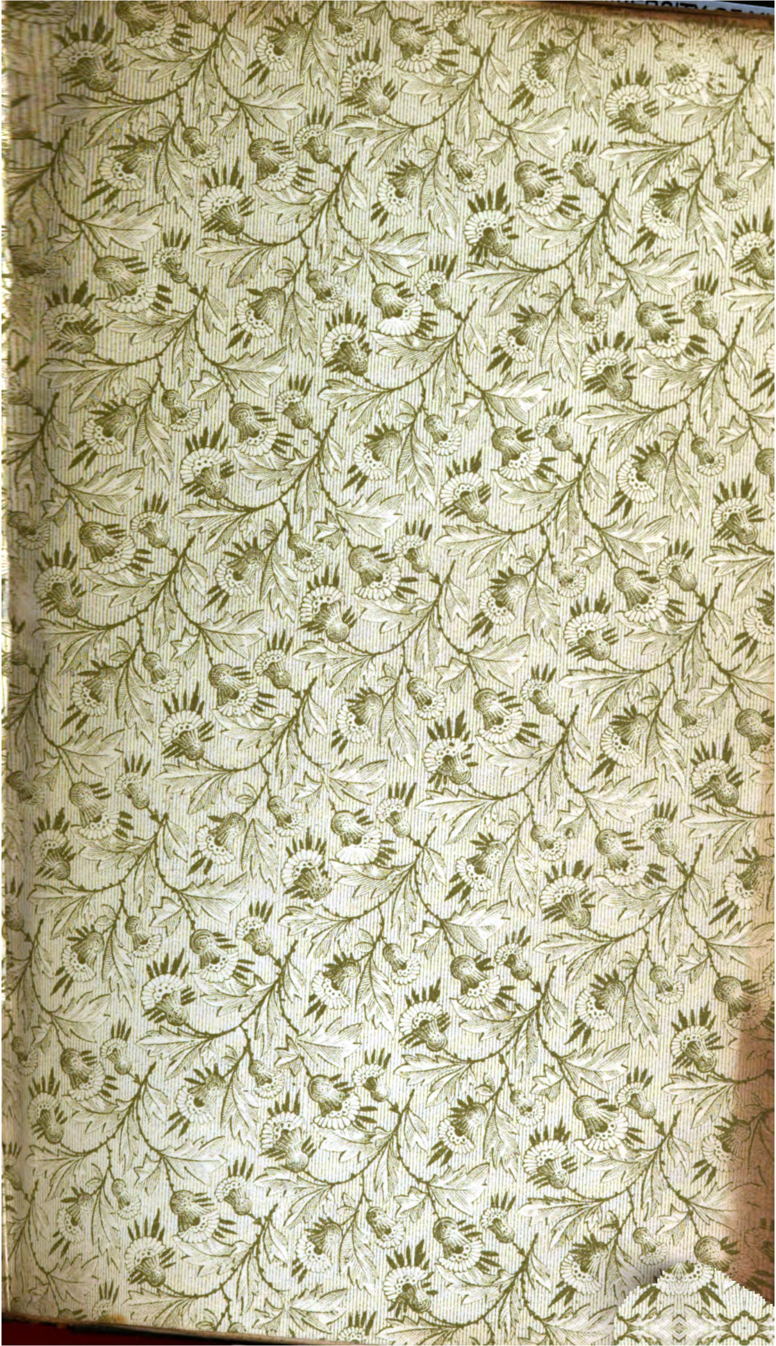

A
RUDIMENTARY TREATISE
ON
FOUNDATIONS
AND
CONCRETE WORKS:

CONTAINING

A SYNOPSIS OF THE PRINCIPAL CASES OF FOUNDATION WORKS, WITH THE USUAL MODES OF TREATMENT,

AND PRACTICAL REMARKS ON

FOOTINGS, TIMBER-PLANKING, SAND, CONCRETE, AND BÉTON, PILE-DRIVING, CAISSONS, AND COFFERDAMS;

WITH

AN ACCOUNT OF THE NEW MOLE EXECUTED IN BÉTON AT THE HARBOUR OF ALGIERS.

ILLUSTRATED BY WOODCUTS.

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AND OTHER WORKS.

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PREFACE.

On the completion of the last of the four volumes which form my contribution to Mr. Weale's Series of Rudimentary Treatises, a few words on the circumstances under which they have been written may not be out of place.

The whole of these four volumes have been written whilst fulfilling professional engagements, the duties of which have left me no leisure for study or literary occupations, and from this circumstance not only has their publication been delayed to an extent that could not have been anticipated by Mr. Weale or myself, but I have been unable to give them that clearness of arrangement and completeness of detail which can only be attained by careful and leisurely revision. I hope, however, that although defective in style and arrangement, and in many points less complete than would have been the case could I have devoted more time to their composition, these volumes may prove of service to those to whom they are especially addressed, viz., to workmen and others engaged in the "Art of Building," who wish to obtain a general knowledge of the principles of their art, as a groundwork for the study of those particular branches to which their attention may be specially directed.

To those readers who may not have purchased the "Art of Building," it may be necessary to explain that the present volume is written in continuation of the chapter in that work devoted to the subject of "Foundations," and is intended to give further information on those parts of the subject which could then only be touched upon very briefly. I may also observe, that many subjects which are treated of very fully in other volumes of the rudimentary treatises are here for that reason left unnoticed, or are merely glanced at in a cursory manner; as for example, the blasting of rocks, the nature and properties of limes and cements, the construction of travelling and other cranes, and of hoisting machinery in general.

In making the remarks on concrete, and the usual practice of builders in its use, which will be found in Chapter IV., I feel that great respect is due to the opinions of the elder members of the profession, with whom I am unwilling to differ; but in every observation of this kind which may be opposed to the usual routine of practice, I have written from my own experience, and from careful observation of works executed under my own superintendence, or to which I have had free access, and have been careful to advance nothing hastily, or without due consideration. Unfortunately the practices of the present generation of workmen are greatly of an empirical character, and have been handed down from one generation to another with little or no thought as to how far they are judicious, or in what respects they may be improved upon.

To assist in leading the workman to *think*, and to examine the principles by which the practical details of his work should be regulated, has been my principal aim in writing the volumes now brought to completion; and it will be a source of gratification to me hereafter, when engaged in devising new constructive arrangements to meet the "engineering difficulties" of colonial practice, to think that the last moments spent by me in England have been devoted, however unsuccessfully, to the advancement of the skill and knowledge of the workmen of the mother country.

E. DOBSON.

London, Sept. 3, 1850.

CONTENTS.

NOTICE.—The author having left England before the whole of the volume was sent to press, the correction of the remaining proofs, and the preparation of the index, have been undertaken by Mr. ALFRED DOBSON, who will feel obliged by the correction of any errors that may have passed unnoticed.

RUDIMENTARY TREATISE

ON

FOUNDATIONS.

CHAPTER I.

SYNOPSIS OF THE PRINCIPAL CASES OF FOUNDATION WORKS, WITH THE USUAL MODES OF TREATMENT.

IT may be necessary to premise, that by the term "foundation" we here mean all that portion of any structure which serves only as a basis on which to erect the superstructure, and not merely the work which may be requisite for the purpose of forming an artificial bearing stratum, in which restricted sense the word is often used. Thus we speak of "natural" and "artificial" foundations, meaning, in the one case, a solid natural stratum on which we may safely build; and, in the other case, an artificial bearing stratum of timber, concrete, faggots, &c., placed upon ground which of itself would be too soft to bear the pressure of a building, without some contrivance of this kind to distribute the weight over a large surface. The reader will therefore be good enough to bear in mind that, in the following pages, the term is used in its most extended sense.

The object to be attained in the construction of any foundation is, to form such a solid base for the superstructure that no movement shall take place after its erection. We must bear in mind that all structures built of coursed-masonry (whether brick or stone) will settle to a certain extent, and that, with a few exceptions, all soils will become compressed, more or less, under the weight of a building, however trifling its character. Our aim, therefore, will be not so much to attempt to *prevent* settlement, as to ensure that it shall be *uniform*, so that the superstructure may remain without crack or flaw, however irregularly disposed over the area of its site.

The principles to be kept in view in the treatment of all cases where the natural soil is at all of a doubtful character, may be thus briefly stated:—

1st. To distribute the weight of the structure over a large area of bearing surface.

2nd. To prevent the lateral escape of the supporting material.

Foundations may be divided into two great classes:—

Class I.—Foundations constructed in situations where the natural soil is sufficiently firm to bear the weight of the intended structure.

Class II.—Foundations in situations where an artificial bearing stratum must be formed, in consequence of the softness or looseness of the soil.

Each of these great classes may be subdivided as under, viz.:—

Division A.—Foundations in situations where water offers no impediment to the execution of the works.

Division B.—Foundations under water.

The methods used for constructing foundations under water may also be divided under three heads, viz.:—

1st. Skeleton foundations formed of piles.

2nd. Solid foundations executed *under* water.

3rd. Solid foundations laid in the dry by means of caissons or cofferdams, from which the water is temporarily excluded.

The above classification may be thus briefly summed up:—

Object......Uniformity of settlement.

Principles..{To extend the bearing surface.
To retain the supporting material.

Foundations divided into two classes:—

Class I.—NATURAL Foundations.

Division A.—Foundations in dry ground.
Division B.—Foundations under water.

Subdivided into

1. Skeleton Foundations;
2. Solid Foundations formed *under* water.
3. Solid Foundations formed inside caissons or cofferdams.

Class II.—ARTIFICIAL Foundations.

Division A.—Ordinary Foundations.
Division B.—Foundations under water.

This classification, as will be seen, has reference simply to the circumstances of the several cases occurring in practice, irrespective of the constructive arrangements applied to their treatment; thus we have considered whether the ground be hard or soft, wet or dry; and, if wet, whether the work be executed under water, or whether the water be temporarily excluded.

The adoption of this arrangement in the following synopsis enables us to consider the general principles of the treatment of foundations, which are constant and permanent, apart from the practical details of the subject, which are ever varying with the progress of mechanical science and with local circumstances; reserving the examination of the constructive arrangements in common use at the present day for the subsequent chapters of the work.

We now proceed to enumerate the principal cases occurring in practice and the modes of treatment usually adopted:—

CLASS I.

FOUNDATIONS FORMED IN SITUATIONS WHERE THE NATURAL SOIL IS SUFFICIENTLY FIRM TO BEAR THE WEIGHT OF THE SUPERSTRUCTURE.

DIVISION A.—FOUNDATIONS IN SITUATIONS WHERE WATER OFFERS NO IMPEDIMENT TO THE EXECUTION OF THE WORKS.

Case 1.—***Bearing stratum not liable to be affected by exposure to air or water, as solid rock, indurated gravel, &c.***

In founding upon a natural bottom of this kind, the only precaution necessary is to level the foundation-pits so that the masonry may start from a horizontal bed. Should any vacuities or irregularities occur in the firm ground, it will be found better to fill them up with concrete, which, once set, is nearly incompressible under anything short of a crushing force, than to bring up masonry for that purpose, as the compression of the mortar-joints is certain to cause some irregular settlement. If it is unavoidably necessary that some parts of the foundation shall start from a lower level than others, care must be taken to keep the mortar-joints as close as possible, or to execute the lower portions of the work in cement, or some hard-setting mortar, otherwise it will be very difficult to keep the courses level in the superstructure, the work settling most at those points where the greatest number of mortar-joints occur.

Strong gravel may be considered as one of the best soils to build upon, as it is almost incompressible[a], is not affected by exposure to the atmosphere, and is easily levelled.

Sand is also almost incompressible, and forms an excellent foundation so long as it can be kept from escaping; but as it has no cohesion, and acts like a fluid when exposed to running water, it must be looked upon with suspicion, and treated with caution.

A bottom of solid rock, although at first sight appearing to offer many advantages to the builder, is not in practice found to be a desideratum. The labour of forming a level bed is generally considerable[b], and, unless the strata be nearly level, it commonly happens,

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[a] The superiority of gravel over clay as a bearing stratum is well shown in the following remarks made by Mr. Bidder, at the Institution of Civil Engineers, June 23, 1846:—"In the case of the bridge over the Grand Junction Canal, on the line of the Northampton and Peterborough Railway, the rails were laid upon girders, resting upon bedplates, with piles under each end. . . . . Part of these piles were driven into dry gravel, and a few into the Oxford clay. It was found that, when the engines and carriages passed over the former, no visible effect was produced; but with the latter there was a very evident sinking, and an especial provision against such an effect became necessary. The result of Mr. Bidder's present experience induced him to believe that, in clay, or wet soils, it was not advisable to trust a greater weight than 12 tons upon each pile; but, in gravel, there was scarcely any limit to their vertical bearing strength."—Vide "Minutes of Proceedings," 1846.

[b] The histories of the three most celebrated of modern lighthouses, viz., the

in the area of a large building, that some portions will rest upon the rock, and others upon some adjacent

Edystone *, the Bell Rock †, and the Skerryvore ‡, afford instructive examples of the trouble and expense attendant on preparing a level bed in hard rock. In the construction of the Edystone, the rock on which it stands was cut by Smeaton into steps, and each course of masonry was dovetailed into the upright face of these steps. At the Bell Rock and the Skerryvore, the base of the intended structure was brought to a uniform level and sunk below the adjacent surface of the rock. The labour attendant on this operation at the Skerryvore will be understood by a short extract from Mr. Alan Stevenson's account of the work :—"After a careful survey of the rock, and having fully weighed all the risks of injuring the foundation, I determined at once to enter upon a horizontal cut, so as to lay bare a level floor of extent sufficient to contain the foundation-pit for the tower. The very rugged and uneven form of the rock made this an almost necessary precaution, in order to prevent any misconception as to its real state, for it was traversed by numerous veins and bands inclined at various angles, on the position and extent of which the stability of the foundation in no small degree depended. That operation occupied 30 men for 102 days, and required the firing of no fewer than 246 shots, chiefly horizontal, while the quantity of material removed did not greatly exceed 2000 tons. . . . . When the floor had been roughly levelled, I again carefully surveyed the rocks with a view of fixing precisely the site of the foundation-pit, and of taking advantage of its form and structure to adopt the largest diameter for the tower of which the rock would admit. . . . . After much deliberation and repeated examinations of all the veins and fissures, I was enabled to mark out a foundation-pit of 42 ft. in diameter, on one level throughout. . . . . The outline

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* "Narrative of the Building, and a Description of the Construction of the Edystone Lighthouse with Stone, by John Smeaton, C.E., F.R.S." London, 1791.

† "Account of the Bell Rock Lighthouse, by Robert Stevenson, Engineer to the Northern Lighthouse Board," &c. Edinburgh, 1824.—Found also in the Rudimentary Work on Lighthouses in the series, in 3 vols.

‡ "Account of the Skerryvore Lighthouse, with Notes on the Illumination of Lighthouses, by Alan Stevenson, Engineer to the Northern Lighthouse Board." 1848.

After the success which has attended the efforts of the French engineers employed on the harbour works of Algiers, in forming béton foundations on the most rugged rocks, and exposed to heavy seas, it may be fairly questioned whether, in cases similar to that of the Skerryvore, a foundation of béton, dovetailed as it were into the natural cavities of the rock, would not prove as efficient against the force of the waves as one formed by cutting away the rock to form a sunk bed, as done at the Bell Rock and the Skerryvore.

stratum, as clay or gravel, and the irregularity of settlement thus caused is most troublesome to deal with[a].

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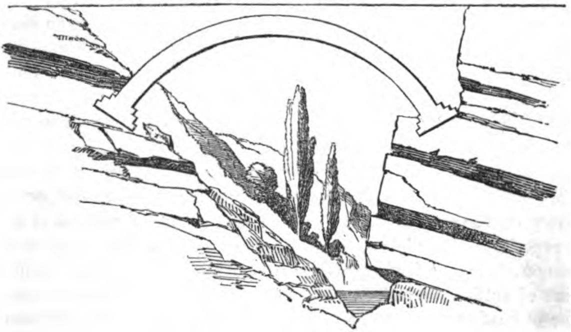
of the circular foundation-pit, 42 ft. in diameter, having been traced with a trainer on the rock, numerous jumper-holes were bored in various places, having their bottoms all terminating in one level plane, so as to serve as guides for the depth to which the basin was to be excavated. The depth did not exceed 15 inches below the average level already laid bare by the cutting of the rough horizontal floor which has just been described; and before the close of the season of 1839, about *one-third* of the area of the circle had been cleared, and was ready for the final pick dressing, which prepared it for the reception of the first course. . . . . Another considerable source of labour was the dressing of the vertical edges of the basin, as that implied cutting a *square check*, 15 inches deep, and about 130 feet long, in the hardest gneiss rock, and the labour attending which can only be fully estimated by a practical stonecutter who has wrought in such a material. The plan employed was to bore all round the periphery of the circle, $1\frac{5}{8}$ inch vertical jumper-holes, 6 inches apart, to the required depth, and to cut out the stone between them. The surface thus left was afterwards carefully dressed, so as to admit vertical and horizontal moulds, representing truly the form of the masonry which the check was intended to receive. The experience of the labour attending that operation gave me great reason for congratulation on having adopted a foundation on one level throughout, instead of cutting the rock into several terraces, at each of which the same labour of cutting angular checks must necessarily have been encountered. The cutting of the foundation occupied 20 men for 217 days in all. . . . The rock, indeed, was in many places so hard as often to make it seem hopeless that tools could make any impression on it. The time employed in the excavation, and the number of tools expended on it, were very great, as a pick seldom stood more than three strokes in the harder quartzose veins; but our perseverance was at length amply rewarded, by obtaining a foundation so level, and so fairly wrought throughout the whole area of a circle 42 feet in diameter, as to present to the view the appearance of a gigantic basin of variegated marble."

[a] An excellent illustration of the danger of building on a partially compressible stratum is given by Mr. Hughes in his Papers on the Foundations of Bridges, from which we extract the following details (vide "Bridges," vol. i. part iv., Weale, London):—

"The piers of a large aqueduct, eleven in number, with two abutments, had all been founded on gravel, a few feet below the surface, and stood remarkably well, the masonry appearing without a flaw when they were carried up to their full height of about 50 feet. One of the piers at the south end, however, was founded one part on the gravel and the other on very

Beds of rock, with partings of clay between them, are not to be trusted to, especially if lying in an inclined position, as they are liable to slip, and thus to cause serious derangement of the superstructure. Much, however, must depend upon the situation of the work. Thus in building a bridge, on inclined strata of this nature, over a ravine, as shown in fig. 1, the foundations on the one side would be perfectly secure, whilst those on the opposite side would be always liable to disturbance, from the pressure of the inclined strata.

