which would thus be thrown upon the girder was calculated to amount to 2½ tons at each of the points where the principal bore upon it; giving a total pressure of 5 tons: this was on the supposition that the weight of the roof itself, and the action of the wind upon it, would be equivalent to a weight of 40 lbs. on the foot superficial.

Fig. 1.

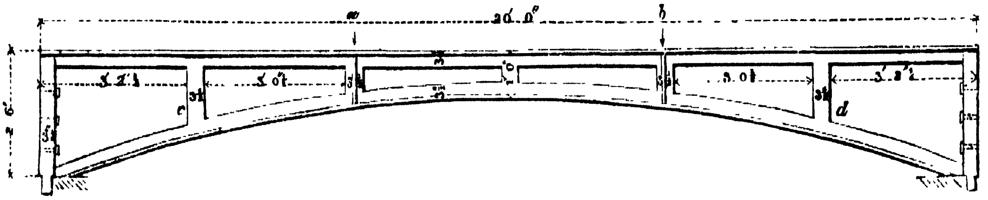
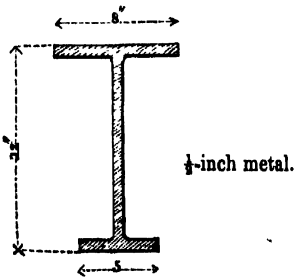


Fig. 2.



Section.

The roof was erected by a contractor who furnished the plan, and undertook the work at his own risk: when it arrived on the ground, I was struck with the slightness of the girders, and insisted on subjecting them to the necessary proof before placing them in the work. Accordingly, two girders were placed at a short distance apart, and properly fixed; balks were then laid across from one to the other, at the two points *a* and *b*; and upon these planks were laid, which carried pigs of iron. The girders did not show much symptom of weakness until 4 tons were placed on the platform; but with this load, which was less than one-half of what the two should have carried, the two vertical braces, *c* and *d*, were broken by a tendency of the under flange of the girder to rise at those points in a direction perpendicular to the curve, and the whole very soon gave way, and was completely smashed. In this case, not only was the metal too thin, but the connecting pieces between the upper and lower flanges were too slight, and too far apart; the top flange was made wider than the bottom, in order to give a bed for the shoe of the principal: had the openings been filled in, the girder might have stood the test, though even then the girder would have been but slight.

Fig. 3.

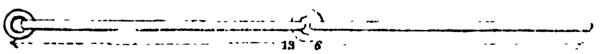


Fig. 3 shows two links of a chain guy for supporting a pair of shears, erected for lifting heavy weights, such as boilers, &c.: these links were about 6 feet 6 inches long, and were made of 2-inch round iron: they were subjected to the following proof by means of an hydraulic press.

With 35 tons, these two links stretched $\frac{1}{10}$ of an inch.
With 40 tons, do. do. $\frac{3}{8}$ do.

and had then a permanent set.

With 60¼ tons they stretched 3¼ inches and broke, the metal being clean and sound: in this case the breaking weight was about double that which might have been fairly placed upon the chain, viz., about 31 tons, which would have been at the rate of 10 tons upon the square inch; for although 35 tons did not apparently cause any set during the time the experiment lasted, yet it is impossible to say that that weight might not have caused such an effect, if left for a sufficient length of time.

W. D.

IV.—*Notes and Experiments on Iron Girders.*

Since the publication of the sixth volume, in which a set of Tables was given, computed from Tredgold's formulæ for the strength of iron beams or girders of different forms, I have procured the following formula, which is that deduced from Mr. Hodgkinson's experiments. "As the distance between the supports in feet, is to the depth in feet of the beam in the middle of its length, so is the area in inches of the bottom flange, to a fourth quantity, which, when multiplied by a constant number to be determined by experiment, will give the breaking weight in tons."

This given number may be taken at 27·3 for common beams; then half of this quantity will be the weight which the girder will bear, if distributed equally over its length. The ratio of the area of the middle section of the top flange to that of the bottom should be about 1 to 4, or 4·5.

The annexed wood-cut represents a girder of 18 feet bearing: the maximum weight which would ever be thrown upon it, including the weight of a fire-proof floor, was considered to amount to about 200 lbs. on the foot, or 14 tons spread over its length: two of these girders were then placed at a short distance apart from each other, and loaded uniformly over their whole surface with iron ballast; a horizontal line was struck upon one of the girders, and the deflection measured when each weight was applied.

Twenty tons of ballast gave a deflection of $\frac{1}{4}$ inch.