Fig. 1.



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hard Whinstone rock, the surface of which was merely levelled, and the building at once commenced. When carried up to about 30 feet, a formidable fissure was observed from top to bottom of this pier, and the only possible source to which the mischief could be traced was the step of founding the pier partly on the rock and partly on the gravel. Had the whole pier been on the rock, it would, of course, have stood without any settlement; had the whole been on the gravel, it would, perhaps, have settled to a trifling extent, but would, no doubt, have stood as well as all the other piers, which were founded entirely on the gravel; placed, however, partly on the rock, which was perfectly solid, and partly on the gravel, which slightly yielded beneath the great pressure upon it, the consequence followed as described above."

Case 2.—Bearing stratum affected by exposure to air or to water.

Soils of this character must be carefully protected from exposure, either by laying the foundations so deep as to be beyond the reach of summer heats and winter frosts, or by covering the bottom of the foundation-pit with a stratum of concrete. For want of these precautions, many buildings with shallow foundations on clay soils become rent and seriously injured by the contraction and expansion of the ground on which they rest.

Some soils, which are naturally so hard as to require blasting for their removal[a], rapidly disintegrate on ex-

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[a] Disintegration from Chemical Action.—Vide "Minutes of Proceedings of the Institution of Civil Engineers," March 26, 1844.—"Mr. Taylor believed that the mechanical action of water produced many of the effects which had been mentioned, but the chemical action upon clays, and even upon solid rocks, must not be overlooked. He would instance, particularly, the well-known action of the air upon shale, which, although so tough and hard under ground as to require the agency of gunpowder for its excavation, became, after a few weeks' exposure to the air, thoroughly decomposed.

"Decomposed granite, called by miners 'pot grawen,' was extremely troublesome in mines; it consisted principally of feldspar and potash, and was the China clay so much used in potteries. This substance would appear to have been formed by the decomposing action of the air, or of chemically-formed oxygen.

"Pyrites, which appear to have abounded in the strata of the New Cross cutting, not only had a natural tendency to decomposition when exposed to the action of the air, but also affected everything with which it was in contact.

"It had become fashionable to account for all changes by attributing them to the agency of electricity, and since the interesting researches of Mr. Fox, of Falmouth, there was much reason for believing that electricity was capable of producing these wonderful changes. It was easy to understand that as soon as chemical action began electricity might be generated; its flow would be conducted through the fissures and veins of mineral substances; decomposition of the existing material proceeded, and other forms were assumed; this action could not be continued without a corresponding alteration of the posure to the atmosphere, undergoing a chemical action which completely destroys their cohesion. It therefore requires considerable caution when laying foundations upon ground which is at all exposed, as, for instance, in throwing an arch over a railway cutting, to guard against this source of danger. Many of the beds in the lias formation, which when first opened have the appearance of hard rock, will run into sludge after being exposed for a short time to the atmosphere. We remember a striking instance of this kind, in which a railway contractor made use of a hard stratum of shale as ballasting, for which at first sight it appeared well adapted, but in the course of a short time it was nothing but a mass of mud, and was scraped off to make way for ballast of a more durable character.

As a general rule, when dealing with ground of this expansible and treacherous character, the less it can be exposed to the air, and the sooner covered up again, the better for the work.

Precautions of this nature are indispensable in cases where work has to be built against an upright face of expansible material, as in the execution of tunnels, sewers, retaining walls, abutments of bridges, and similar constructions, which are liable to be forced out of the upright by the lateral pressure of the soil, and much

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bulk of the mass, and when it reposed on an inclined bed, of which the surface was covered with a semifluid film, such as the London clay was described to be reduced to by the solvent effects of water, the slightest expansion or contraction would suffice to set the whole superstratum in motion, and to produce the slips.

"Primary rocks were subject to the same effects, and in sinking through porphyritic rocks, fissures were frequently found, filled with foreign matter, which swelled and forced in the sides of the shafts, when such an event was least expected; such occurrences could not be guarded against, as the direction of these fissures was usually parallel with that of the shaft."

practical instruction may be derived from the study of works of this nature[a].

Case 3.—*Bearing stratum underlying soft ground of considerable depth.*

In cases of this kind, where the expense of bringing up a solid foundation from the hard ground is too great to allow this to be done, a number of supports must be brought up through the soft ground, on which to form a platform to carry the superstructure. This may be done in a variety of ways, of which the following are those principally employed:—

1st. By excavating holes to the depth of the soft ground, and refilling them with sand, gravel, concrete, or some equally incompressible material. This system is scarcely known in this country, but has been much used on the Continent, the method usually followed being to drive down a timber-pile to the required depth, and then to withdraw it, and fill the hole with sand. Full details of the method of using sand in foundation works will be found in the "Annales des Ponts

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[a] Expansion of clay when exposed to the air.—Vide "Minutes of Proceedings," as above.

Mr. Hawkshaw said, "In the tunnel on the Manchester and Bolton Railway the timbers were frequently broken by the expansion of the clay, although it appeared quite dry."

Mr. Foster said, "In the Primrose Hill and the Kilsby tunnels, if the cutting was left for a few days without completing the brick arching, the timbers were broken. The expansion appeared to be nearly the same, whether it was caused by the air, as in the former case, or by the water, as in the latter instance."

Mr. Thomson remarked, "That in the Box Tunnel, it was usual to allow 6 inches for expansion between the face of the work and the timbers, and that space was scarcely sufficient."

Mr. J. Simpson "had seen, at Richmond, a well of 4 feet diameter completely closed in one night by the swelling-up of the bottom, although there was not any water in it."

et Chaussées" for the year 1835, and also in the fourth volume of the "Papers on Subjects connected with the Duties of the Corps of Royal Engineers," London, Weale, 1840.

2nd. By *driving* piles of wood or iron through the soft ground until they rest on the solid stratum.

3rd. By *screwing* piles into the ground until they reach the firm ground.

4th. By hollow cylinders of cast iron, *lowered* until they rest upon the bearing stratum, the soft material being removed from the interior of the cylinder to enable it to descend.

Under this head may be included all hollow piling, whether driven by impact, lowered by gravity, or forced down by atmospheric pressure, as in Dr. Pott's process.

Case 4.—*Crust of good ground resting on a treacherous substratum.*

In the treatment of all cases of this kind, it may be laid down as a general rule, that it is best to let well alone, and to abstain from all disturbance of the ground by ramming, driving piles, or similar expedients, simply taking precautionary measures to avoid any wounding of the good ground, or escape of the substratum. It need scarcely be said, that it is important to reduce the weight of the structure as much as possible, and to distribute it over a large area of bearing surface.

When the substratum is simply compressible, it may sometimes be brought to its extreme settlement by weighting the foundations before commencing the superstructure, which may afterwards be carried up without fear of subsequent movement.

If the substratum be soft soapy clay, care should be taken to avoid exposing it by cutting deep ditches or drains in the neighbourhood of the work, as this might cause extensive slips.

If the substratum be of sand, there will be probably little or no settlement so long as it remains undisturbed; but if exposed to the action of water no dependence can be placed upon such ground, as it will be always liable to be undermined. Thus a chimney might stand perfectly secure for many years upon a substratum of dry sand, and be undermined and destroyed in a few days by sinking a well near it, or even by laying in a drain at some considerable distance from its site. Thus, in the neighbourhood of salt works, the ground gradually sinks, from the pumping of the brine springs; this may be seen at Northwich, in Cheshire, to a very striking extent. We may here remark, that the numerous instances of failure which have at different times occurred from the escape of sand and loose ground from below buildings, which would otherwise have been perfectly secure, shows the great attention and care required in executing drainage-works in the neighbourhood of existing buildings.

Lastly, if the substratum be of a peaty nature, it will generally be seriously affected by drainage, and it will therefore be desirable to drain the site as perfectly as possible before commencing operations.

Many buildings about Moorfields, London, have undergone serious settlements during the last few years, in consequence of the morass from which the district takes its name having become thoroughly drained by the construction of new sewers. At the London Institution in Finsbury Circus, the outer walls were built on the substratum of gravel underlying the peat, whilst the inner walls rested on the peat itself, which, being prevented from spreading by the outer walls, formed a good bottom so long as it remained wet, but on the formation of the new sewerage they began to sink, and it was found necessary to underpin them with concrete, an operation which was skilfully and successfully performed.

This instance of failure affords an instructive lesson as to the insufficiency of sheet-piling round a building to prevent settlement, when the substratum is full of water, although a most valuable precaution in many cases.

CLASS I.

DIVISION B.—FOUNDATIONS UNDER WATER.

We have just been describing the leading cases occurring in building upon a natural bottom; we now come to the reconsideration of these cases, with the superadded difficulty of their occurring under water. In some cases it may be sufficient to bring up a number of isolated supports, and this is almost always practicable, except in the case of a rock bottom. In the majority of instances, however, nothing less than a solid foundation will meet the requirements of the structure. If the ground be not exposed to scour, and does not underly a soft stratum, we can safely lay our work simply *on* the ground, and this may be done under water by a variety of means. If, on the other hand, there is a liability to scour, or the firm ground is covered by soil which must be removed before commencing the work, it becomes necessary temporarily to exclude the water from the site of the foundation by means of caissons or cofferdams. In considering, therefore, the several methods adopted for executing hydraulic foundations, it will be convenient to class them under three heads, viz.:—

1. Pile foundations.
2. Foundations constructed *under* water.
3. Foundations from the site of which the water is temporarily excluded during the execution of the work.

Subdivision 1.—*Pile Foundations.*

Method 1.—*Timber Piling.*—Timber piles are objectionable when partly out of water, as they are liable to decay at the water-line. In tidal waters[a], also, timber is soon attacked by the worm, and becomes rapidly destroyed by its ravages. No certain preventive is as yet known for this evil; but saturation with oil of tar, by Mr. Bethell's process, is at present considered to be effectual, and has stood a trial of some years at Lowestoffe Harbour, without a single instance of failure. The use of timber piling is very general, and numerous examples will occur to the mind of the reader.

Method 2.—*Cast-iron Piling.*—Cast-iron piles may either be solid, their section being +, or hollow, either square or round. When hollow, the ground is usually removed by boring from the interior of the pile, to facilitate its descent, and by this means cast-iron piles can be driven into gravel or chalk with great facility. Cylindrical piles, driven into chalk, were used by Mr. Tierney Clarke in the construction of the Town Pier at Gravesend[b]. Square piles, driven into sand, were adopted by Mr. Simpson at the new pier of Southend, where they support an upper tier of wooden piles[c]. Solid piles of cast iron have been used in many places,

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[a] The action of the worm does not appear to be always confined to salt water.

[b] "Transactions of the Institution of Civil Engineers," vol. iii. part 3.

[c] "Minutes of Proceedings of the Institution of Civil Engineers," 1850.

amongst others in the foundation of a swing bridge over the river Wensum, at Norwich, on the line of the Norfolk Railway, by Mr. Bidder[a]. Cast-iron piling will not last for any considerable length of time in salt water, as it becomes gradually softened, so that it can be cut with a knife. This renders the employment of cast-iron piling in sea-works rather precarious.

Method 3.—*Screw-piling.*—This method of fixing piles has of late come considerably into use and has been applied to the construction of lighthouses in situations where all other methods would have failed. Screw-piles are exceedingly well adapted for obtaining a foothold in situations where an ordinary pile would fail, as, for instance, on a sandbank. A full account of Mr. Mitchell's invention, and of some of the most important works to which it has been applied, will be found in the "Minutes of Proceedings of the Institution of Civil Engineers" for 1848.

Method 4.—*Hollow cast-iron Cylinders.*—These may be considered as large hollow piles. They may be made to descend simply by gravity, the ground in the interior being excavated so as to allow them to descend by their own weight, or they may be forced down by atmospheric pressure, as in Dr. Pott's process[b]. Lastly, they

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[a] "Minutes of Proceedings of the Institution of Civil Engineers," 1846.

[b] An excellent notice of Dr. Pott's "Patent Pneumatic Apparatus for Sinking Foundations by means of Atmospheric Pressure in Deep Water, Movable Sands, Mud, Shingle, or Bog," is given in the Supplement to the Work on Bridges, in 4 Parts, published by Mr. Weale, from which we give the following extract:—

"This invention, which is the subject of a patent, is for improvements in the construction of foundations (under any of the circumstances mentioned above) for piers, embankments, breakwaters, or other similar constructions. It is equally applicable for the sinking of wells in analogous positions.

"It consists in the use of hollow tubes, usually of cast iron, of any size, and almost of any shape, which are sunk into their places by means of the atmospheric pressure. The lower extremity of the tube is open, and being placed upon the ground, of whatever nature it may be, the air, water, or semi-fluid material in the inside is extracted by pumps, or by any of the well-known means of producing a vacuum. It is usual to create this vacuum, or rather, more correctly speaking, to rarefy the air in the interior of the tubes, by placing them in communication with large vessels from which the air is previously withdrawn by means of a pipe and a stop-cock. As soon as the communication is effected, the air in the interior of the tubes rushes into the empty vessels, leaving the atmospheric pressure upon the pile-head without any counteracting resistance. If the strata to be traversed be of a yielding semifluid nature, they are also acted upon by the same cause, and flow up into the tube, or hollow pile, which at the same time descends with corresponding rapidity. The materials thus introduced are removed, or, if the strata be more resisting, they are thrown out, so as to attain the greatest possible rarefaction of the air, and the operation is repeated until the piles are fully driven. A succession of tubes may be placed upon the first by means of flanges, or other joints, so that they may be driven of any length required.

"The shapes of the tubes usually employed are either cylindrical, angular, or conical; they may be made to fit into one another so as to form a continuous close piling; or they may be made with grooves to receive plates, such as have been employed upon the river-walls of the Thames.

"Upon the first introduction of this invention, it was applied more as a means of driving hollow piles of the usual dimensions of wooden ones. Subsequent experience has led to a considerable modification in its use. The fact that the atmospheric pressure is in the proportion of the surface exposed to its action has induced the patentees to increase the diameter of the piles gradually, until at length they have ceased to act in a manner such as we are accustomed to consider the latter to act."

Dr. Pott's process seems well adapted for sinking piles or caissons through a soft stratum to a hard one, and is being adopted in several large works at present uncompleted. It does not come within the province of this volume to pass any opinion upon the merits of an invention which as yet is quite in its infancy, but we would advert to a few points which appear important. If the stratum to be passed through be tolerably firm, it will, in ordinary cases, be better to *bore*, and to sink the cylinders by dead weight. If the substratum be of clay, or other compressible material, it will be necessary, after sinking the caissons to the intended depth, to weight them with a load at least equal to that which they are intended to support, as the greatest pressure that can be brought upon the top of the caissons by the exhaustion of the air does not exceed one ton per superficial foot, which is far less than the weight often thrown upon pile foundations. It is also questionable how far the cutting edge of the bottom of the caisson may facilitate its settlement may be *screwed*[a] into the ground in the same way as a

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when loaded with the weight of the superstructure, and whether the system may not from this cause be found inferior to that of cylinders with bottom flanches *screwed* into the ground under Mr. Mitchell's patent. It may be not uninteresting to our readers to give a brief notice of a system successfully employed in France for sinking through a quicksand, which is precisely the opposite to that of Dr. Pott's.—Vide Dr. Ure's "Dictionary of Arts, Manufactures, and Mines," Supplement, art. "Ventilation."

"These striking results, obtained on one individual at a time, with a small experimental apparatus, have been recently reproduced, on a working scale, with many persons at once enclosed in a mining shaft, encased with strong tubbing formed of a series of large sheet-iron cylinders riveted together, and sunk to a great depth through the bed of the river Loire, near Languin. The seams of coal in this district of France lie under a stratum of quicksand, from 18 to 20 metres thick (20 to 22 yards), and they had been found to be inaccessible by all the ordinary modes of mining previously practised. The obstacle had been regarded to be so perfectly insurmountable that every portion of the great coal basin that extends under these alluvial deposits, though well known for centuries, had remained untouched. To endeavour by the usual workings to penetrate through these semifluid quicksands, which communicate with the waters of the Loire, was in fact nothing less than to try to sink a shaft in that river, or to drain the river itself. But this difficulty has been successfully grappled with through the resources of science boldly applied by Mr. Triger, an able civil engineer.

"By means of the above frame of iron tubbing, furnished with an air-tight ante-chamber at its top, he has contrived to keep his workmen immersed in air sufficiently condensed, by forcing pumps, to repel the water from the bottom of the iron cylinders, and thereby to enable them to excavate the gravel and stones to a great depth. The compartment at top has a man-hole door in its cover, and another in its floor. The men, after being introduced into it, shut the door over their heads, and then turn the stop-cock upon a pipe in connection with the condensed air in the under shaft. An equilibrium of pressure is soon established in the ante-chamber, by the influx of the dense air from below, whereby the man-hole door in the floor may be readily opened to allow the men to descend. Here they work in air, maintained at a pressure of three atmospheres by the incessant action of leathern-valved pumps driven by a steam-engine. Whilst the dense air thus drives the waters of the quicksand communicating with the Loire out of the shaft, it infuses, at the same time, such energy into the miners that they can easily excavate double the work without fatigue which they could do in the open air."

[a] This method of using cylinders appears likely to be very successful. As

screw-pile. When the cylinders are of large dimensions, they are usually filled up with concrete or brickwork, and may be considered as caissons rather than piles.

Subdivision 2.—Solid Foundations laid under Water.

Method 1.—*Pierre perdue, or Random work.*—This method consists in throwing masses of stone into the

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yet, we believe, the only published notice of the system is a short note to the account of Mr. Mitchell's system of screw-piling, in the "Minutes of the Proceedings of the Institution of Civil Engineers," 1848, just referred to, and from which we extract the following particulars:—

"Mr. Brunel has recently caused a very interesting and conclusive experiment to be tried, near the proposed site of the bridge for carrying the South Wales Railway across the River Wye, at Chepstow.

"A cast-iron cylinder, 3 ft. diameter externally, 1½ inch in thickness, cast in lengths 10 ft. each, with internal socket and joggle joints, secured with pins and run with lead, was armed at the extreme bottom with a sharp wrought-iron hoop, and a little above it was a helical flanch projecting 12 inches all round from the body of the cylinder, around which it made an entire revolution with a pitch of 7 inches. By means of capstan-bars, worked by manual labour, and by strong winches, this cylinder was screwed into the ground, near the bank of the river, but out of the influence of the tide, to a depth of 58 feet, in 48 hours and 14 minutes, through stiff clay and sand, down to the marl rock. In descending to that depth, the cylinder made one hundred and forty-two revolutions, and the average rate of sinking per revolution very nearly accorded with the pitch of the screw. The time quoted is only that which was actually consumed in forcing the cylinder down, as it was allowed to rest for long periods, whilst the interior core of clay was repeatedly cleared out, and on account of the breakages of the ropes and the capstan-bars, and other casualties incidental to all first experiments. In spite of the great surface exposed to lateral friction, the cylinder was always started again with comparative ease, and its progress downwards was very uniform.

"It is the intention of Mr. Brunel to try a cylinder 6 feet diameter, with a large helical flanch or screw, before deciding upon the dimensions of the cylinders for the foundations of his bridges, to be placed in situations where there is a great depth of mud, stiff clay, and sand. Of this and the subsequent experiments, accounts may probably be given hereafter, by Mr. Brunel's permission. August, 1848."

water, and leaving them to arrange themselves. This is not a system of construction that can be adopted in rivers, where it is of consequence to avoid contracting the waterway, but is made use of in sea-works, for the construction of breakwaters, jetties, and like constructions. It is, however, not to be depended on in situations exposed to the run of the sea, as a base for any permanent erections, as wharf walls, lighthouses, &c., the more exposed parts of the work being liable to dilapidation, and requiring continual renewal. The two most celebrated instances of this system of construction are the Cherbourg[a] and Plymouth[b] breakwaters, the respective histories of which are full of interest and instruction.

Method 2.—*Random blocks of béton.*—The insecurity attending works erected on a foundation of *pierre perdue* led the French engineers engaged on the harbour works at Algiers to substitute for the ordinary-sized blocks of stone previously used, large masses of béton, of such size as to be immovable by the waves. The force of a blow given by a wave depending on the surface exposed to its violence, whilst the resistance offered by the mass increases as its weight, there will always be a limit to the moving force of the waves.

Except in some few special cases, it is practically impossible to employ stones sufficiently large to fulfil this condition; but there are few situations where it is not possible to manufacture artificial blocks of béton, of from 10 to 20 tons weight, which may with great ease be floated to the spot where they are to be immerged.

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[a] "Description des Travaux Hydrauliques de Louis Alexandre de Cessart, Doyen des Inspecteurs Généraux des Ponts et Chaussées." Paris, 1808.

[b] "Account of the Breakwater in Plymouth Sound, by Sir John Rennie." London, Weale, 1848.

The new mole at Algiers is a successful example of this mode of construction on a large scale. The reader may consult, with great advantage, in reference to this subject, M. Poirel's account of the new works at Algiers[a], which is, in fact, a complete treatise on the subject of submarine foundations.

Method 3.—*Béton laid in caissons lined with tarpaulin.*—This method of using béton has been recently brought into notice by its adoption in portions of the works at Algiers, and is exceedingly well adapted to forming foundations on a rugged rock bottom in shallow water, where it is desirable that the work should be brought up with a face vertical, or nearly so, to avoid contracting the waterway, or to allow vessels to come alongside a wharf.

The caisson employed is a large box, without bottom or top, the sides of which are roughly cut to suit the irregularities of the rock on which it is placed. It is lined with tarpaulin, which is allowed to adapt itself freely to the bottom, and prevents all danger of the newly laid béton being injured by the action of bottom springs, or by the run of water through the cavities left between the rock and the sides of the caisson. The béton is lowered to the bottom of the caisson in a box with a movable bottom, by which contrivance it is deposited in a solid mass, without any risk of the lime being washed out, which is always more or less the case when concrete or béton is dropped *through* water without any protection of this kind. When the mass thus formed by successive deposits reaches the surface of the water, it is left for some days to become hard; and when this

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[a] "Mémoire sur les Travaux à la Mer, comprenant l'historique des ouvrages exécutés au Port d'Alger, et l'exposé complet et détaillé d'un système de fondation à la mer au moyen de blocs de béton. Par M. Poirel, Ingénieur-en-chef des Ponts et Chaussées." Paris, 1841.

has taken place, the sides of the caisson are removed, and the cloth lining cut away, to be used again in the formation of the next length.

This method of constructing foundations appears especially adapted to the case of an uneven rock bottom, in situations where the construction of a water-tight cofferdam, and the levelling of the rock to receive regular masonry, would be attended with heavy difficulty and expense.

Method 4.—*Solid masonry laid on the natural bottom, with the aid of the diving-bell.*—This is an extensively used method of forming submarine foundations, and is very successful where there is no danger of scour, and where the bottom can be readily brought to a level surface. By means of travelling-cranes, moving on tramways erected over the site of the work, each stone can be lowered to its place, and its position verified by the diving-bell, with as much precision as on dry land. If the situation of the work does not afford stones of sufficient weight to withstand the shock of the waves, masses of béton may be used instead.

Subdivision 3.—*Foundations from the Site of which the Water is temporarily excluded.*

Method 1.—*Solid masonry sunk in caissons, or chests of timber, of which the bottoms rest on the surface of the ground.*—This system of forming foundations is now but little used, on account of the difficulties with which it is attended. If the ground be soft or loose, the foundation is liable to be undermined; if it be hard, there is great difficulty in forming a level bottom, and the cross strain thrown in consequence upon the unsupported parts of the timbers leads to fractures and dangerous movements in the superstructure, as in the well-known case of Westminster Bridge.

Method 2.—*Masonry built in caissons grounded upon a bed of béton.*—This is a method of using caissons which is quite free from the objections just named. If there be any liability to scour, the ground must be dredged out to a sufficient depth before putting in the béton. This system of construction is used on the Continent, but as yet is little if ever practised in this country.

Method 3.—*Masonry built in caissons resting on a pile foundation.*—This is a very economical system of construction, and well adapted to situations where there is a liability to scour, or where the bearing stratum is at a considerable depth. The piles, having been driven down until a firm bottom is reached, are cut off to a uniform level as near the ground as possible, and the caisson is lowered upon them, the timbers forming the bottom of the caisson being disposed so as to rest on the pile-heads. This method of forming foundations is not extensively practised, but it has been adopted with great success by Mr. Rendel in the Lary Bridge at Plymouth[a]. The foundations of a handsome railway bridge over the Meuse at Liege[b], in Belgium, were also constructed in this manner.

Method 4.—*Foundations laid in the interior of a cofferdam.*—A cofferdam may be defined as a water-tight wall constructed round the site of any work, for the purpose of laying dry the bottom, by pumping out the water from the inclosure thus formed. Cofferdams are now used in foundation-works to a great extent; they are usually constructed of timber piles driven close together in rows round the site of the work, the space between the rows being filled with puddle. The number of rows of piles, and the thickness of the puddle-wall, must depend on the situation of the work, but in

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[a] "Transactions of the Institution of Civil Engineers," vol. i. Weale.

[b] "Railways of Belgium." Weale.

ordinary practice dams are usually made much too slight for their intended purpose, through the mistaken economy of contractors, to whose discretion all *temporary works* are usually left in this country. In the last chapter of this volume the reader will find descriptions of some of the best examples of cofferdams that have been constructed in this country, to which we refer him for the practical details of the subject.

Portable cofferdams are sometimes used with advantage in particular situations.

Cast-iron grooved sheet-piling has been also adopted with much success for cofferdamming in shallow water.

CLASS II.

FOUNDATIONS ON AN ARTIFICIAL BEARING STRATUM.

DIVISION A.—ORDINARY FOUNDATIONS.

Case 1.—*Ground soft but not fluid.*

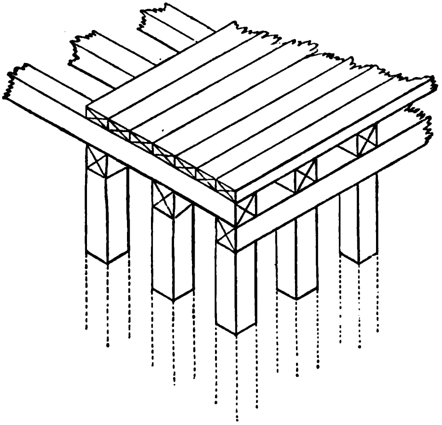
We may treat ground of this kind in two very different ways:—

1st. We may consolidate the soft ground by driving piles into it until it becomes so compressed that the piles are prevented from sinking by lateral friction.

2nd. We may interpose a platform of fascines, timber, or concrete, between the surface of the ground and the superstructure, thus distributing the weight of the latter over a large extent of bearing surface.

These methods are often combined; a very usual method of proceeding is to surround the site of the work with sheet-piling, to prevent the escape of the ground, which is then consolidated by driving piles into it at short distances from each other. The piles are then sawn off level, the ground between them removed for 2 or 3 ft. deep, the excavation filled up with concrete,and the whole is then planked over to receive the masonry of the superstructure. Sometimes the planking is laid, not on the heads of the piles, but on a network of horizontal timbers, as shown in fig. 2. The practice of

Fig. 2.



driving piles into soft ground to consolidate it, is not one to be recommended; its effect being usually to pound up the soil, and to bring it into a state which can best be described by comparing it to batter-pudding. Instead of *driving* piles in these cases, a much better plan is to *bore* holes with a large auger to a considerable depth, and to fill them with sand, which, from its property of acting almost as a fluid, is a most valuable material for distributing pressure over a large area of surface. In the case of a timber pile, the pressure is transmitted only in the direction of its length, but a sand pile transmits the pressure laid on it, not only to the bottom, but to the sides of the excavation, and does not injure the ground by vibration. In many soils, where the ground is too soft to carry the weight of the walls of a building without artificial aid, a wide trench filled with dry sand will be found a more effective precaution against settlement than the use of timber planking, concrete, or any other expedient which simply distributes the pressure in a vertical direction.

Case 2.—*Soil of a semifluid nature, as Mud, Silt, or Peat.*

Cases of this kind occur chiefly in navigation and drainage works, and are exceedingly difficult to treat successfully. The principle to be kept in view is the formation of a firm platform, on which the work shall be allowed to float, as it were, on the fluid soil, into which it will sink to a considerable depth. This must be allowed for in the construction of the work, and, if possible, the foundation should be weighted to the full weight of the superstructure before the latter is commenced, so as to avoid any considerable movements after the completion of the work. In this country timber platforms are usually adopted in works of this nature; in Holland, platforms of fascines are employed as will be presently described. The great point to be attended to is the equal distribution of the weight of the structure over the foundation, which will then settle in a vertical direction, and cause little injury, whilst any irregular settlement would rend the work from top to bottom.

CLASS II.

DIVISION B.—FOUNDATIONS UNDER WATER.

We now come to the consideration of the most difficult class of foundations, viz., those of hydraulic works in soft alluvial soils.

If the ground be tolerably firm, we may enclose it with a dam; but in this method of proceeding there is always great danger of the bottom being lifted[a] by the pressure of the water, and it is generally necessary to weight the ground with planking and stones to prevent accidents. Sometimes it may be advisable to execute

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[a] Vide "Memoir of the Canal of Exeter," "Minutes of Proceedings of the Institution of Civil Engineers," 1845, from which we extract the following notice of the method adopted for overcoming the difficulties arising from the *lifting* of the ground.

"The excavation for the entrance lock at Turf proceeded very favourably through a stiff alluvial clay without water to a depth of nearly 20 feet below the surface of the marshes, when, on the occasion of a pile being driven to ascertain the depth at which a harder foundation would be obtained, water forced its way up around the pile, and the following morning, the sides of the excavation were found to have sunk perpendicularly at least 10 feet, and the bottom of the lockpit had risen to a greater height than the sides, exhibiting on its surface peat, moss, roots of trees, and a great variety of marine plants, rushes, fern, &c., but with very little water. It was, however, now evident that there would be much water to contend with in sinking to the required depth for the foundation. In order to accomplish this, a complete close kerbing of whole timber piles was driven, enclosing a space for the invert and the side walls of the lock; these piles were well strutted by transverse whole timbers. The excavation was then made, and the lock was founded in short lengths between the transverse struts. It was presumed that the pressure of water from the tide without the lock would have a tendency to force up and raise the invert and the gate platform; several flues, formed of elm plank trunking, were therefore laid in the rubble masonry, which formed the bed for the invert; these flues were carried under and throughout the lock, and terminated in a vertical well beyond the upper gates of the lock; thus the subwater was allowed to circulate, and to rise without obstruction to a corresponding height with the tide. This had the desired effect*, for the platforms never exhibited any tendency to rise, and there was no settlement in the masonry.

"Mr. Telford, who saw this work in progress, declared he had never seen so troublesome a foundation, and he highly approved of the method adopted for preventing the upward pressure of the subwater."

* It is not easy to understand the precise object of these precautions, as the upward pressure would remain unaffected by them.

the work in small portions, completing one division before the excavation for the next is commenced.

When the ground is semifluid, the formation of a cofferdam becomes impossible. The most effectual method of proceeding is to sink the work in large caissons, the bottom having been first covered with a bed of fascine work, weighted with stones or brickwork, and sunk on the site of the work. These fascine beds are much used by the Dutch in their hydraulic works, and are sometimes of large dimensions, and several feet in thickness; they are formed of bundles of fascines crossing each other at right angles, securely bound with tarred rope, and strengthened with poles and wicker bands. These platforms are weighted with gravel and broken stone, and sunk by means of guide-ropes in the required situation, where they are secured by long stakes and piles driven through them. A very excellent account of the "Art of Building with Fascine Work," is given in the "Minutes of Proceedings of the Institution of Civil Engineers" for 1847, from the pen of Mr. G. B. Jackson, to which we would refer the reader who is desirous of studying the subject in detail.

The foregoing brief sketch may be regarded as an outline of the general principles of "foundation works," the filling up of which must be supplied by the student from personal observation, and from the records of executed works. It is by studying the accounts of difficulties successfully overcome by others that the young engineer is best enabled to prepare himself for the obstacles which are sure sooner or later to beset his own career, whilst the failures of men eminent in their profession teach him humility, and impress on his mind the necessity for patient investigation and untiring perseverance if he wish to master a subject, the difficulties of which are ever on the increase with the growing requirements of commercial enterprise, in spite of all the facilities afforded by the science and mechanical skill of the nineteenth century.

In the chapter we are now bringing to a close we have called the reader's attention simply to general principles, without entering upon mechanical details more than was unavoidably necessary; in the succeeding chapters we propose to examine the practical details connected with the execution of foundations, so far as the scope of a rudimentary treatise will allow. To give an account of all the different systems of construction that have from time to time been proposed, or even of all those actually in use at the present day, would lead us far beyond our limits; we have therefore selected for illustration a few leading heads, the study of which will form a good preparation for the commencement of that self-education by which alone the student can make himself master of any branch of knowledge.

The subjects referred to are as follows, viz.:—Footings; Timber Platforms; Sand, Concrete, and Béton; Pile Driving; Caissons; and, lastly, the construction of Cofferdams. To each of these heads we propose to devote a separate chapter.

CHAPTER II.

ON FOOTINGS.

In commencing the erection of a building it is usual to spread the bottom courses of the masonry considerably beyond the face of the superincumbent work. These spread courses, or, as they are more technically called, footings, answer two important purposes:—

1st. By distributing the weight of the structure over a larger area of bearing surface, the liability to vertical settlement from the compression of the ground is greatly diminished.

2ndly. In the case of isolated structures standing on a comparatively small base, they form a great protection against the danger of the work being thrown out of the upright by the action of the wind.

Let us take, for instance, the case of a chimney stalk 100 feet high, standing on a base 10 feet square, and exposed to heavy gales. The compression of the ground to leeward to the extent of 0·025 ft. would be sufficient to cause the top of the stalk to overhang 6 inches. If, however, we increase the base to 20 ft. square, we not only double the leverage with which the foundation resists the force of the wind, but the bearing surface is quadrupled, so that the total resistance is 8 times greater than in the first instance.

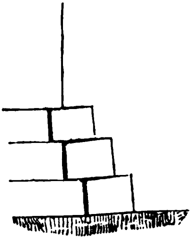
It need scarcely be said that for footings to have any useful effect, they must be securely bonded into the body of the work, and of sufficient strength to resist the violent cross strains to which they are exposed.

The common practice of builders, whether the materials be brick or stone, is unfortunately very faulty in these respects; and to neglect in this matter may be attributed many unfortunate failures and settlements in works otherwise well executed.

Let us first consider the case of stone foundations.

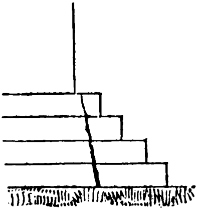
1st. It should be remembered that the lower any stone is placed in a building the greater weight it has to support, and, therefore, the greater the risk arising from any irregularities in the working of the beds, which should be dressed perfectly true, and with as much or even greater care than in the upper part of the work.

Fig. 3.



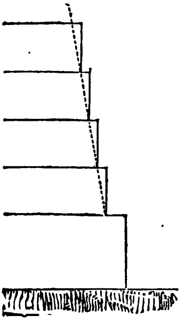
2nd. No back joints should be allowed beyond the face of the upper work, except where the footings are in double courses, and every stone should bond into the body of the work several inches at least. Unless this is attended to, the footings will not receive the weight of the superstructure, and will be useless. (See fig. 3.)

Fig. 4.



3rd. In proportion to the weight of the superstructure the projection of each footing course beyond the one above it must be reduced, or the cross strain thrown on the projecting portion of the masonry will rend it from top to bottom, as shown in fig. 4.

Fig. 5.



In building large masses of work, such as the abutments of bridges, and the like, the proportionate increase of bearing surface obtained by the projection of the footings is very slight, and there is generally great risk of the latter being broken off by the settlement of the body of the work. It is therefore usual, in these cases, to give very little projection to the footing courses, and to bring up the work with a battering face, or with a succession of very slight set-offs. (See fig. 5.)

Footings of undressed rubble built in common mortar cannot be too much reprobated, as the compression of the mortar is sure to cause movements in the superstructure. A much safer way of using rubble is to break it up tolerably small, and lay it in the trenches *without* mortar, as it forms a hard unyielding bottom so long as it is prevented from spreading laterally by the pressure of the ground. Where the building material is small rubble, the best way of proceeding is to lay the foundations with cement mortar, so that the whole will form a solid mass; in which case the size, shape, and dressing of the stone is of little consequence.