April	13.—4 tons	added, making	24 tons;	deflection	$\frac{3}{8}$.
,,	15.—2 do.	do.	26 do.	do.	$\frac{3}{8}$.
,,	16.—2 do.	do.	28 do.	do.	$\frac{3}{8}$.
,,	17.—2 do.	do.	30 do.	do.	$\frac{3}{8}$.
,,	18.—2 do.	do.	32 do.	do.	$\frac{3}{8}$.
,,	20.—4 do.	do.	36 do.	do.	$\frac{9}{16}$.

April 23.—Deflection still the same, the weight having remained undisturbed.

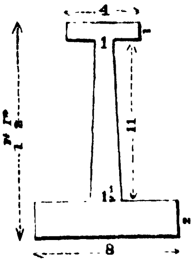
April 29.—No alteration had taken place in the deflection, and the weights being removed, the girder resumed its original form, showing no trace of a set or permanent alteration of form.

The section annexed shows the relative proportions of the upper and under flanges of the girder: the top and bottom of the girder were parallel, but the lower flange, being 8 inches broad at the middle, diminished to 4 inches at the point of support.

The computed breaking weight, according to Mr. Hodgkinson's rule, would be

$$\frac{16 \times 1{\cdot}166}{18} \times 27{\cdot}3 = 28{\cdot}28 \text{ tons}:$$

half of this, viz., 14 tons, distributed over the whole length, should be its maximum load; whereas it carried 18 tons, or 36 tons placed on two girders, without showing any symptoms of giving.



The average weight of a large number of these girders amounted to about 16¾ cwt.

W. D.

V.—*Particulars of an Experiment performed on the 15th and 16th of April, 1844, upon two of the Principals belonging to the Roof over the Passenger Shed at the Bricklayers' Arms Station, South Eastern Railway.*

The experiment was tried for the purpose of ascertaining the absolute strength of the principals of the roof, a section and elevation of which are given in Plate XLV.

The clear span was 52 feet 6 inches. The rafters were made of flat bar iron, $2\frac{1}{4}$ wide and $\frac{5}{16}$ thick, put together in pairs, with a block of wood $1\frac{3}{8}$ inch thick between the two, as shown in fig. 2; the tie bar (*b c*) of the truss and the suspension bar (*b d*) were each of them formed of flat bar iron, 2 inches wide and $\frac{3}{8}$ thick, while the lower tie bar (*a b*) was 3 inches wide and $\frac{7}{16}$ thick.

Two principals, chosen indiscriminately from a number prepared for erection, were placed side by side at the same distance apart as that adopted in the roof; the shoes at the feet of the principals rested upon ordinary rails, laid transversely, and the principals themselves were covered with boarding in a manner precisely similar to that made use of in the roof, with the exception of the hoop-iron tongues, which in the experiment were omitted. Diagonal boards were laid down upon the top of the boarding, as a substitute for the ordinary flat iron. Upon the morning of the 15th, 32 rails, each 5 yards long, and weighing 71 lbs. to the yard, were laid upon one of the principals: this weight remained until the morning of the 16th, without the slightest symptom of yielding being manifested. It being determined to load the principal until a fracture should take place, a scaffolding was erected over it, so that the load might be added without endangering the safety of the labourer engaged in the operation.

The load was gradually increased until it amounted to 54 rails, each 5 yards long, and one rail 4 yards long: upon adding the fifty-fifth rail of 5 yards long, a fracture took place.

Comparison of the load borne by a principal when in its place in the roof, with the load to which it was submitted during the experiment:

Weight of principal per foot superficial on plan	3 lbs.
Boarding	4
Slates	7
Total weight per foot superficial on plan	14

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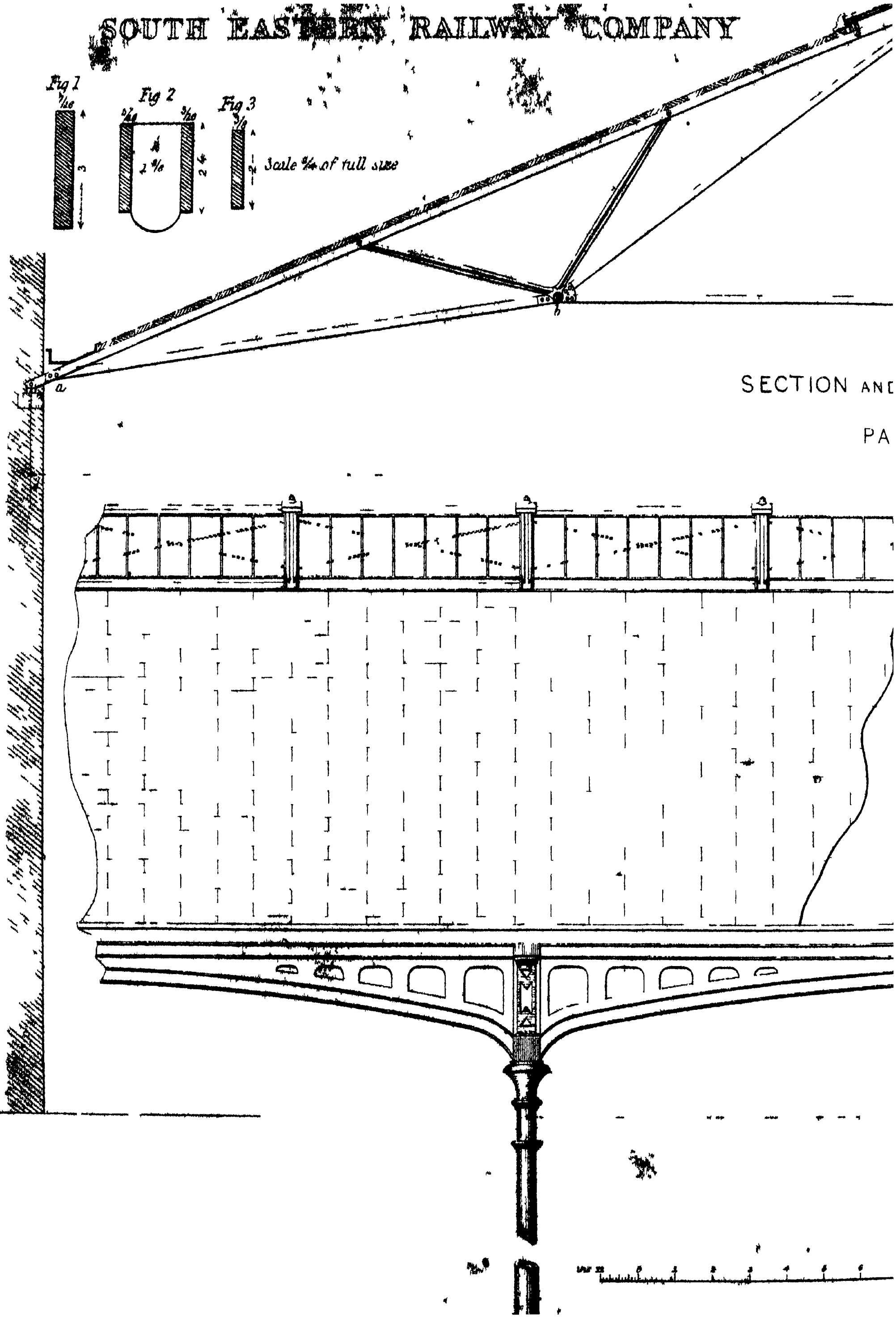
SOUTH EASTERN RAILWAY COMPANY



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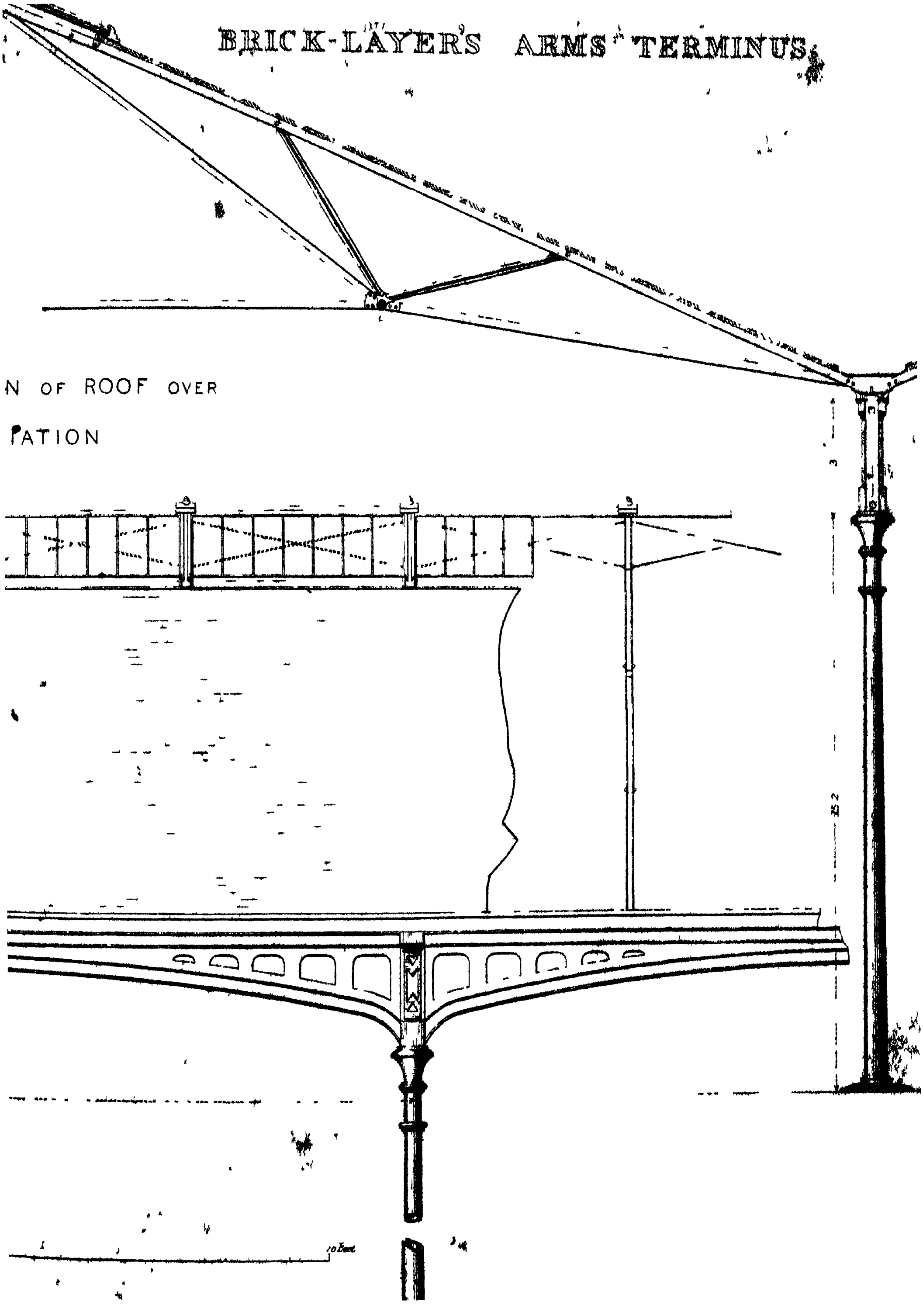