In building with brick, the great point to be attended to in the footing courses is to keep the back joints as far as possible from the face of the work, and in ordinary cases, the best plan is to lay the footings in single courses; the outside of the work being laid all headers, and no course projecting more than ¼ brick beyond the one above it, except in the case of 9 in. walls.

If it be wished to introduce more longitudinal bond into the work, the courses must be double, the heading course above, and the stretching course below (see figs. 6, 7, 8, and 9).

Fig. 6.

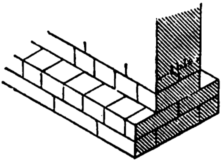


Fig. 7.

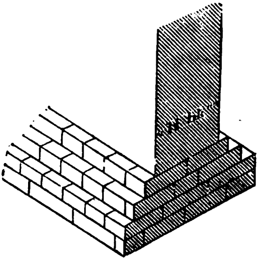


Fig. 8.

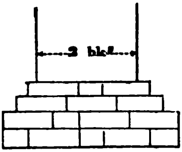
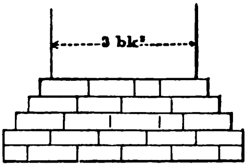


Fig. 9.



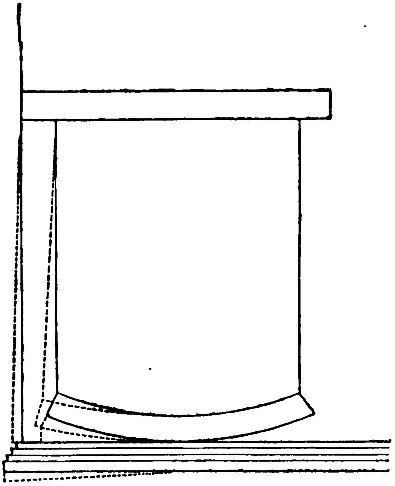
It is scarcely necessary to add, that the bricks used for footings should be the hardest and soundest that can be obtained. It is desirable that the bottom course should in all cases be a double one.

Too much care cannot be bestowed upon the footing courses of any building, as upon them depends much of the stability of the work. If the bottom courses be not solidly bedded; if any rents or vacuities are left in the beds of the masonry; or, if the materials themselves be unsound or badly put together; the effects of such carelessness are sure to show themselves sooner or later, and almost always at a period when remedial efforts are useless.

Before leaving the subject of footings, it may be desirable to notice an injudicious method of using inverted arches under openings, which often leads to serious evils. Inverted arches should only be used where there is a proper abutment for them on *both* sides. If used at the quoins of a building, as shown in fig. 10, the effect of any settlement will be to throw the quoin out of the upright, as indicated in an exaggerated manner by the dotted lines. An instance of this lately came under the author's notice, in which it was necessary, in order to save the building, to cut out portions of the arches.

In cases where the ground is soft, and a large extent of base is requisite, the expense attendant on spreading

Fig. 10.



out the solid work to the requisite extent renders it necessary to adopt some cheaper method of proceeding. Three methods may be mentioned:—1st. To put in a wide footing course, so to speak, of timber, which, from the nature of the material, may be safely carried to a considerable distance beyond the masonry without any fear of injury from cross strain. 2nd. We may put in a layer of concrete, which may be considered as a footing course of artificial stone, having, however, but little transverse strength, and, consequently, requiring the depth of the stratum to be carefully proportioned to its projection; and, lastly, we may build upon a layer of sand, or similar material, which, pressing against the sides as well as against the bottom of the foundation-pit, distributes the weight of the superstructure over a large resisting surface. We shall examine each of these methods in the two succeeding chapters.

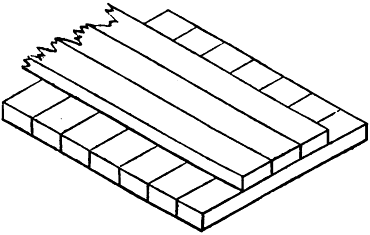
CHAPTER III.

ON PLANKING.

In erecting buildings on soft ground, where a large bearing surface is required, planking may be resorted to with great advantage, provided the timber can be kept from decay. If the ground be wet and the timber good, there is little to fear, but in a dry situation, or one exposed to alternations of wet and dry, no dependence can be placed on unprepared timber. We do not here propose to enter upon any examination of the relative premerits of the different processes employed in the preservation of timber. The systems most in use are those known respectively as Kyanizing, Paynizing, and Creosoting. Whatever method is employed, care should be taken to effect the process strictly according to the directions of the patentees, otherwise no dependence can be placed upon the results.

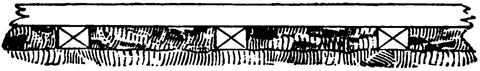
The advantage of timber is that it will resist a great cross strain with very trifling flexure, and, therefore, a wide footing may be obtained without any excessive spreading of the bottom courses of masonry. The best method of employing planking under walls is to cut the stuff into short lengths, which should be placed *across* the foundation, and tied longitudinally by longitudinal planking laid to the width of the bottom course of masonry, and firmly spiked to the bottom planking. (See fig. 11.)

Fig. 11.



A common method of planking foundations is shown in fig. 12; the space under the planking being intended to be well rammed. There is, however, so much risk of this being done in an imperfect manner, that it is much better to have the ground flushed up with concrete to the top of the sleepers, so that the planking may rest on a solid level surface.

Fig. 12.



In planking foundations of considerable extent, such as those of the abutments of a bridge, it is better to lay the planking in two thicknesses, crossing joint and spiked together, and laid crossing the courses of the masonry diagonally. This makes sounder work than if the joints of the planking were parallel to those of the masonry.

CHAPTER IV.

SAND, CONCRETE, AND BETON.

We have, at the head of this chapter, named, in the relative order of their value as artificial foundations, three methods of forming a hard bearing stratum for distributing the weight of a building over a large area of compressible ground, or for bringing up a solid foundation from a considerable depth where there are objections to the use of masonry or timber for effecting that object.

Sand.—The use of sand, and its value as a means of distributing weight, has been known from a very early period, but it has been very little, if at all, adopted in this country.

It may at first sight seem paradoxical that a loose substance, such as sand, having no cohesion amongst its particles, and proverbial for its instability, should be of any use as a material for foundations, especially when we consider that it is very similar to a fluid, and, if unsupported, can scarcely be made to stand at any slope whatever. It is, however, to these very qualities that it owes its value, which consists in distributing the weight laid upon it, not only in a vertical, but in a horizontal direction, the lateral pressure exerted against the sides of the foundation-pit greatly relieving the bottom. In very soft ground, it need scarcely be said, this system of construction cannot be adopted, as the sand would work itself gradually down; but in all situations where the ground, although soft, is of a tolerable consistency, so that the sand is confined, the use of this material is attended with many advantages as regards both the cost and the stability of the work.

The most complete published account of the use of sand in foundations will be found in the "Annales des Ponts et Chaussées," for the year 1835, before referred to, which goes into the subject in great detail. From this account, and from the fourth volume of "Papers of the Royal Engineers," we learn, that not only is it in use in India and in Surinam, where it is often recommended as the only method of forming a foundation in bad soils, but that it has been adopted in works at Geneva, Bayonne, and Paris, and probably many other places.

There are two methods of using sand, viz., in layers and as piles. In forming a *stratum* of sand, the soft ground should be taken out several feet in depth, and the sand well rammed as it is thrown in, so as to ensure its being thoroughly forced into the sides of the foundation-pit; after which there will be very little, if any, risk of irregular settlement. The surface of the sand may be protected in a variety of ways—by planking, paving, or otherwise, according to the nature of the materials at hand; but care should of course be taken to lay the masonry of the superstructure at sufficient depth to prevent all risk of scour from surface water, or from any other accidental source of injury.

Sand piling is a very economical and efficient method of forming a foundation under some circumstances where timber piling is usually resorted to in this country. It would not, however, be effective in very loose wet soils, as the sand would work into the surrounding ground. Sand piling is executed by driving wooden piles to a short depth, and then withdrawing them and filling up the holes with sand, which should be well punned, so as to force it well into every vacuity. In situations where the stability of piles arises from the pressure of the ground round them, these sand piles are found to be of more service than timber ones, and for the following reason:—A wooden pile can merely transmit pressure in a vertical direction, and, consequently, exerts no lateral thrust upon the ground through which it passes, except whilst it is being forced down; but a sand pile acts in a different manner, transmitting pressure not only against the bottom but against the sides of the hole it fills, and thus acting on a large area of bearing surface.

The treatment of the ground above the piles is very simple. It should be covered over with planking, concrete, or masonry, to prevent its being forced up by the lateral pressure exerted by the piles; and, on the stratum thus formed, the superstructure may be built in the ordinary manner.

A layer of small broken stone, gravel, burnt clay, ballast, or any similar hard material, will be found also of great service when distributed over the area of a foundation. Indeed it may fairly be questioned, whether a great proportion of the concrete foundations in this country made with chalk lime, or with very weak water limes, do not act by transmitting the pressure of the structures laid on them against the sides of the foundation-pits rather than by their resistance to cross strain, although they may become in time thoroughly consolidated. Our own experience leads us to feel that, unless the lime used in the composition of concretes is such as to ensure the formation of a mass which shall at once become firm and solid throughout, it will be better, under ordinary circumstances, to use the gravel in a loose state, merely punning it to force it thoroughly into the sides of the trenches. If this view be correct, much expense is often incurred in making bad concrete, where a layer of broken stone, or gravel, would be cheaper and more effective; and we would especially recommend those of our readers who may have opportunities of examining concrete foundations which have been only a short time executed, to do so with especial reference to this point, which is of considerable importance.

Concrete.—Concrete[a] is an artificial conglomerate, or pudding-stone, in which the pebbles which make up the greater part of its bulk are cemented together by

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[a] It may be necessary to remind the reader that the term "concrete" is here applied exclusively to that made of gravel concreted with chalk lime or weak stone lime.

lime mortar. As generally made, concrete is nothing more than a weak artificial stone, possessing little strength when exposed to transverse strain, even when the cementing material is thoroughly hard, which it may be fairly presumed, in most cases, does not take place for many months, if at all, although the outer crust may become firm in the course of a few hours. It is, therefore, the most prudent course, in putting in a concrete foundation, to force the concrete into the trenches, ramming it continually, so that it shall exert considerable lateral pressure. It is a common practice with contractors to make the concrete course exactly of the specified width, irrespective of the extent to which the trenches have been excavated, and where any vacuities occur, to keep up the concrete temporarily with boarding, which is removed as the concreting advances, and the vacant space is filled with loose earth, and punned or not as the chance may happen. This is a most improper practice, and would often lead to serious failures, from the crushing of the weak and newly-formed concrete, were it not that in most cases the strength given to the foundations of our important works is greatly in excess of that required to resist this effect. It is, therefore, desirable, in drawing up specifications for concrete works, to require that the whole extent of excavation should be filled in with concrete, and that, if the trenches are got out too wide, they must be filled up with concrete at the contractor's expense. If the sides of the foundation-pits are carefully trimmed, and the concrete punned up solidly against them, the success of the work will be in a great measure independent of the cementing properties of the lime, and the gradual consolidation of the mass will be an *additional* source of security.

Another practice, which we cannot too strongly condemn, but which has the sanction of many professional men of high standing, is that of throwing the concrete into the foundation-pits from a raised stage, with a view to consolidate it. Our own experience confirms us in the opinion that the contrary effect is produced, and that this practice not only tends to separate the particles which have been previously brought into close contact, but that the admission of the air into the mass renders it less compact, and tends to prevent the lime and sand from properly entering into combination with each other. We ourselves prefer to tip the concrete from the barrow as close to the surface as possible, and to keep it constantly punned as the work proceeds, so that no vacuities shall remain in any part. We also prefer that it should be brought up in successive layers, not exceeding 12 inches thick, the wheelers working gradually round the whole area, and being followed by the punners, so that no vertical junctions exceeding 12 inches in height can occur at any point, and the whole mass is more likely to be homogeneous than if the work is commenced at its full thickness and driven forward, which is certainly in most cases the easiest way of proceeding.

Concrete is a valuable material when applied in a proper manner, viz., in underground works where it is confined on all sides, and is, consequently, subjected to little cross strain; but it is not fit to be used *above* ground as a substitute for masonry, and will not bear exposure to water.

Mr. Burnell, in his " Rudimentary Treatise on Limes, Cements, and Mortars," has given such admirable directions for the composition of concretes and bétons, that it is unnecessary for us here to enter into much detail on the subject; a few remarks may, however, be acceptable to the reader who may not have Mr. Burnell's work at hand to refer to.

Concrete is made of gravel, sand, and ground lime, mixed together with water; the slaking of the lime taking place whilst in contact with the sand and gravel. It is difficult to give any definite proportions for the several ingredients, but the principle to be followed in proportioning the several quantities of sand and stones should be to form as much as possible a solid mass, for which purpose it is desirable that the stones should be of various sizes, and angular rather than rounded. The common material is unscreened gravel, containing a considerable portion of sand and large and small pebbles, but small irregular fragments of broken stone, granite chippings, and the like, are of great service, as they interlace each other and bond the mass together. The proportion of lime to sand should be such as is best suited to form a cement to connect the stones. This must depend in a great measure on the quality of the lime used; the pure limes requiring a great proportion of sand, whilst the stone limes, and those containing alumina, silica, and metallic oxides, require a much smaller proportion.

The lime chiefly used near London for making concrete is stone lime from Merstham, in Surrey, which has slightly hydraulic qualities. The most usual proportions adopted by London architects are about $\frac{1}{7}$ of ground stone lime to $\frac{6}{7}$ of unscreened Thames ballast, or good clean gravel.

The lime and gravel should be thoroughly incorporated by being repeatedly turned over with shovels, sufficient water being added to ensure the thorough slaking of the lime without drowning it. Concrete should not be thrown into water, because ordinary stone lime will not set under such circumstances; and it should be carefully protected from any wash or run of water, which would have the effect of washing out the lime, and leaving the concrete in the state of loose gravel. Concrete made in the way just described swells slightly before setting, from the expansion due to the slaking of the lime, and does not return to its original bulk. This property makes it valuable for underpinning foundations and similar purposes.

Béton.—Béton may be considered as hydraulic concrete; that is, concrete made with hydraulic lime; and is chiefly used in submarine works, as a substitute for masonry, in situations where the bottom cannot be laid dry. It differs from ordinary concrete inasmuch as the lime must be slaked before mixing with the other ingredients, and it is usual to make the lime and sand into mortar before adding the stones. Concrete also is used hot, whilst béton is allowed to stand before being used, in order to ensure the perfect slaking of every particle of lime. Belidor directs that the mortar shall first be made, with pozzuolana, sand, and quicklime. When the mortar is thoroughly mixed, the stones are to be thrown in (not larger than a hen's egg), and also iron dross well pounded; the whole is then to be thoroughly incorporated, and left for twenty-four hours. The proportions are to be as follows:—

Pozzuolana .	12	parts.
Sand	6	,,
Good quicklime	9	,,
Small stones .	13	,,
Ground slag .	3	,,
	43	

The béton is to be lowered into the water in a box, with a bottom so constructed that it can be opened, and its contents discharged, by pulling a cord, so as to deposit the béton on the bottom without having to fall through a depth of water, which might wash away the lime. For the same reason it is necessary, before commencing to lay the béton, to surround the site with sheet-piling, to protect it from the action of the water, and to guard against the danger of the softer portions of the work being carried away by tempests before they become consolidated.

The ordinary method of using béton on the Continent is in alternate layers of béton and rubble stone. A layer of béton, about a foot in thickness, is first spread over the whole area of the foundation, and on this is laid a stratum of rubble, which, sinking into the soft béton, becomes thoroughly incorporated with it. On this is laid another layer of béton, followed by another course of rubble; this system being pursued until the work reaches the intended height.

At the harbour works of Algiers, alluded to in the first chapter of this volume, béton has been used on a large scale, in a very different way to that just described; and the published account of the manner in which the works were conducted, and of the reasons which led to the adoption of the systems of construction there employed, is so interesting, that we have thought it desirable to transfer to our pages, without abridgment, the first three chapters of M. Poirel's work before referred to, which form a tolerably complete treatise on the use of béton for submarine foundations.

Béton, as prepared on the Continent, is seldom if ever used in this country, but concrete is sometimes made with blue lias lime, when it, in fact, becomes a species of béton, and must be treated in a similar way. The lime must be ground or beaten to powder, and before being mixed with the gravel it must be slaked, and allowed to stand for a considerable time, to ensure the thorough slaking of every particle. The lime and sand should be brought into the state of mortar before adding the stones. If it is attempted to make concrete with lias lime, in the same way as with the ordinary stone lime, the lime, from its refractory nature, is but imperfectly slaked, many particles remaining in the state of quicklime. The practical effect of this mode of treating concrete is, that the more refractory particles continue to expand in the interior of the mass after the outside has set perfectly hard, and the whole becomes more or less disintegrated.

If, also, any particles remain in the state of quicklime, subsequent exposure to water will cause them to slake, and in so doing they burst, and split the work in immediate contact with them.

It may be worth remarking here, that béton or rough rubble masonry executed with cement or mortar, was well understood and practised in former times, but *concrete,* as made at the present day, appears to be a modern invention, and is in every way inferior to it.

ACCOUNT OF THE WORKS RECENTLY EXECUTED IN BÉTON AT THE HARBOUR OF ALGIERS.

(Translated from the French of M. Poirel, Ingénieur-en-chef des Ponts et Chaussées.)

Rebuilding of the Old Mole.

The roadstead of Algiers, exposed like all those of the north of Africa, is completely open to sea-board.

The little basin which forms the harbour at the western extremity, and at the entrance of the roadstead, was formed in 1530 by Khaïr-ed-din, brother of Barbarossa. Having made himself master of a little islet lying in front of the town, and upon which the Spaniards had a fortress, he resolved, for the double purpose of securing his new possession, and of forming a harbour in front of Algiers, to connect this rock with the town by means of a jetty, which is called by his own name. Its length is 574 ft. 1 in. (175 mètres), with a top width of 118 ft. 1 in. (36 mètres), and it lies nearly east and west. Besides the Khaïr-ed-din jetty, a mole in prolongation of the islet shelters the basin from the easterly winds. This mole is 410 ft. 1 in. in length (125 mètres), with a maximum width of 311 ft. 7 in. (95 mètres), and its direction is north-east and south-west.