Weight of principal per foot superficial	3 lbs.
Boarding	4
Iron rails	60
	67

The area of the portion of roof supported by one principal, and the weight per foot, was computed as follows:

Span of roof 52 feet. Distance between
Principals $6\frac{1}{3}$ feet
$52 \times 6\frac{1}{3} =$ say 330
55 rails, each 5 yards long $= 55 \times 5 \times 71 = 19525$ lbs.
1 „ 4 „ $1 \times 4 \times 71 = 284$
19809
$19809 \div 330 = 60$ lbs.

The yielding at this experiment was caused by the bending of the part of the rafter between the king head and the adjacent tie bar: the deflection amounted to 3 inches.

Note.—Although the rails forming the weight were laid as carefully as possible over the principal, yet the boarding must have transferred some of the weight to the other: a more satisfactory experiment would have been to have loaded the two with double the weight.

W. D.

VI.—*Detail of Experiments made to ascertain the amount of Condensation of Gravel and Sand, or similar materials, when made into Concrete; being an Abstract of a Report forwarded to the Inspector-General of Fortifications.*

By Lieut.-Col. THOMSON, *Commanding Royal Engineers, Corfu.*

Description of mode of making experiment.

IN compliance with an order directing the repetition of Col. Rancourt de Charville's experiments, two water-tight wooden measures were prepared, each of which was exactly one cubic foot; one of them was filled with broken stone, or sand, or mixture under experiment, and the other with water: the two measures were placed side by side, and the water carefully ladled from the water vessel, and poured gradually into the other: the first effect on the sand was a sinking at the point where the water descended, and finally, when the whole mass was saturated, the general surface sank in a similar manner. The water was still poured in until the whole measure had been filled, and the depth of the surface of the sand below the rim was then taken as the amount of condensation. The number of inches the water measure had been depressed by the removal of the water required to fill the sand measure, diminished by the number of inches of condensation, and divided by 12, or the total depth of the measure in inches, gives the proportion of water to sand, or of the void spaces to the volume of solid matter.

Abstract of Experiments.

Proportion of water to volume of solid material taken as 1.

In broken stone	·468
In coarse sand	·297
In fine sand	·281
In fine and coarse sand in equal proportions	·245
Do. mixed, two of coarse and one of fine	·260

In the last two experiments the mixture of coarse and fine sand was effected by shaking them together, and it was naturally to be expected that the condensation would be reduced below its amount in practice. Another experiment was therefore made, in which the coarse and fine sand were mixed together on the ground, and then thrown into the box; and the proportion of solid material to vacant space was then 1 to ·239.