The circuit of the basin thus formed terminates at the little mole of the Lazaretto. Its area is nearly ten acres (4 hectares), and it is capable of containing 60 vessels, 30 of which are of about 300 tons, and a very few of 800 tons burthen. Vessels of a larger tonnage lie outside. The greatest depth of the harbour is at present 16 ft. 4 in. (5 mètres), but this may increase from the scour.

Khaïr-ed-din Jetty.—The Khaïr-ed-din jetty, abutting at one end on the shore, and at the other end on the Isle de la Marine, presents a continuous line without exposing any head to the sea. Besides this, it is protected by several groins, formed by portions of the bank of rocks on which it stands. However, in spite of the masses of rubble annually placed on it since the time of Barbarossa, to say nothing of the quantity of stone thrown upon it in 1833 and 1834, since the occupation of Algiers by the French, the foot of the jetty was constantly laid bare at several points, and the breaches were always increasing.

This jetty, on which are built the large warehouses for military stores, necessarily first demanded the attention of the government, because it was of especial importance to secure the buildings of which it forms the foundation. This work was intrusted, in 1831, to M. Nöel, engineer of the hydraulic works of the harbour of Toulon, from which service he was temporarily detached. He reinstated the whole body of the jetty for a width of 6 ft. 6 in. (2 mètres), to the height of 16 ft. 4 in. (5 mètres), above the water. The new masonry is executed in a perfect manner, and is extremely substantial. Unfortunately, the insufficiency of the funds put at the disposal of the skilful engineer who directed this work, and the shortness of the time assigned to his mission, did not permit him to renew the base of the jetty, the breaches in which continued to extend, and which it has been impossible to stop, except by protective works formed with blocks of béton.

The Mole.—The mole is much more exposed than the jetty. It stands out into the sea, to which it presents a pier-head whose direction is nearly perpendicular to that of the winds which blow into the roadstead with the greatest force. It was therefore on this so much threatened point that the Turks lavished all the resources at their disposal, both in men and money. They employed upon it the greater number of their slaves, and spent annually on it from 160 to 180 *boudjons,* that is, more than 12,500*l.* of English money. Laugier de Tassy, one of the most exact historians of the government of Algiers, where he resided in 1727, thus expresses himself on this subject:—

"As the great mole is directly exposed to the north, in order to prevent its being carried away by the heavy shocks of the sea, which breaks fiercely on a sandbank running the whole length of the mole on the outside of the harbour, it is necessary to employ the slaves of the Beylick throughout the year at a quarry of hard stones near Point Pescade, and to remove these stones and throw them into the sea along the whole length of the mole, in order to secure it. The sea carries away nearly all the stone that is thrown in, but care is constantly taken to replace it."

First Works undertaken by the French.—The head of the mole, in which the sea had opened a large breach, was also repaired in 1831, but the new masonry resting on loose masses of rock, which were disturbed by every heavy sea, was entirely destroyed at the commencement of the bad weather of the winter of 1832. All repairs that could have been made on the face of the work would infallibly have undergone the same fate, because the base on which it was built was of a shifting nature. In addition to this, the head of the mole was placed in the worst possible direction, being perpendicular to the north-east (that is, to the point whence the wind blows into the roadstead with the utmost force), and forming a considerable re-entering angle with the line of the mole.

The first operation to be performed was to raise in front of the head of the mole a massive embankment of large blocks, in order to protect it from complete destruction, and to form a bank under cover of which the foundation might be subsequently restored, it being intended that the mass of stones should be arranged by the action of the sea to the slope required for their equilibrium. It was therefore necessary to consider the means of procuring a considerable quantity of stone, and for this nothing was prepared; quarries, roads, means of conveyance, everything was wanting, everything had to be created.

From the commencement of the season of 1833, an active search was made for quarries from which might be obtained blocks containing from 70 to 140 cubic feet each (2 to 4 cubic mètres): numerous explorations were made at all points where there was a hope of obtaining them; roads were opened from all the quarries to the city gate; the streets widened; the approaches to the mole enlarged, so as to allow of the passage of vehicles, which before could not get on the mole; and notwithstanding the difficulties encountered in extracting large blocks from a geological formation presenting no regular stratification or continuous stratum,—in spite of the universal want of resources inevitable in a barbarous country recently conquered and placed under military rule,—by the month of December about 212,000 cubic feet of stone had been thrown into the sea.

In the winter of 1833-34 these masses of stone became completely arranged, and took an average slope of 1 in 6. The embankment, which had been carried up above the level of the sea, had sunk 13 ft. 1 in. (4 mètres) below it, and during its subsidence many of the blocks had been carried by the action of the waves inside the harbour. It was found that one of them, containing 35 cubic ft. of stone, had been thrown by the waves upon the top of the mole to the height of 13 ft., and to a horizontal distance of 98 feet, and that another, containing 141 cubic feet, had been carried completely across the mouth of the harbour to the Musoir de la Santé.

This serious displacement of the blocks, which tended to throw them back into the harbour, was a radical defect, which made it necessary to renounce the ordinary system of random blocks. The only means of not falling again into the same error was, instead of using blocks of from 100 to 141 cubic feet, below which size they were displaced by the waves, to throw in masses of such dimensions that they should resist the action of the sea and remain immovable, which is possible, since the action being proportioned to the surface struck, whilst the resistance of the block increases as its mass, there must necessarily be a point where the latter predominates. This limit was at first fixed at 706 cubic feet, but it has since been found that the blocks remain stationary when only half that size. The raising masses of this size from the quarries was not to be thought of, on account of the difficulty of quarrying them, and the equally great difficulty presented by their carriage. There remained, therefore, no other course to adopt but to make them artificially, and this led to the adoption of béton as a material for the blocks.

These blocks are of two kinds; some are formed in the water, on the site they are to occupy, the others are made on shore, to be afterwards thrown into the sea.

First kind of blocks, made in place with béton, immersed in lined caissons.—Blocks of the first kind are made by immersing béton in lined caissons grounded upon the intended site of the block. The sides of the caissons are formed of a framework of timbers, lined on the inside with double layers of planking, crossing joint, the bottom being cut to the profile of the ground. They are also lined on the inside with tarred cloth, which forms a kind of sack. This cloth is nailed to the woodwork, and extends the whole height of the caisson up to 1 ft. 8 in. (·50 mètres) above the level of the water. The four sides of the caisson are connected by hinged angle-irons, so that they can be easily unshipped. They are taken up at the end of from ten to twelve days, and all that is required to fit them for being used a second time is to lengthen or shorten them a little, to bring them to the shape of the ground. When fixed together, a cloth is fitted to them, which must be of sufficient size to adapt itself to all the irregularities of the bottom that it covers. The caisson thus formed becomes a real sack, of which the sides are strengthened by the wooden framing on which the cloth is stretched and fixed. The mass of béton which fills it can then mould itself perfectly to the ground, and connect itself with it by the very irregularities of the latter, whilst with the flat-bottomed caissons generally employed in founding works in water without laying dry the bottom, it is necessary to remove the roughnesses of the ground by bringing it to a nearly level surface, an operation which is difficult, and which can never be attended with perfect success.

These caissons are prepared in the yard and launched into the harbour, whence they are towed by pontoons and floated to their intended sites. They are then weighted by means of wooden boxes slung all round the outside of the caisson, and filled with balls or with pig-iron. The caisson thus fixed, a machine for lowering the béton is set up on a travelling scaffold, communicating with the shore by a temporary bridge.

Considerations which led to the employment of lined caissons.—We were led to this method of making artificial blocks by a process which the Italians employ when they wish to repair the breaches which take place in masonry under water. This process consists in filling with béton sacks similar to those used in fortification, placed one over another in the breach to be closed. Starting on this idea, we filled with béton and threw into the sea, during heavy weather, a sack much larger than the common ones, and at the end of some days, when the sea was calm, we found this block very hard, and possessing great resistance. All that was further wanted to succeed, by an analogous process, in forming blocks of large dimensions, was to make the sack so strong that it should not burst, and to fill it with béton on the very place where it was wished to immerse the block; a problem which has been solved as we have just explained, the caisson above described being nothing else than a large cloth bag, of which the sides are strengthened by timber framing.

The cloth lining of the caisson indispensable to protect the newly-immersed béton from the wash of the sea.—The cloth lining which forms the bottom of the caisson is the essential and capital part of this mode of construction, without which it would be very defective. With a simple caisson without a bottom, it would be impossible that the sides should be cut exactly to the profile of the ground on which it is to rest; and besides, were that practicable, there would never be the certainty of being able to immerse the caisson *exactly* in the place for which it had been prepared. There would, therefore, always remain openings between the caisson and the ground, and the sea, finding its way under the sides of the caisson, would penetrate into the mass of the béton; instead of which, in the lined caissons, the action of the sea is never directed against the béton itself, but only against the cloth, without causing any injury to the material it envelops.

What has been here advanced is easily understood, and a great number of experiments authorize the establishment of the principle, that "*whenever béton is immersed in water which may be agitated before its setting, or wherever it may be lowered into a foundation pit where there are bottom springs, it is imperatively necessary that it should be completely protected from wash.*" This principle, laid down for caissons formed with framed sides, applies with still greater force to piled dams; as these latter are never water-tight, it is indispensable, under the conditions above specified, to line them with water-proofed cloth up to the water line.

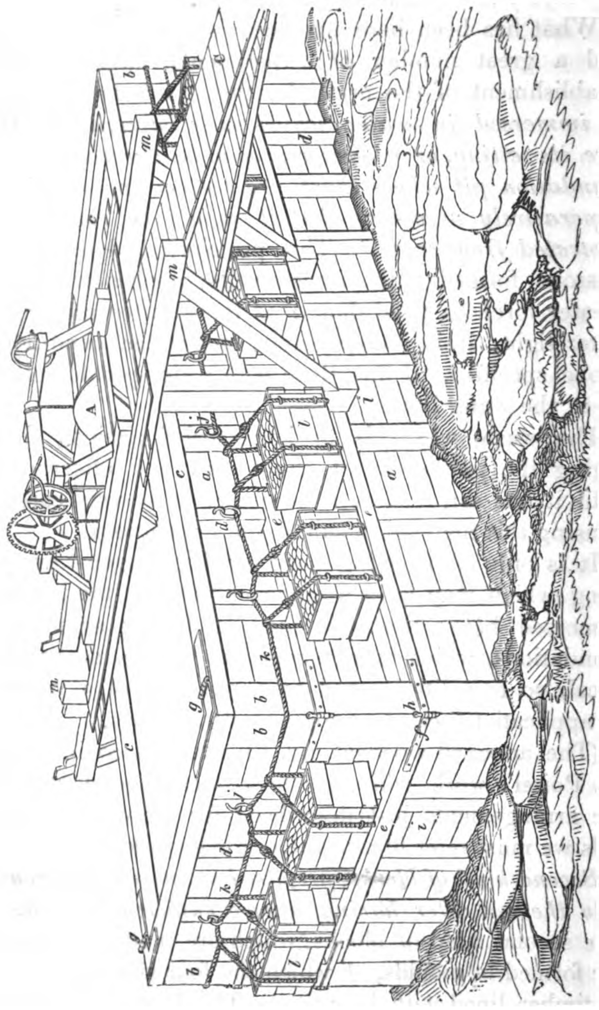
The wash, which is to be guarded against, first, during the putting in of the béton, and afterwards, until it has set, renders it necessary to be very careful in using this material in submarine foundations.

It is only after having made provision against everything which may have a tendency to wash the newly-immersed béton that this plan of laying submarine foundations, which is otherwise so simple, so economical, so expeditious, and so susceptible of a variety of applications, can be adopted with security.

(The annexed woodcut, fig. 13, which is copied from M. Poirel's work, will give the reader a good idea of the arrangements just described; for the working details we must refer him to the original work.)

Second kind of blocks, prepared on shore and thrown into the sea after having become sufficiently hard.—The second kind of blocks, which are made on shore, are formed in moulds, of which the four sides are made of timber lined with boarding. The bottom on which

Fig. 13.



they are set up rests upon a framing of large balks, forming part of an inclined plane, ending at the point where the block is to be sunk. These moulds, like the caissons, are without internal strutting. When the béton with which they are filled is well set, the sides of the mould are removed, and the block thus deprived of its covering is launched into the sea.

Composition of mortar and béton.—The mortar used in making the béton immersed in the caissons is made of one part of rich lime, slacked and made into a paste, mixed with two parts of Italian pozzuolana.

For the blocks made on shore the pozzuolana is mixed with sand, in equal quantities.

The lime in use at Algiers is from a primitive gray limestone, somewhat granular and very hard; its weight is about 156 lbs. per cubic foot. Slaked in the usual way, and reduced to the consistence of a thick pulp, it absorbs once and a half its own weight of water. It increases in bulk in the proportion of 1 to 1·75.

The pozzuolana employed is the same which is used along all the Mediterranean coast for making hydraulic mortars. It is found in the caverns of St. Paul, near Rome, and is sifted on the spot, through sieves of thin iron plate, pierced with rectangular openings 0·078 in. wide, 0·78 in. long, and 0·39 in. distant from each other.

One part of lime, with two parts of pozzuolana, make two parts of mortar. If the pozzuolana is used without sifting, it takes from eight to ten days before the mortar will bear the needle[a] of M. Vicat without sensible depression.

If the pozzuolana is sifted, the process of hardening is nearly twice as rapid; that is to say, at the end of

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[a] It may be necessary to explain to some readers that this refers to the method pursued by M. Vicat for testing the hardness of the mortars and cements on which he experimented.

five or six days the needle makes no impression on it. The mortar, composed of one part of sand, one of lime, and one of sifted pozzuolana, such as is made for the blocks of béton moulded on shore, does not attain the same hardness under from eight to ten days.

The béton is composed of one part of mortar with two of stones broken up into pieces, containing each about 1½ cubic foot, which forms two parts of béton. Its weight is about 137 lbs. per cubic foot. That which is made with pure pozzuolana only, without admixture of sand, rapidly acquires a cohesive strength, of which the following experiment will give a pretty exact idea.

A block, after thirty-six hours' immersion, was stripped by a heavy sea of the caisson in which it had been made, and thus laid bare it withstood, without any support, and without the least fracture, the shock of very heavy waves. It must, however, be added, that if the wind had not abated, or had the swell increased, this block would certainly have been destroyed.

A prism of béton 11·7 in. long, 3·9 in. thick, and 3·9 in. wide, made of mortar composed of one part of lime, one of pozzuolana, and one of sand, dried in the air, and tested by the machine described by General Treussart in his "Mémoire sur les Mortiers," supported, at the end of twenty days, a weight of 310 lbs. before it broke.

A similar prism, immersed immediately after it was made, supported, after the same number of days, a weight of 203 lbs.

Manner in which the blocks of béton were used in the reconstruction of the Mole of Algiers.—The blocks of béton, whose nature and composition have been above described, were employed in the following manner in the construction of the Mole of Algiers :—

1st. Masses of béton, of from 2000 to 6000 cubic feet, were made on the spot, in lined caissons, the inside face of these masses, on the land side, being placed according to the new direction given to the line of the top of the mole.

2nd. On these first blocks were placed moulds, containing from 353 to 1765 cubic feet, which were filled with béton, and when once set, these blocks were launched into the sea, so as to form a second line in front of the first.

3rd. The space left between these two lines of blocks of béton was filled up with stone in blocks of from 106 to 247 cubic feet. (The natural stone was only used to accelerate the work, and to economize the pozzuolana; but it would generally be more advantageous to use only blocks of béton.)

4th. Behind this double line of defence, and under its shelter, the ground was dredged to the depth of 6 ft. 6 in. below the water line, for a width of 9 ft. 9 in., and the whole of this space was filled up with a continuous mass of béton.

It must be fully understood that this work was not undertaken at once along the whole length of the mole; but that it was effected successively piecemeal, so as not to enter upon a greater length in each year than could be completely finished in the course of the season.

This work, which has perfectly succeeded, establishes beyond all question, 1st. That blocks of béton have sufficient strength to resist the heaviest seas without injury, and that they form indestructible masses. 2ndly. That these blocks are immovable when above a certain size, which at Algiers has been found to be 353 cubic feet, but which may perhaps vary a little under different local circumstances.

The mole, on which the preservation of the harbour of Algiers depends, was, at the time of the occupation of the city by the French army in 1830, in a state of complete dilapidation and imminent ruin, notwithstanding extensive repairs by the Turks, continued annually during two centuries. By using blocks of béton instead of natural stone, it has been practicable in five years only, and at a cost of less than 84,000*l.*, to rebuild nearly 700 feet of the mole, and to give it a stability which is proof against the severest test.

Construction of the new Mole.

Plan for a new mole of blocks of béton.—After the rebuilding of the mole, and at the end of the season of 1838, a commencement was made of a plan for the enlargement of the harbour of Algiers by means of a new mole, 1650 ft. in length, in continuation of the old one; it was to be constructed entirely of blocks of béton of 353 cubic feet, prepared on shore; and at the end of a month or two, according to the season, dropped into the sea, as is done with natural blocks in embankments of *pierre perdue.*

In the works previously described the blocks were made on the beach, whence, by an inclined plane, they were launched into the sea. This system, which answered well for forming a line of sea-wall in front of the mole to be rebuilt, could not be applied to the construction of the new mole in prolongation of the old one. As it would not have been possible to place on inclined planes more than three or four blocks abreast at the tip, and as they must have been allowed a month or two for setting before immersion, the result would have been that not more than from forty to fifty could have been thrown in during the year.

Plan for the carriage and immersion of the blocks by land.—It therefore became necessary to make a large number of blocks beforehand in the work-yard, whence as they became sufficiently hard they might be removed to the spot where they were to be sunk. This was effected by the following means, which are now (1841) in course of execution:—

The blocks of béton are all of the same form, that of a rectangular prism, 11 ft. long, 6 ft. 6 in. wide, and 4 ft. 11 in. high, and contain 353 cubic feet, deduction being made for the bottom grooves. They are made by filling with béton a chest, which forms a mould. This mould has four framed sides, each made of five uprights, lined with fir planking, and tenoned at top and bottom into a cap and sill. The ends of the caps and sills have mitre-joints, and are fastened with angle-irons, which bring them up close when put together, and which are easily unshipped when the block is to be bared.

The bottom of the mould is formed by a layer of sand, 2 in. thick, spread over the surface of the yard to prevent the béton from adhering to it. On the sand are placed three rectangular moulds, made of three boards, for the purpose of forming grooves about 5 in. square, for passing underneath the block the chains by which it is to be raised.

From sixty to seventy men working eight hours can make four blocks. The blocks are placed rather more than a yard apart, to facilitate the handling of them during their removal.

Three carpenters can take to pieces and reset a mould in an hour. The same frames, with slight repairs, will serve for making about fifty blocks.

From four to six days after filling the mould, its four sides are removed and set up again to form a new mould. Thus exposed, the block becomes in a month, or at the latest two, sufficiently hard to be thrown into the sea.

This last operation is divided into two stages; first, the lifting of the block, and afterwards its conveyance to the point where it is to be sunk.

To raise the block two chains are used, which are passed through the grooves prepared for that purpose, and four screws placed at the ends of the grooves, two on each side of the block. The chains are attached to the heads of the screws, and the nuts are keyed into spoked wheels, by which the former are turned. Sixteen men, four at each wheel, will raise the block 20 in. from the ground in twenty minutes.

The block being lifted from the ground, a low truck is run under it, with wheels barely 10 in. diameter, placed in the thickness of the wood; two greased boards, placed on the truck, serve to facilitate the descent of the block. It is drawn along an iron tramway by a capstan worked by eight men. When it reaches the end of the road, a slight tilt is given to it, which is sufficient to cause the block to slide from the wagon by its own weight, carrying the greased boards with it.

Second system of carriage and immersion by water.—The blocks to be sunk are sometimes also transported by sea. The block is lowered into the water on an inclined float until it has sunk to the depth of 3 ft. 3 in. When it is fixed in this position, a machine is brought over it composed of two pontoons, between which it is symmetrically placed; the pontoons are attached to it by means of chains passed under the block, and thus at once support it and transport it, just as camels are used by the Dutch to lighten vessels and to take them out into deep water.

The two systems of immersion by land and by water are employed simultaneously in the construction of the new mole. The 280 feet of new work completed up to the 1st of June, 1840, afford decisive evidence in favour of this method of constructing piers with blocks of béton of not less than 353 cubic feet, thrown irregularly upon each other. It proves that blocks of this size invariably remain in the position in which they were sunk.

On the last half of the new mole eight cross sections have been taken at equal distances. Although they differ from each other, they generally give, for the slopes to which the blocks settle, an average of 1 to 1 seaward, and of ½ to 1 towards the inside of the harbour. From the cubic contents given by calculations based on these sections, and compared with the notes kept of the quantity of blocks sunk between them, it is found that the voids are nearly a third of the solids, or, which amounts to the same thing, that they form one-fourth of the whole mass.

These observations have not yet been sufficiently numerous to permit us to generalize the conclusions just deduced from them; it will be necessary to verify them by the results that will be obtained in carrying on the work during ensuing years. But they may, even at present, be considered as supplying a sufficient approximation, and may serve as a basis for the estimates of plans that may have to be drawn up for the construction of piers with blocks of béton. They give the cube of the material actually required for an embankment of which the length, top width, and the depths at different points are ascertained, from which may be found the expense to which the work should amount.

When the foundation of the mole of Algiers, formed, as has been shown, of blocks of béton, has been completed along its whole length, the remainder of the body of the work (which will be brought up to nearly 20 ft. above water) will be finished with béton carried up inside cases of the form which it is intended to give to the face of the work.

Behind the revetment formed with blocks of béton, can be formed on the harbour side wharfs of such width as may be desirable, simply by a stone embankment brought up to within about 16 ft. below water, and on which may be raised a solid mass of béton immersed in lined caissons.

Defects of the ordinary System of Construction with Pierre Perdue, and the advantages resulting from the substitution of blocks of Béton for natural blocks.

Piers of Pierre Perdue.—The system generally employed in our times for the construction of sea piers, is that known by the name of *pierre perdue.* It was practised by the ancients, as may be seen at the port of Civita Vecchia, which was constructed in the reign of Trajan. By the moderns it has been applied in various ways; the most remarkable instance is the Cherbourg Breakwater, which was begun in 1784, and is not yet completed.

The materials used in the construction of these piers vary generally in bulk from 7 to 70 or 100 cubic feet; below this size they are shaken and overturned; but, according to the partisans of this mode of construction, this movement is only temporary, and the action of the waves working on the mass gives the latter a definite slope, at which it becomes capable of resisting the heaviest seas.

This slope is a double one, the upper slope varying from $\frac{1}{6}$ to $\frac{1}{10}$, and the lower from $\frac{1}{1}$ to $\frac{1}{1\frac{1}{2}}$. The depth at which the change of inclination takes place varies from 13 to 16 ft. under low-water mark, according to the varying force of the sea in different localities. It is generally admitted, that below this depth the sea is not agitated, and that the change of slope is caused by this fact. Nevertheless, it must be acknowledged that the motion only diminishes, and never entirely ceases. A great number of well-known facts prove that the sea exerts great force at depths of 32, and even of 65 feet below the surface.

In stormy weather the waters become turbid, to a certain distance from shore, in consequence of the action of the waves on the bottom of the sea, an action sufficiently strong to detach seaweed and madrepores, which are thrown upon the shore, where they are found in abundance after every gale. For this reason, also, the fishermen, after the return of calm weather, are obliged to wait a day or two before they cast their nets, because the mud upon which the fish remain has been disturbed, and it must settle again before they will return to it[a].

Inherent defects of this mode of construction.—Even if we admit that the slope taken by the blocks remains the same, it does not follow that the blocks themselves

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[a] M. Aimé, Professor in the College of Algiers, and Member of the Scientific Commission, has made direct experiments on the motion of the waves, which prove that this motion is plainly felt at depths of 50 to 65 feet. The interesting results obtained by this young savant have been recorded in several papers addressed by him to the Institute.

undergo no displacement, but only that their motion, instead of being indefinite, is confined within certain limits, just as the sand and pebbles of a natural beach are continually set in motion by the action of the waves, although the section of the beach remains unaltered; and that the blocks never attain a state of complete rest is proved by the noise made by their rolling over each other whenever the sea is rough. Besides, as it must be acknowledged that they are movable until their mass has taken the slope at which they will remain without displacement, they must necessarily be worn by friction as long as this displacement goes on, and the effects of this grinding would soon be perceived, for a single winter is sufficient to round the sides of large angular fragments of very hard stone. We know that sand and pebbles are thus formed along the shore, at least partially so, by the motion of blocks thrown by the sea against the cliffs.

Independently of these destructive results, which are only slowly developed, there are others which become manifest even during the execution of the work. It is generally admitted that the pier-heads should be formed with stones of larger size than those which form the body of the work, in order to prevent the harbour channels from being choked by the displacement of the materials, which, having no support, are carried round the head along the inside face of the work. Now the successive sections of a pier in course of construction, constantly present a head seaward at every stage of its progress. The materials of which it is composed must therefore be driven round each of the portions by which it is successively terminated, and thus carried inside that part of the sea which it is intended to inclose to secure still water; and if the pier is built parallel to the shore, and at no great distance from it, this displacement of materials will inevitably produce a diminution of depth over the greater part of the area of the harbour.

Difficulties which occur in its execution.—Having exposed the inherent defects of the system of *pierre perdue*, it remains to mention the difficulties attendant on its execution. In what we are about to say on this subject, we will take, as an example, what has been done at Algiers; the results obtained from the use of natural blocks at this harbour may be equally applicable to other localities.

1st. In the neighbourhood of the piers to be built it is not always possible to find quarries of stone sufficiently hard to resist violent blows, and which will be durable under water.

2nd. The working of quarries fulfilling these conditions occasions enormous waste. It is a point generally agreed upon that no stones should be employed under from 18 to 27 cubic feet, and the opinion of those engineers who, with M. Cachin, considered that the smallest materials were not only useful but necessary, to fill up the voids between the large stones and to form with them a compact mass impenetrable to the waves, is now nearly abandoned. Now, at Algiers, of the total yield of the quarries, only one-third consists of blocks of the above-named dimensions, the remaining two-thirds consisting only of rubble and small blocks.

3rd. The small blocks, up to the size of 70 ft. cube, are carried by means of trucks, or on low two-wheeled carts. The carriage (including handling, loading, and unloading) amounts to nearly 4*d.* per cubic foot. Blocks exceeding 70 cubic feet are carried on strong four-wheeled carts, to which are harnessed from 28 to 30 horses, when the block is one of about 250 cubic feet.

4th. The handling in the quarry, as well as the landing, is managed with a number of crabs. Wherever the ground will allow of it, the cart is backed to a loading-place sloping from the level on which the block rests; the latter being moved along on rollers until it reaches the cart. This operation, although a long one, is the easiest of execution; but it is not practicable for all blocks.

An idea may be formed of the difficulties presented by these operations from the price paid for them at Algiers. The handling amounted to more than 1*d.* per foot cube for blocks of from 70 to 105 cubic feet, and to 2⅓*d.* for blocks of 211 to 247 cubic feet. The loading and unloading cost somewhat less than 1*d.* per foot for blocks of 70 to 105 cubic feet, and to 2*d.* per foot for those of 211 to 247 cubic feet. The handling and loading of large blocks might, no doubt, be simplified, if a considerable quantity had to be removed, by the aid of machinery that might be set up in the quarries; but it would be impossible to facilitate these operations sufficiently to reduce the price to any important extent.

5th. When the blocks have been loaded, their carriage from the quarry to the spot where they are to be sunk, if upon an ordinary road, amounts to a very high price. At Algiers it was found that it could not be done for less than about 4½*d.* per foot, with a lead of 1¼ mile, when the blocks were from 100 to 300 cubic feet.

The most favourable case would be that in which the quarry is formed immediately on the spot where the pier joins the shore, as at the harbour of Ratoneau, at the entrance of Marseilles. But this circumstance rarely occurs; there will be almost always a certain distance to pass between the quarry and the pier; and in proportion as this distance is greater or less, and the space to be crossed offers more or less obstacles to the establishment of a continuous tram-road, the difficulties of transport will be more or less considerable; in very many localities the construction of a tram-road uniting the quarries with the pier would be quite impracticable.

6th. In what has been said above, we have had in view only piers connected with the shore; but if isolated breakwaters are required it would be necessary, as at Cherbourg, to employ a mixed system of carriage by land and water; and it is easy to satisfy ourselves that the methods employed at Cherbourg, which are the most ingenious and the best contrived imaginable for blocks such as those of which the breakwater is formed, and which never exceed from 70 to 106 cubic feet, would be extremely difficult of application when masses of much larger size are in question.

Advantages of the system of construction with blocks of Béton.—The defects and difficulties which we have just pointed out in the method of construction with *pierre perdue* disappear when, instead of natural blocks of from 14 to 70 cubic feet, weighing from about 1 to 5 tons, masses of béton are substituted of 353 cubic feet and weighing nearly 22 tons. The works which have been executed on this latter system in the harbour of Algiers completely prove its superiority. It presents numerous advantages over the system of *pierre perdue,* of which the principal are:—

1st. Immediate stability, whilst ordinary rubble work is never secure. 2nd. Incomparably greater facility in the carriage of materials, generally so troublesome and expensive when blocks have to be quarried exceeding 100 cubic feet. 3rd. A considerable reduction in the sectional area of the pier, and, consequently, a remarkable saving of cost. 4th and lastly. That the system is everywhere applicable, now that our advanced knowledge of the subject of hydraulic mortars enables us to make béton in every locality.

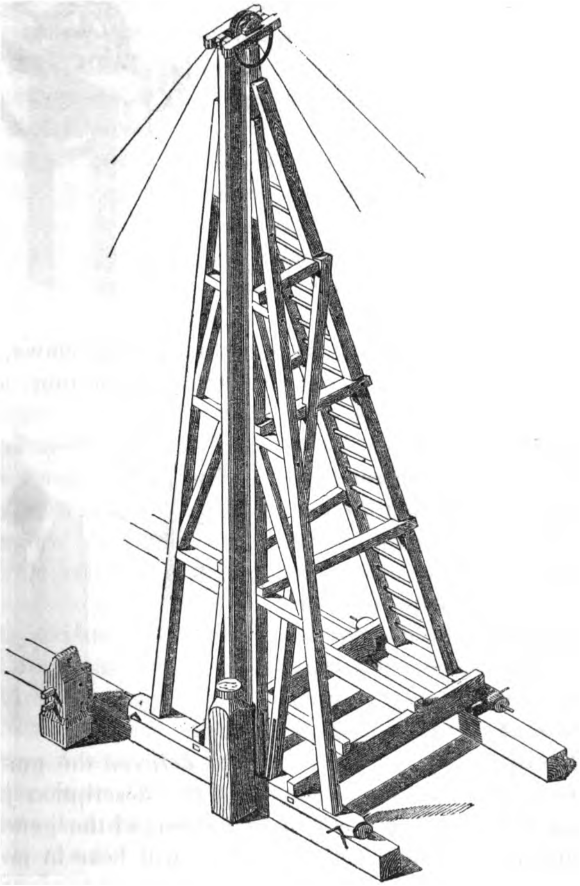
CHAPTER V.

PILE DRIVING.

The usual method of driving piles is by a succession of blows given by a heavy block of wood or iron (called a monkey, ram, or tup), which is raised by a rope or chain passed over a pulley fixed at the top of an upright frame of timber, and allowed to fall freely on the head of the pile to be driven.

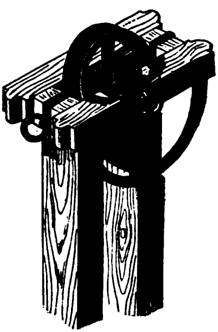
The construction of a pile-engine is very simple, and whatever may be the nature of the power employed, or the way in which it is applied, there is very little difference in the arrangement of the principal parts of the guide frame. (See fig. 14.) The essential parts of a pile-engine are the leaders or guides, two upright pieces of timber which guide the ram in its descent, and which are stayed in two directions by framing. The base of the framing is generally planked over and loaded with stones, or iron ballast, to counterpoise the weight of the ram, as, without this precaution, the whole would be

Fig. 14.



in unstable equilibrium. The leaders are framed into a strong bottom sill, and with a top frame (see fig. 15), on the sides of which are placed the bearings for the pulley round which the hoisting-chain is passed.

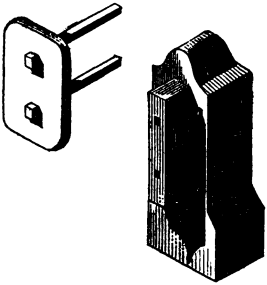
Fig. 15.



The ram (see fig. 16) itself is usually of cast iron, with a projecting ear, which passes between the guides, and is kept from falling forwards by a plate keyed on behind them.

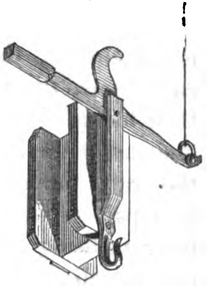
The hoisting-chain is attached to a pair of claws, or nippers, which clip an eye on the top of the ram, and are opened to release the latter by pulling a line. The nippers can be made self-acting, by attaching the line to the pile that is being driven, by which means the fall can be kept uniform throughout the descent of the pile. Sometimes a claw lever (see fig. 17) is used instead of a pair of nippers, and occasionally the ram is placed *between* the guides instead of in front of them: but the description just given will enable the reader to understand the general arrangement of a pile-engine, if he will bear in mind that the minor details are seldom exactly alike in any two engines.

Fig. 16.



We shall briefly describe the engines most in use for pile-driving, and say a few words on their comparative efficiency.

Fig. 17.



The pile-driving machines most commonly used in this country are of four kinds: viz., the ringing engine, the crab engine, Nasmyth's steam-hammer, and Clarke and Varley's atmospheric engine.

The Ringing Engine.—This is the simplest of all the pile-engines in use. It takes its name from the large pulley or *ring*, round which the hoisting-rope passes. The frame of the engine consists only of the leaders, bottom sill, and head and side braces. The frame is kept in its required position by guy ropes or by a movable prop. The ram is usually of hard wood, hooped at both ends, and comparatively light, so that it can readily be lifted by the united exertions of from 8 to 12 men pulling on as many ropes attached to the main rope. It is used with a slight fall, and consequently it is unnecessary to detach it from the rope at each blow, and no claws or nippers are required. This machine is very effective, and well adapted for the use to which it is applied, viz., for driving piles to a short distance, and where no great force is required. The blows are given with great rapidity, and with little waste of power, and the portability of the machine enables it to be readily moved about from place to place. It is made from 10 to 15 feet high; the weight of the ram about 3 cwt.

The Crab Engine.—The crab engine, of which we have just given several illustrations, is the machine in ordinary use in this country for driving all kinds of piling. It differs from the ringing engine in being made larger, viz., from 20 to 50 ft. in height, and is strengthened and braced in proportion. It is used with a ram weighing from 6 to 18 cwt., a crab winch being used to raise the ram. In the ringing engine the rope is attached to the ram, and is carried down with it at each blow, the men allowing the falls to escape from their hands simultaneously; but, in the crab engine, as one end of the hoisting chain is fastened to the drum of the crab, the fall of the ram is effected by attaching it to a pair of nippers, or to a claw lever, the release of the ram being effected at the proper height, either by a simple self-acting apparatus, or by a line attached to the nippers, by pulling which the ram is released at any required height according to the fall required. The crab engine cannot be considered an economical one where great force is required, the advantage gained by the fall being small compared with the power employed. There is also a great deal of time lost between each blow, in lowering the chain and re-attaching it to the ram.

The crab engine is not unfrequently driven by steam-power, the steam engine being sometimes placed on the frame of the engine itself, but more frequently at some convenient spot near the work, the chain being wound round a drum attached to the steam engine, and led to the pile engine by means of pulleys fixed wherever a change of direction becomes necessary. This method of using steam power has been applied on a very large scale at the works of the New Grimsby Docks, where the whole of the piles of the large cofferdam were driven in this way by two stationary engines, which, in some cases, were several hundred yards from the piles that were being driven.

It is supposed that steam power was first applied to this purpose by the late John Rennie, in 1801-2, for driving the piles of the cofferdam of the entrance of the London Docks. Two years later, viz. in 1804, the same gentleman made use of a steam engine of 6-horse power, driving two pile engines simultaneously in forming the cofferdam at the entrance of the Hull Docks.