The practical results therefore of these experiments, as regards the proper composition of concrete, may be thus stated:

Broken stone	1000	parts require	468	parts mortar.
Coarse sand	1000	,,	297	,,
Fine sand	1000	,,	281	,,
Mixed, half and half	1000	,,	245	,,
Mixed, two coarse to one of fine . .	1000	,,	261	,,
Half and half, mixed previously, without shaking	1000	,,	239	,,

Of these it appears, that the mixture of coarse and fine sand in equal proportions requires the least quantity of matter to fill the void spaces, and is therefore the most economical mixture: that quantity is nearly ¼, and may be taken as such; therefore the proportion of lime and mixed sand to constitute the mortar of the concrete is 1 to 4, forming 4 parts of mortar. In respect to broken stone, the proportion of mortar to stone, if there were no condensation of the sand, would be 1 to 2, and the concrete would consist of—1 lime, 4 mixed sand, 8 broken stone; but it has been seen that the mixed sand, when loosely thrown together, condenses by about ⅙ of its bulk: hence 8 parts of stone will require ⅙ more of the loosely mixed sand to fill its void spaces; or, in other words, the 4 measures of sand will fill the spaces of a less quantity of stone. The correct proportion is therefore—

Lime 1; loosely mixed sand 4; broken stone 6·85;

and it may therefore be assumed that 6 measures of stone are not in excess, making the proportion for concrete—

1 lime; 4 sand; 6 broken stone with shingle.

The same experiment was tried, and the result gave, for concrete—

1 lime; 4 mixed sand; 8 shingle,

when the shingle is clear and composed of moderately sized pebbles; but if, as is generally the case, the shingle is mixed with a considerable proportion of sand, it becomes necessary to make an allowance for this sand.

Mixtures of shingle and broken stone were also tried, and the results for concrete were

1 lime; sand in shingle 1⅓; ditto, uncombined 2; pebbles in shingle 2⅔; broken stone 3;

or, lime 1; sand 2; shingle 3; broken stone 4.

In using the concrete it should be thrown from an elevation sufficiently great to produce, by the momentum obtained, an instantaneous consolidation of the mass, without the agency of the repeated blows of a rammer, which act unequally, and tend to disturb commencing cohesion. It is also desirable, in the act of throwing down the concrete, not to spread it too much, as the material is thereby separated and formed into thin laminæ of variable composition and consistence. Nine or 10 feet appears to be a good height from which to throw concrete.

Large stones should not be thrown into concrete, as the cohesion between them and the mortar will be inferior to that of a properly constituted mass.

The lime should be ground, to insure a regular proportion in the mixture and a due blending of material; if the lime be unground and slacked in lump, care should be taken not to soak it in water.

An experiment was lately made by me, in order to discover the amount of condensation of the Thames ballast in forming it into concrete, so as to enable me to ascertain the number of cubic yards of gravel required to form any given number of cubic yards of concrete.

A measure, 2 feet long, 2 feet wide, and 1 foot 8¼ inches deep, was filled with Thames ballast, the cubical content being 11,664 cubic inches: a portion of lime equal to ⅛th of this quantity, or 1458 cubic inches, was then added to this, and the whole made into concrete with a proper proportion of water: it was then turned back into the measure, which it filled to within 2¼ inches of the top.

Therefore, 11,664 cubic inches of ballast,
With 1,458 cubic inches of lime,
Made 10,368 cubic inches of concrete;

a loss upon the ballast of 1296 cubic inches, or rather more than 11 per cent. The accuracy of this proportion of loss was corroborated by the person in charge of the contract-work at the New Marine Barracks: he stated to me, that in measuring the concrete which had been thrown in for foundations, and which amounted to upwards of 2000 cubic yards, he found that the quantity of gravel consumed was nearly 2200 yards: he estimated the loss roughly at between 10 and 11 per cent.

W. Denison.

VII.—*Account of an Experiment on the Strength of the Principals of a Wrought Iron Roof of 62 feet 4 inches span.*

In the spring of the present year an accident, accompanied with some loss of life, occurred in the erection of a wrought iron roof at a railway station; and as I was then about to erect some roofs of a similar description in Her Majesty's Dockyard at Woolwich, I thought it desirable to submit one of the largest to such a trial as would put beyond a doubt its capabilities of withstanding any strain which might be brought upon it.

Plate XLVI. will show the general construction of the roof, and the sections give the dimensions of the various parts. The elevation of the shoe shows the mode in which the rafter abutted against it, and how the tie rod was keyed up. The sections of the struts and rafters are represented as being equally thick from end to end; but in point of fact, the metal at the point where the upper web met the vertical part of the **T** iron was $\frac{9}{16}$ instead of $\frac{1}{2}$ inch in the rafter, and $\frac{7}{16}$ instead of $\frac{5}{16}$ in the struts.

The whole weight of a principal, together with the castings for the skylight, the lathing for the slates, &c., would amount to 2020 ℔s.; the weight of the slating to 3628 lbs.; and as the whole area of the roof between a pair of principals, or the part supported by one principal, was 504 square feet, the total weight of the roof, when completed, would be about 11½ ℔s. per square foot of its area. It was then decided to prove it with an additional load, beyond that of the principals and lathing, of 30 ℔s. on the foot, which would be equal to an actual load, beyond the weight of the roof itself, of 21 ℔s. per foot; an allowance far beyond what it would ever be likely to be subjected to.

The mode in which the experiment was made was as follows:

Two of the principals were framed together, and placed about 3 feet apart; the lathing for the slates was riveted to the rafters, and the shoes were fixed in blocks of granite, so as to make every thing as stable as possible. The two principals were then shored up in such a manner as to prevent any lateral motion, but so as in no way to assist them in sustaining the load: the load was then uniformly distributed on the back of the lathing: it consisted of iron bars of various lengths, which were carefully weighed, and an equal load was placed on each side of the roof. The only effect produced by the load of 30 ℔s. on the foot was to tilt the inner side of the shoe a little, raising it about $\frac{1}{16}$ of an inch from the stone at the inner edge. This was evidently owing to the position of the tie rod, which was below the line of pressure of the rafter. An alteration which would have brought the line of the tie rod 2 or 3 inches higher, would have had the advantage of remedying this tendency to tilt, and at the same time of shortening the struts and key bolts.

The roof having stood the proposed test, I intended to have discontinued the trial, but the contractor was anxious to ascertain the actual load which such a roof would bear; and Captain Brandreth, R.E., having given his consent, we proceeded to apply additional weights, with a view of destroying the truss. A weight equivalent to 37 lbs. on the foot made no difference: with a load of 20 tons, equivalent to a pressure of about 46 lbs. on the foot, one of the long struts (A) from the king bolt in one of the principals began to bend laterally; and the roof at the point where this strut abutted, not being supported, settled a little: the rafter bending under the load, and the king bolt at that point yielding too, pushed the tie bolt downwards. Still, however, there did not appear, after a time, any tendency in these parts to settle more; and accordingly an additional load of 1 ton 9 cwt. 16 lbs., or 3¼ lbs. per foot superficial, was placed on the roof, making a total weight of about 50 lbs. or a little more on the foot: with this load, the corresponding strut in the other principal gave way in the same manner as before described, but no part seemed disposed to break. However, having evidently arrived at the practical limit of the strength of this roof for all useful purposes, I did not think it necessary to push the experiment further, and accordingly relieved the roof from the weight.

In examining the sections of the parts of the roof, it will be seen that the long strut next the king bolt is of precisely the same section as the shorter one, nearer the bearing of the truss; and evidently if the one is strong enough, the other must be stronger than necessary: but the experiment showed that the long strut was the weak point in the truss. Had an additional ½ inch been added to the width of the upper web of the strut, the whole would probably have stood firm under a much greater weight. On the whole, I consider the experiment valuable, as giving an idea of the extent to which it may be possible to carry the system of wrought iron trusses of this simple form.

W. D.

H . M . DO

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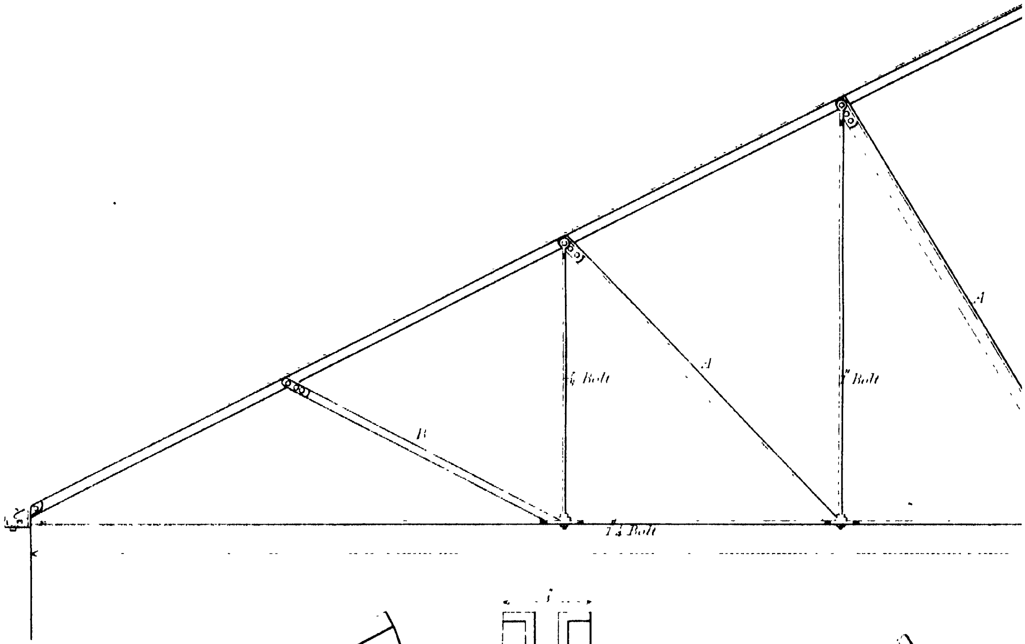
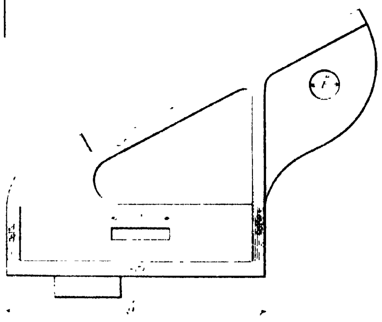
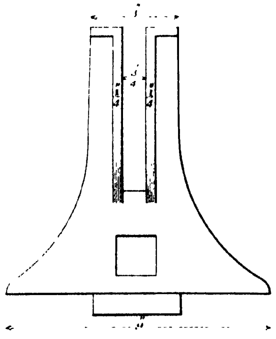
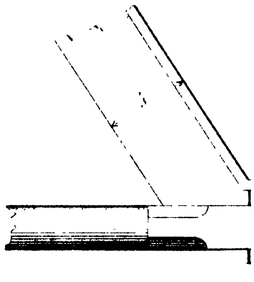