Where the hoisting chain is wound round the drum at a considerable distance from the pile engine, it is obvious that considerable care, and a series of well-arranged signals, are requisite to prevent overwinding. These difficulties may be overcome by substituting for the ordinary crab-winch, hoisting machinery fixed close to the base of the pile engine itself, and worked by a strap from the driver of the steam engine passed round a pulley on the shaft of the hoisting drum, which, by a self-acting apparatus, is thrown out of gear on the ram's reaching the required height. An apparatus of this kind, used by Mr. James Milne at the Montrose Harbour Works, is fully described in the third volume of the "Minutes of the Proceedings of the Institution of Civil Engineers."

When steam power is applied to work the ordinary pile engine, it will be obviously to the interest of the contractor to allow as little time as possible to be spent in shifting the guide-frame from one pile to another, as the steam must be kept up all the time, and there will be little saving effected if the steam engine is lying idle during a great portion of the day. This is not of so much importance if the engine is used for other purposes, as pumping, sawing, &c., or if it is applied to work several pile engines at once; but, under any circumstances in which steam power is used, it will be found economical to lay down a light tramway along the line of the work, on which the guide-frames may be shifted as each pile is successively driven, with the least possible waste of time.

Nasmyth's Steam Pile Driver.—This important application of the steam hammer to the purpose of pile driving may be said to have effected a complete revolution in the art of pile driving, and by its means works have lately been completed, which, without such mechanical aid, may be said, humanly speaking, to have been impracticable.

The essential parts of Nasmyth's steam pile driver are :—

1st. A vertical guide post, with a pulley and chain for hoisting the hammer and pitching the piles.

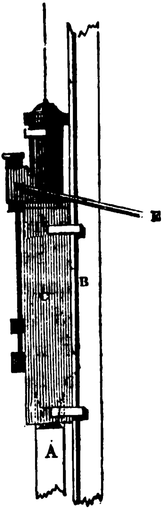
2nd. A wrought-iron case, which acts as a guide to the hammer in rising or falling. This case is clamped to the guide post by sliding clamps, and, resting on the top of the pile, grasps the neck and shoulders of the latter, so that it cannot in any way swerve or twist from its proper position.

3rd. The steam hammer, which is attached to a piston-rod passing out of the bottom of a cylinder fixed on the top of the wrought-iron case just described.

4th. A steam boiler, from which the steam is led to the cylinder by a set of steam pipes with elbow joints to allow of the pile-driving apparatus following the pile in its descent.

Besides the above-named arrangements, Nasmyth's steam pile driver, as usually made, is provided with a small steam engine for hoisting the hammer and "pitching" the piles, with wheels and locomotive gear, by which it can be propelled on a tramroad, and with horizontal saws for cutting off the heads of the piles to a level surface after they have been driven. It would be impossible to explain these arrangements without a great number of illustrations, and, as they do not affect the principle of the application of the steam hammer to pile driving, and have already been published, we shall here only give a small side view of the driving machinery, by which the reader will be enabled to understand the action of the hammer upon the pile (see fig. 18). A is the pile in course of being driven; B the guide post; C the wrought-iron case resting on the head of the pile, and working freely on the guide post, to which it is attached by clamps at top and bottom; D the steam cylinder; E the steam pipe from the boiler. The action of the machine is as follows:—The pile to be driven having been drawn up and placed in its proper position, the driving apparatus is hoisted and lowered on the shoulders of the pile. The hoisting chain is then let free, so that the apparatus may rest entirely on the pile, and follow it in its descent. The steam being then let in under the piston, the machinery begins to work, and the hammer inside the wrought-iron case showers down blows upon the head of the pile at the rate of 75 to 80 per minute. As each blow is given, the driving apparatus follows the pile, which is its only support, and it is, therefore, free to slide down the guide post the moment the pile begins to sink, the jointed steam pipe accommodating itself to every motion of the apparatus. The steam valve is opened and shut by a lever passing through an opening in the case C (not shown in the cut), to which motion is given by contact

Fig. 18.



with a small inclined plane on the hammer block. When the steam has raised the piston to its proper height, the steam valve, by the action of this lever, is closed, and an outlet valve opened, which allows the steam to blow out into the air, and the hammer to descend. As soon as the pile is driven to the required depth, the apparatus is again wound up, the locomotive gear set in motion to bring the engine in front of the next pile, and this latter having been pitched, the apparatus is again lowered, and the driving goes on again as before.

"The peculiar merits of Nasmyth's steam pile driver" (to quote from a writer in the "Engineer and Architect's Journal," Sept., 1848), "consist, in the first place, in the direct manner in which the elastic force of steam is employed as the agent by which the 'monkey' (or block of iron which strikes the head of the pile) is lifted to the height requisite for that purpose. Secondly, in the very peculiar and original manner in which the pile itself is made to act as the only support for the active or blow-giving portion of the apparatus, by which arrangement the entire dead weight of the apparatus in question is turned to most important account as a '*persuader*,' to assist the pile in sinking into the ground when in the act of being driven, this dead weight also acting very importantly as an anti-recoil agent, so far as its entire weight (three tons) can accomplish that object. Thirdly, in the peculiar manner in which the pile-driving part of the apparatus is permitted to sink down along with the pile, and guide it in its descent, so as to remove all chance of the pile twisting, or in any respect swerving from the true position given to it at the commencement of the operation of driving. Fourthly, in the peculiar manner in which a vast increased degree of energy is given to the blows of the monkey beyond that which is due to the height through which it falls."

This last sentence refers to an arrangement which we have not yet noticed. The holes for blowing off the steam are placed a short distance below the top of the cylinder, which is made air-tight. The instant the piston passes these openings in its upward action, all further motion in that direction is terminated by the compression of the air then confined in the space between the top of the piston and the under side of the cylinder cover; which compressed air, on recoiling, adds to the force of the blow all the energy it would have acquired by falling from the height to which the monkey would have been carried by the momentum given to it in the upward direction by the lifting action of the steam on the under side of the piston.

The usual weight of the ram employed is 35 cwt., and the fall 3 ft.

In the above sketch of Nasmyth's steam pile driver we have purposely avoided unnecessary detail, our object being only to give such a popular description as would enable the general reader to understand the principle of the machine. Those who wish to study its very interesting mechanical arrangements will find full drawings and descriptions of every part of it in the number of the "Engineer and Architect's Journal" quoted above.

Nasmyth's steam pile driver is exceedingly well adapted for driving continuous rows of piles, and for work in any situation where a great number of piles have to be driven within a short distance of each other. It has been used with great success and pecuniary advantage in piling the foundations of the High Level Bridge at Newcastle-upon-Tyne, and at the viaduct over the river Tweed, near Berwick. It has been employed very largely also at the New Grimsby Docks in piling the foundations for the entrance locks; and it was an interesting sight to see it at these works gradually working its way from side to side of the immense excavation, doing its work with an economy and despatch quite unattainable with the common engines.

For works of small extent no economy would result from the use of Nasmyth's engine, its first cost (about 1500*l.*), and the expense of moving it from place to place, restricting its economical application to works of large extent, such as those just named, and where it is truly invaluable.

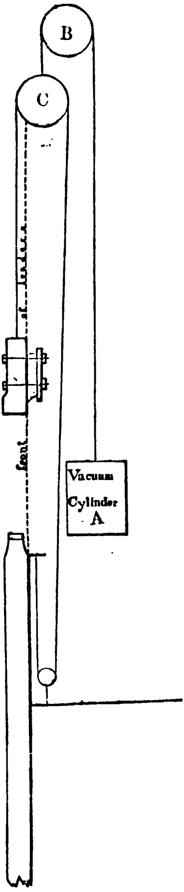
It should be noticed, before leaving the subject of Nasmyth's engine, that it possesses the great advantage of a heavy ram worked rapidly with a light fall, by which means the piles are driven more steadily, with less recoil, and with less injury to the timber, than with a light ram and a heavy fall. We shall presently have occasion to advert to this when considering the economy of power in pile driving.

Clarke and Varley's Atmospheric Engine.—This very useful engine may be described as a modification of the ringing engine, the ram being shackled to the hoisting chain without the intervention of nippers, and carrying it down with it in its descent. The lift of the ram is effected by one end of the hoisting chain being made fast to the rod of a piston working in a cylinder, which is connected by pipes with the receiver of an air-pump, worked by a steam engine placed in any convenient part of the work. By means of a floating pulley the fall of the ram is made double the length of stroke of the piston, and by an ingenious arrangement of the chain to which the ram is shackled, the fall can be adjusted at pleasure to anything less than that amount.

The following description is from the "Engineer and

Architect's Journal," Nov., 1848:—"This machine consists of a vacuum cylinder of wrought iron, A (fig. 19), closed at the bottom and open at top, having an air-tight piston, and self-acting slide gear, fixed to any convenient part of the frame of a common pile engine. The piston-rod is connected to a chain which passes over a fixed pulley, B, on the top of the engine; to the end of this chain is suspended a pulley, C; over this passes a second chain, one end of which is attached to the ram, and the other, passing down under the bottom of the frame, is brought up and affixed to the head of the pile. The power is derived from a small steam engine, fixed at any convenient spot, which works an air-pump for producing the exhaustion. Communication is made between the air-pump and the pile-driving machine by small wrought-iron tubes, connected together by flexible joints of vulcanized india-rubber. *Thus the machine possesses the incalculable advantage of being worked at any required distance from the steam engine, and moved about with as much facility as a common crab engine.* The mode of action is as follows:—The ram being supposed down on the pile head, and the piston consequently at the top of the vacuum cylinder, communication is opened by the valve gear with the air-pump, exhaustion then takes place in the cylinder, the piston

Fig. 19.



descends by the external pressure of the atmosphere and raises the ram; when the piston arrives at the bottom of the cylinder the valves reverse themselves; communication with the air-pump is then shut off, and the external air admitted under the piston; equilibrium being now restored, the ram falls with the full effect of gravity upon the pile; the valves are again reversed, and the same operation is repeated. Thus a succession of short heavy blows is given, rapid of course, in proportion to the power of the steam engine, and as, by the arrangement of the pulleys, the distance between the pile head and the face of the ram is always the same, a regularity of action is obtained quite unknown to the old pile driver; the injurious effect on the head of the pile, and rebound of the ram, consequent upon great height of fall, avoided; and the ram being permanently fastened to the chain, the whole time lost by the re-attachment after every blow is saved."

The atmospheric pile driver was first used in 1848, for driving the piles of the cofferdam for a wharf wall at St. Katherine Docks, where it gave great satisfaction. Mr. Crate, the clerk of the works at these docks, states that he drove forty-two piles, 18 ft. deep, into a bed of very hard compact gravel at the rate of three piles each tide of about three and a half hours, whilst to drive one pile only by the ordinary hand engine occupied five tides before it could be finished, and even then was left 2 ft. above the height required to be driven.

We have had the opportunity of seeing the atmospheric pile engine driving piles into strong gravel on the works of the Ambergate, Nottingham and Boston and Eastern Junction Railway, near Ratcliffe-upon-Trent, where the average time taken for driving a pile to the depth of nine feet was exactly nine minutes, and if proper arrangements had been made for shifting the engine after the driving of each pile, four piles per hour would have been driven with great ease, whilst with the common crab engine two piles per day was the outside performance. The steam engine used for working the air-pump was a small portable engine, used also for pumping.

The great merit of this engine consists in the adoption of the floating pulley, by which a sufficient fall can be obtained without making the stroke of the piston inconveniently long. The success of the atmospheric engine has induced Mr. Clarke to give the subject his careful attention, and he has designed an improved steam pile driver, on a somewhat similar principle, with a 5-ft. fall, to be worked by a piston, with a comparatively short stroke. As this, however, is as yet almost an untried invention, any detailed notice of it would be out of place in a work of this kind.

In a great many instances the power at hand to drive a pile considerably exceeds the resistance offered by the ground to its descent; but in driving through a hard stratum, or in driving piles which have to sustain a heavy weight, it is sometimes difficult to effect the required object by ordinary means, and it becomes important to know how the greatest effect may be produced with the least expenditure of power.

Suppose, for instance, that with a ram weighing 10 cwt., working with a 10-ft. fall, we are unable to get a pile down to the required depth; we have two courses open to us—we may take a heavier ram, which will require greater power to lift in the same time, or we may give a greater fall, which will require the same power to be exerted for a longer period. Putting aside for the moment the question of which will injure the pile least, let us confine ourselves simply to the question of the comparative power required to be exerted.

In order to calculate exactly the force of the blow given by the ram of a pile engine, it would be necessary to know the resistance of the atmosphere, and the amount of friction against the guides of the engine; but as these retarding forces are very trifling, compared with the whole force of the blow, and as these considerations would make the calculation exceedingly complicated, they may in practice be safely disregarded, and it will be sufficient to remember that such retarding forces exist. Now,—

The momenta of falling bodies are as the products of their weights by their velocities.

The velocity acquired by any falling body is directly as the time occupied in its descent.

The spaces fallen through are as the squares of the times of descent.

A body falling freely in a vacuum falls through $16\frac{1}{12}$ ft. in the first second of time, and the velocity acquired at the expiration of the first second is $32\frac{1}{6}$ ft. per second.

Let,

Weight of ram . . . . $= w$,
Fall of ditto, in feet . . . . . . $= f = 16\frac{1}{12} \cdot s^2$
Time of descent in seconds . . . $= s = \sqrt{\frac{f}{16\frac{1}{12}}}$
Velocity of ram at moment of striking the pile,

$$= v = 32\tfrac{1}{6} \cdot s = 32\tfrac{1}{6} \sqrt{\frac{f}{16\frac{1}{12}}} = 2\sqrt{16\tfrac{1}{12} f};$$

Momentum or force of blow

$$= m = w\,v = w\,(2\sqrt{16\tfrac{1}{12} f});$$

a simple formula, which gives the force of the blow in terms of the weight and fall of the ram.

From the above values of s and v the following table[a] has been calculated, by which the comparative force of the blow given by a ram whose weight $= 1$, with falls varying from 1 to 40 ft., can be at once read off by inspection. (See next page.)

Thus the momentum of a ram weighing 1 ton and falling from a height of 10 ft., will be to that of the same ram falling from a height of 30 ft. as 25·3 to 43·9, and, in common parlance, the blows thus given would be called respectively of the forces of 25·3 tons and 43·9 tons; a blow given by a ram weighing 1 ton, and striking at a velocity of 1 ft. per second, being called of the force of one ton.

We must, however, guard the young reader against supposing that impact and pressure can be compared together in any way, or, in other words, that a blow nominally of the force of a ton will balance a pressure of a ton weight, or produce the same effect in sinking a pile. Of the comparative effect of impact and pressure in driving piles we as yet know nothing, and the question is so complicated, from the great number of points that have to be taken into consideration in reducing the results of experiment into a definite form from which some rule for our guidance might be obtained, that we can only lay down in general terms the following empirical rule, that, in *ordinary cases*, if a pile will resist an *impact* of a ton, it will bear without yielding a *pressure* of 1½ ton. But to return to our immediate subject.

It will be at once seen by the reader, as a natural consequence of the law by which the velocities of falling

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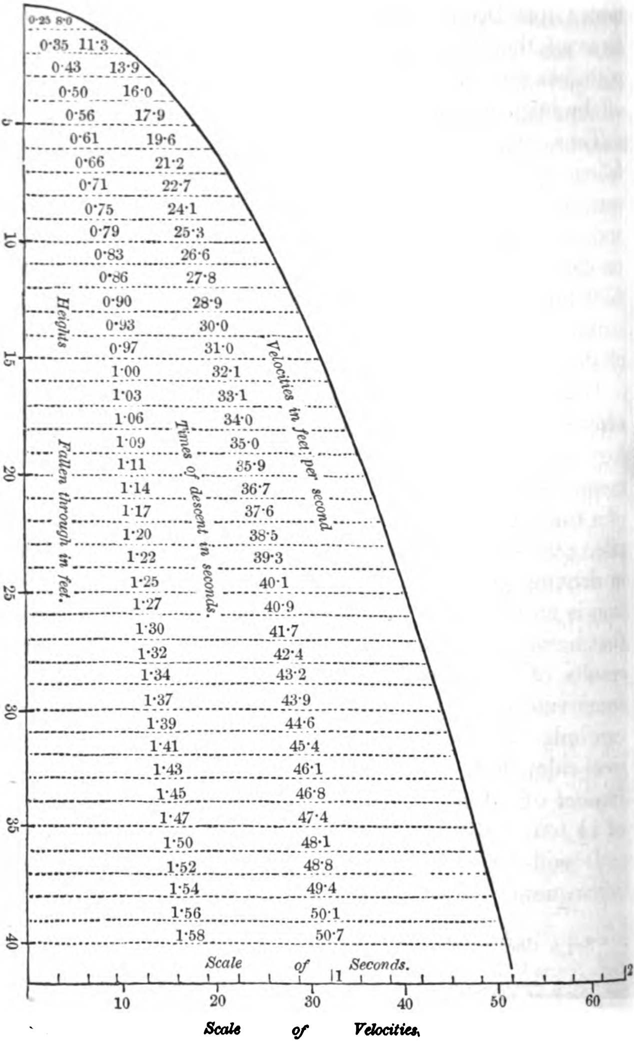
[a] See a similar table and interesting paper in the "Engineer and Architect's Journal," for January, 1842. It is to be regretted that the writer did not, however, explain that there is no means of comparing pressure and impact. The table has been recalculated for the purpose of this volume.


0·25 8·0
0·35 11·3
0·43 13·9
0·50 16·0
0·56 17·9
0·61 19·6
0·66 21·2
0·71 22·7
0·75 24·1
0·79 25·3
0·83 26·6
0·86 27·8
0·90 28·9
0·93 30·0
0·97 31·0
1·00 32·1
1·03 33·1
1·06 34·0
1·09 35·0
1·11 35·9
1·14 36·7
1·17 37·6
1·20 38·5
1·22 39·3
1·25 40·1
1·27 40·9
1·30 41·7
1·32 42·4
1·34 43·2
1·37 43·9
1·39 44·6
1·41 45·4
1·43 46·1
1·45 46·8
1·47 47·4
1·50 48·1
1·52 48·8
1·54 49·4
1·56 50·1
1·58 50·7
Heights Fallen through in feet.
Times of descent in seconds.
Velocities in feet per second
5
10
15
20
25
30
35
40
Scale of Seconds.
1
2
10
20
30
40
50
60
Scale of Velocities.

bodies vary as the square roots of the heights fallen through, that the power expended in driving a pile will also be as the square root of the height to which the ram is raised.