Side Elevation of Shoe



Front Elevation of Shoe



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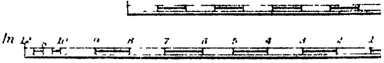

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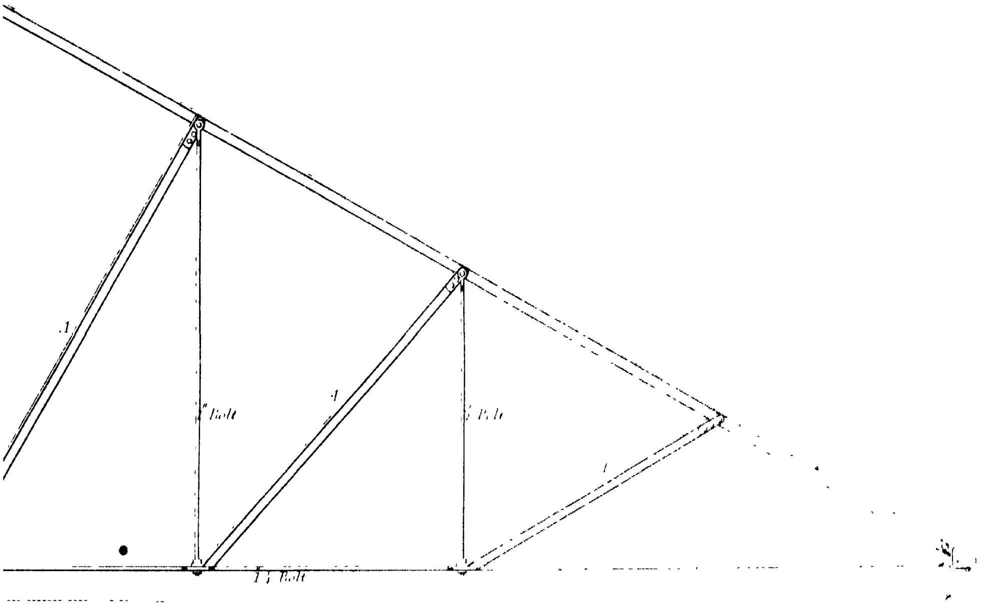

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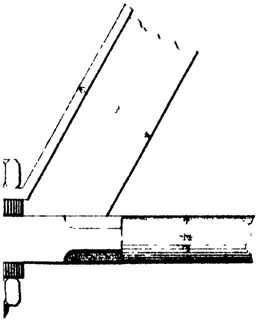

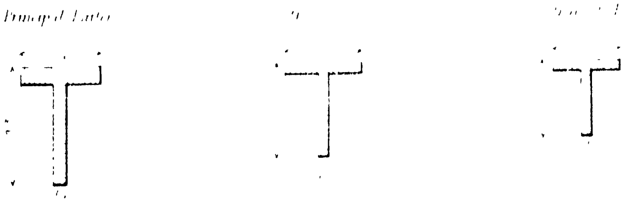

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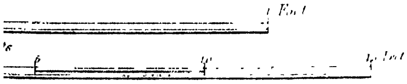

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VIII.—*Memorandum on the Use of Asphalte in covering Casemates.*

HAVING lately observed at Verona a mode of avoiding some of the difficulties encountered in covering casemates with asphalte, the following short description of it is forwarded, as it may possibly not be generally known.

Over the masonry covering the casemates, which has a slope of about 1 in 9, coarse canvass is stretched, and the asphalte is laid on very hot over this, in a coat of only ¼ inch thick, being spread by means of a small wooden trowel, with which the surface is rubbed smooth, a little sand being used to prevent the asphalte adhering to the wood. Thus the air in the masonry, when heated by the asphalte, instead of rising in bubbles and honey-combing it, raises the whole layer, and does no injury. Partial settlements are also thus prevented from causing fractures in the asphalte, since it does not adhere to the masonry, and is supported by the canvass: the thickness therefore may be reduced probably one-half with perfect safety by the use of this method.

P. J. BAINBRIGGE,
Lieutenant, Royal Engineers, Cologne.

END OF VOL. VII.

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ABSTRACT OF RESOLUTIONS

MADE AT A MEETING OF THE CORPS OF ROYAL ENGINEERS.

Dublin, 11th April, 1843.

At this Meeting, held for the purpose of taking into consideration a proposition for forming an Aid-M moire, from Colonel Lewis, Commanding Royal Engineer in Ireland:

It was Resolved—

1. That the Officers of the Corps, generally, be requested to offer their assistance, and select such article from an alphabetical list as they may desire to contribute.
2. That Officers who have already published, have the refusal of the subjects on which they hav written.
3. That the work be edited in Dublin, by a Committee of Engineer Officers.
4. That, in the event of subjects being omitted from want of contributors, the Committee be empowere to complete from the best authorities.
5. That the Aide-Mémoire form two volumes, one for the use of the Army generally, and the other a as a practical work for the Corps.
6. That the Committee have no power to alter any subject offered for publication without the consent o the contributor.
7. That persons furnishing Papers, complete, for the Aide-Mémoire, have the privilege of their name or initials being placed at the termination of these articles; such treatises, however, should be in a small a space as possible,—the "Professional Papers" of the Corps being open to disquisitions an dissertations.
8. That the proposition be submitted to the Inspector-General of Fortifications.

The Inspector-General's approval of the foregoing was laid before a Meeting, 26th April, 1843.

THE series of Mr. WEALE'S "QUARTERLY PAPERS ON ENGINEERING" will have many distinguishing features of the bold and stupendous works of modern times. Among several that are in preparation, is the Thames Tunnel, a work which, from its originality, and the difficulties which have been surmounted in its construction, is of peculiar interest to engineers. Sir Isambart Brunel, the Engineer of this great work, has liberally permitted one of his pupils, Mr. Henry Law, to draw up a scientific account, developing its construction and course of operation. It will be acknowledged by all Engineers as a great boon to the profession; and as an example to the student, by setting before him a series of ingenious contrivances which overcame the many obstructions by which the work was impeded. A hasty sketch is here added of the contents of the work:—

Distinguishing features of the Work. The first idea conveyed to Sir Isambart by observing the Teredo Navalis. The size and form of the present Tunnel. Reasons for adopting the square form externally. Its great strength and stability. Security of foundation, the Tunnel being specifically lighter than the displaced ground. Reasons for not going lower.

Description of the Shield. The ample protection which it afforded to the workmen; the various mechanical arrangements for combining strength and security, with facility of movement, and the prevention of derangement in the moving parts; the division of the shield into twelve distinct parts, each complete in itself and capable of alternately supporting the ground and moving forward.

The mode of sinking the Rotherhithe Shaft. Difficulties experienced from the looseness of the ground and the influx of water; bed of quicksand passed through; underpinning resorted to; difficulties increased with the depth; a smaller well sunk inside the shaft to a depth of 80 feet; very extensive quicksand met with, confirming the opinions of the geologists who had warned Sir Isambart not to go too deep. Invert made at the bottom of the shaft.

The operation of putting together the Shield; its passage out of the shaft. Difficulties in managing the shield, from the inexperience of the men. The brickwork commenced behind the shield. Sudden breaking in of the ground, and the means taken for repairing it. Account of the progress of the Tunnel up to the first eruption: the cause of the eruption, and the means adopted for filling the hole in the river and re-entering the Tunnel; the brickwork found uninjured. The works recommenced, and progress before the second eruption. Suspension of the works for want of money.

Resumption of the works. Removal of the old shield and insertion of the new one, a peculiarly hazardous operation. Progress with the new shield. Extreme looseness and fluidity of the ground; various expedients resorted to in order to make progress. Third, fourth, and fifth eruptions; the system of hooks and links resorted to, found very beneficial; great difficulties from the looseness of the ground, the quantity of water, and the impurities in the air. Several large cavities found in the ground. Improvement in the rate of progress as the shield approached the north shore.

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Transverse Section of Tunnel, showing the Manner of Construction.

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Drawing of the first Eruption.

Drawing of the third Eruption.

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