Thus to produce an impact of 32 tons we require in round numbers:—

Weight of Ram, in tons.	Fall, in feet.	Power expended, in tons, lifted 1 foot high.
½	64	32
¾	29	21
1	16	16
2	4	8
3	2	6

The first and last of these cases may be considered as impracticable, and are only inserted by way of illustration; 30 feet may be considered the greatest fall that can be used without splitting the timber, and a ram exceeding 2 tons in weight would be exceedingly troublesome to move from place to place.

In cases where the force required to drive a pile is very small, it is easy to obtain a surplus of power with either the ringing engine or the crab engine, and it will probably be found much cheaper to employ hand labour than steam power. But this only holds good within certain limits. As a general rule, a fall of 15 or 16 ft. is quite the maximum that can be used without risk of injury to the piles, and in practice it is not desirable with the crab engine to use a ram exceeding 12 cwt., as a greater weight involves the employment of additional hands, whose time is almost completely wasted during the shifting of the engine. We may therefore consider, generally speaking, that the maximum force we can exert advantageously with hand labour is that obtained by a 12 cwt. ram worked with a 16 ft. fall. This will give an impact of somewhat less than 20 tons, which is not enough for many cases daily occurring in railway works. For instance, the bearing piles of a timber bridge, which have to sustain the heavy blows given by the driving wheels of our 36-ton locomotives, can scarcely be said to be secure from settlement unless they will *refuse* an impact of 30 tons.

We may, therefore, establish as a principle that wherever an impact exceeding 20 tons is required, it will be desirable to make use of steam or other mechanical power. In many situations where a head of water can be obtained water-pressure engines might be employed with great advantage.

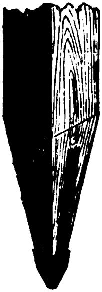
The application of steam power to pile driving is as yet quite in its infancy. The common method of detaching the ram from the hoisting chain at every blow, although a necessary evil in the common hand engine, is quite inadmissible where steam power is to be economically adopted, on account of the time lost in re-attaching the nippers, and, therefore, if the common and very good and simple form of ram and guide-frame is still adhered to, some arrangement similar in principle to that of Clarke and Varley's atmospheric engine appears to be the most advantageous. For heavy work where great power is required, and the extent of the undertaking warrants the outlay, Nasmyth's engine leaves nothing to be desired.

The economy of power is not however the only advantage derived from using a heavy ram with a slight fall. The piles are driven with much less injury, and the splitting of the timber is almost entirely avoided, whilst in working with a fall of from 12 to 20 feet, it is common for every tenth pile to be more or less shaken; and every one who has had the management of pile-driving is fully alive to the anxiety, delay, and expense, attendant on replacing injured piles.

In selecting timber for piles, care should be taken to choose that which is straight-grained and free from knots and ring shakes. Larch, fir, beech, and oak, are the woods most esteemed. In situations exposed to the worm there is little difference in the durability of the best and the worst timber, if unprepared, and, therefore, it is always safest to use some preserving process.

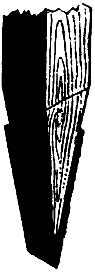
Piles which have to be driven through hard ground require to be *rung*, that is, to have an iron hoop fixed tightly on their heads, to prevent them from splitting, and also to be *shod* with iron shoes; the shoes may be of wrought or of cast iron. For single piles the point of the shoe is placed in the centre of the pile (see fig. 20); but for sheet-piling, the shoes are made not with a point, but with an edge, which is not level, but slightly inclined, so as in driving to give the pile a *drift* towards the pile last driven, by which means a close contact is ensured (see fig. 21). Great care is required, in shoeing a pile, to ensure that the shoe shall be driven perfectly home. The advantage of a cast-iron shoe is, that the inside can be formed with a square butment on which the pile rests, whilst a wrought-iron shoe has to be driven up until the toe of the pile is *wedged* tight, and, as the force with which the

Fig. 20.



pile is driven into the ground greatly exceeds that with which the shoe is driven on the pile, it will often happen that the shoe will burst open, and allow the point of the pile to be crushed before it is down to its full depth.

Fig. 21.



Sheeting piles should be carefully fitted to each other before driving, otherwise they cannot be expected to come in close contact when driven. In some few cases it is worth while to groove and tongue the edges, but this is seldom done, and if the piles are perfectly parallel and truly driven, the swelling of the wood when exposed to moisture will generally secure a tight joint.

As a general rule, broken timber, that is, timber cut out of larger balks, should be avoided. A 10-in. stick of Swedish timber will drive better and with less risk of splitting than a quarter of a 20-in. balk of best Dantzic. If piles must be cut from large balks, the heart of the wood should, if possible, be left in the centre of the pile.

In driving sheet-piling, the piles are kept in their proper position by horizontal pieces of timber called *wales,* which are fixed to guide piles previously driven. In driving cofferdams and similar works, the wales are seldom placed below the water-line, but this may be done with great benefit by attaching the wales to hoops dropped over the heads of the guide piles, and pushed down as low as the ground will permit. In driving into or through a hard stratum, it is desirable that the auger should precede the driving, as it will save much time, and much injury to the piles; and in all cases where a hard-bearing stratum has to be reached at a variable depth, the boring-rod should be used to ascertain the length of pile required, as nothing is more vexatious than finding a pile a few inches too short when driven, or, on the other hand, having to cut off 5 or 6 ft. of good timber, which must be needlessly wasted.

Many writers have endeavoured to lay down rules for calculating the effect of a given blow in sinking a pile, but investigations of this kind are of little practical value, because we can never be in possession of sufficient data to enable us to obtain even an approximate result. The effect of each blow on the pile will depend on the force of the blow, the velocity of the ram, the relative weights of the ram and the pile, the elasticity of the pile head, and the resistance offered by the ground through which the pile is passing, and as we never can ascertain the two last-named conditions with any certainty, any calculations in which they are only assumed must of necessity be mere guesses.

Piles driven for temporary purposes are, at the completion of their term of service, either drawn for the value of the timber and iron shoes, or cut off at the level of the ground if they are in situations where the drawing of the piles might cause any risk to the adjacent work. When sheet-piling has been driven round the foundations of any work, as in forming a cofferdam round the pier of a bridge, there will always be, in the event of its being drawn, the risk of the ground settling down to fill up the vacancy thereby occasioned; but in clay or marl soils this is not the greatest danger, for the water scours out and enlarges the race thus formed, and the bottom speedily becomes broken up, nearly to the depth to which the piles were driven. As a general rule, therefore, it may be laid down, that piles in such situations should never be drawn, but should be cut off at the level of the ground, and this may be done in various ways. 1st. By common means, the men working in a diving-bell, or with diving-helmets. 2nd. By machinery especially constructed for the purpose. 3rd. In the case of cofferdams, by cutting the piles nearly through from the inside with the adze, leaving the pressure of the water on the outside of the piles to complete the operation on the removal of the strutting.

There are many cases, however, in which it becomes necessary to draw piles, and the modes in which this may be done are almost infinite. The common plan, where the situation will admit of it, is to make use of a balk of timber as a lever, one end of which is shackled to the head of the pile, whilst to the other end is applied such power as can most readily be obtained.

A very simple method of drawing piles is by means of a powerful screw, of which one end is hooked to a shackle passing round the head of the pile, whilst the other passes through a cross-head, resting firmly on temporary supports placed on each side of the pile.

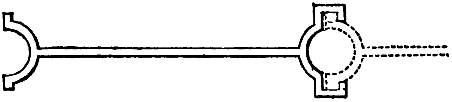
Cast-Iron Piling.

The introduction of cast iron as a material for piles is of comparatively recent date, and although it is not probable that it will ever supersede the use of timber, there are many situations in which it may be used with great advantage.

Cast-iron piles are of two kinds—bearing piles and sheeting piles, the latter being used both for cofferdamming and for wharfing. We have already mentioned the principal forms of bearing piles (page 15), and need here only describe the manner in which iron piles are used for sheeting, in doing which our principal source of information is a "Memoir on the Use of Cast Iron in Piling," published in the first volume of the "Transactions of the Institution of Civil Engineers."

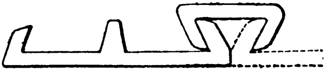
Cast-iron sheet piles were first used by Mr. Matthews in the foundations of the head of the north pier of Bridlington Harbour. These piles were of different forms, the most common being one in which the adjoining piles clipped each other, as shown in fig. 22. The length of these piles was about 8 or 9 ft., their width from 21 in. to 2 ft., and their thickness half an inch.

Fig. 22.



Some time after this, in the beginning of 1822, Mr. Ewart took out a patent for constructing cofferdams of broad cast-iron piles, held together by cramp piles, as shown in fig. 23. The piles were to be made about 15 in. wide, and from 10 to 15 ft. in length.

Fig. 23.



These cofferdam piles have been extensively used by Mr. Mylne, of the New River Head, London, and by Mr. Hartley, of Liverpool, in various works at the Liverpool Docks. Mr. Hartley thus expresses himself concerning their use:—"Considerable care is required in keeping the piles in a vertical position, as they are apt to shrink every blow, and drive slanting. They require to be driven between two heavy balks of timber to keep them in a straight line, as they expose very little section to the blow of the ram, and are so sharp that they are easily driven out of a right line. There is another very necessary precaution to be taken, which is, the keeping of the fall in the same line as the pile; otherwise the ram descending on the pile and not striking it fairly, the chances are, that in a pretty stiff stratum the head breaks off in shivers, and the pile must be drawn, which is sometimes no easy matter." He concludes by saying, "These piles are, on the whole, the most useful tools you can use for their purpose (cofferdamming). I believe they have had as extensive a trial at the Liverpool Docks as anywhere else, and certainly with success. They have generally been driven with the ringing or hand engine, and rams of 3 or 4 cwt., a front and back pile being driven at the same time by one ram."

In 1824 Mr. Walker made use of cast-iron sheet-piling in the foundations of the return end of the quay wall of Downes' Wharf, which required to be rebuilt. In this work the form of the pile was considerably modified from that used by Mr. Ewart, the cramp piles being omitted, and the piles being made merely to overlap each other at the joints.

The next work on record is on a larger scale than those yet mentioned, the wharfing at the sea entrance of the Norwich and Lowestoft Navigation, executed by Mr. Cubitt, and completed in 1832. In this instance the piles were not made to overlap, and it would have been difficult to keep them in line but for the following plan, adopted to secure that object. "This consisted in riveting close to the lower end of the pile about to be driven, a pair of strong wrought-iron cheeks, projecting beyond the edge about 2 or 3 in., which, clasping the pile already driven, served as a guide or groove to keep the pile flush, however thin the edge; and the tendency to turn out or in at the heel was counteracted after a few trials by giving a greater or less bevel to the front or back face."

The next application of iron piles to wharfing that comes under our notice is a wharf on the Lea cut at Limehouse, executed by Mr. Sibley. This wharf is formed of flat cast-iron plates, let down in grooves on the sides of hollow elliptical guide piles, whose greatest diameter is 12 in. The guide piles were 20 ft. long, and were made hollow, to enable an auger to be passed through them, to ease the driving; they were afterwards filled up with concrete. Similar wharfing, on a larger scale, has since been executed adjoining London Bridge, on both sides of the river. The piles on the city side are 43 ft. long, and are cast in two lengths, with spigot and faucit joints.

In 1833–34 Messrs. Walker and Burgess constructed a wharf wall, about 720 ft. long, in front of the East India Dock, at Blackwall, since named Brunswick Wharf. This wharf wall is formed by driving in cast-iron main piles, 7 ft. from centre to centre, the spaces between them being filled up with cast-iron sheet piles, with lap joints, reaching about 8 ft. above low-water mark, whilst the remainder of the height of the wall is made up with three tiers of cast-iron plates, whose width is equal to the distance between the main piles, to which they are bolted. Each main pile is in two heights, the lower part being first driven, and the upper part subsequently bolted on to it.

The great practical difficulty in the application of cast-iron piling to permanent structures is the difficulty of getting the piles all down to the intended level. This difficulty does not exist in cofferdamming, as it is of no consequence in this kind of work whether the heads of the piles range or not.

In driving iron piles it is especially necessary to confine the fall within narrow limits, as a fall exceeding 4 or 5 ft. would be almost sure to fracture the metal. In all cases it is essential to interpose a piece of wood between the ram and the pile head, to deaden the blow, and to distribute its force equally over the pile head.

CHAPTER VI.

CAISSONS.

We have in a former part of this volume briefly explained the methods in which caissons are used, viz. on the natural bottom; on a bed of béton; and on pile foundations. In the present chapter we propose to make a few remarks on each of these methods, and to give, by way of illustration, detailed accounts of two works executed by means of caissons in most unpromising situations—the first in soft bad ground of great depth, the second in loose sand extending to a depth of 60 ft., and liable to shift with every freshet.

We have already spoken of the danger attendant upon sinking caissons upon the natural bottom, on account of the difficulty of forming the latter to a level bed, in default of which the cross strain caused by any irregularities of the surface would be productive of serious injury. But there are cases of soft ground, in which the only available mode of putting in a foundation is by sinking it piecemeal in caissons, weighting them until they have compressed the mud in which they are grounded to such an extent, that no reasonable fear can be entertained of their sinking further with the weight of the superstructure; and, provided there is no tendency to scouring below the bottom of the caissons, such foundations are the very best that can be formed under such circumstances.

The usual material for caissons is timber, the sides being attached to the bottom in such a manner, that on the masonry reaching the required height they can be detached and removed. The late Brigadier-General Sir Samuel Bentham, however, about the year 1810, devised and carried into execution a new kind of caisson, of which the sides should be of brickwork and permanent, the bottom only to be of timber. These permanent caissons, or, as he termed them, "buoyant masses," were used by him with great success in the construction of above 200 feet of sea wall at Sheerness, in the years 1811-12. Sir Samuel's invention is thus described in the "Quarterly Papers on Engineering," part xii:—

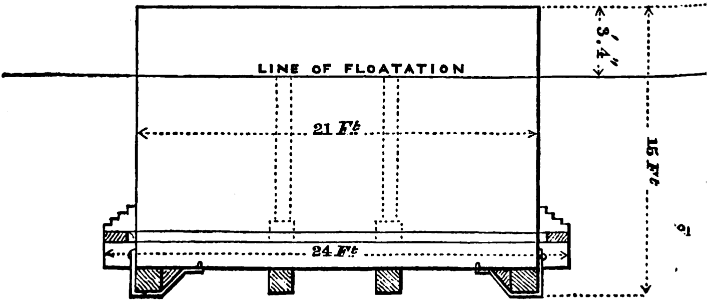
"The invention was that of forming hollow buoyant masses of brickwork or stone, set in Roman cement; which masses, being built on shore to a height above that of the line of floatation, were then to be floated, each mass over the spot it was destined to occupy in the wall, the mass then to be sunk; its height being such as to rise above low water.

"The mass, as executed at Sheerness, thus resting on the foundation, as the tide rose, a flat-bottomed barge was brought over the walls of the mass, and the barge loaded with a weight greater than each mass would afterwards have to bear; on the falling of the tide this loaded barge sank upon the mass, and thus pressed it into the subsoil, until a sufficient bearing was obtained. The mass was then built upon till it arrived at the desired height; the interior was strengthened and filled in with chalk, shingle, or other material, grouted with some indurating matter, up to a certain height, during which operations of course the water was pumped out of the masses when needful.

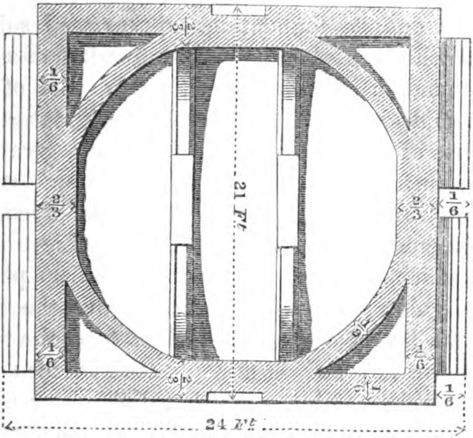
"The bottoms of these masses were formed on a platform of timber, on which was built an inverted arch or dome of brick. The base of each mass from seaward to the interior towards the dockyard was 24 feet; along the line of the wall 21 feet. The masses were so guided in their descent as to be in contact one with the other along that line. The accompanying plan and elevation of the second mass that was deposited exhibits the manner in which strength was given to the walls, by a circular wall built within, and connected with the square walls."

Fig. 24.

ELEVATION.



PLAN. *Fig.* 25.



The injury caused to one of the piers of Westminster Bridge from the ground below the timber platform forming the bottom of the caisson used in its construction not having been made level throughout, is well known, and need not be here particularly recounted. We only allude to it here as a well-known example of the danger of this mode of construction.

Caissons on béton foundations are used on the Continent; but as béton is not used in this country, we believe there is no instance of such a mode of construction having been used in England, although it offers very great advantages in many situations, especially for founding upon an irregular rocky bottom, which it would be difficult to lay dry, and difficult to reduce to a level surface, even if this preliminary difficulty could be disposed of satisfactorily. The béton may be put in by various means, the most satisfactory being that of caissons lined with tarpauling, as practised by the French engineers at Algiers.

Caissons on pile foundations appear well suited to situations where the bearing stratum underlies a depth of soft ground, or in cases where there is a risk of scour, which it is desirable to guard against without going to the expense of laying solid foundations at a great depth below the surface. In the "Art of Building" we have briefly described an example of this mode of construction in the erection of a railway bridge at Liège in Belgium, in which each caisson was sunk in its place by means of guide piles, left standing above the general level of the heads of the piles which form the foundation of the work; we will now give the reader an English example, in which a somewhat different system was pursued, these two examples together containing all the information requisite to enable the reader fully to understand the details of the subject. The following description is compiled from a paper in the 1st vol. of the "Transactions of the Institution of Civil Engineers," the passages between inverted commas being quoted *verbatim*:—

"The Lary Bridge, near Plymouth, is built over the Lary, which is the estuary of the river Plym, and is connected by Catwater with Plymouth Sound. The general width of the estuary is half a mile; but at the site of the bridge the shores abruptly approach each other, and form a strait between 500 and 600 ft. wide. The tide rushes through this strait with a velocity of 3 ft. 6 in. a second, and flows on an average 16 ft. perpendicular. The depth at low water is from 5 to 6 ft.

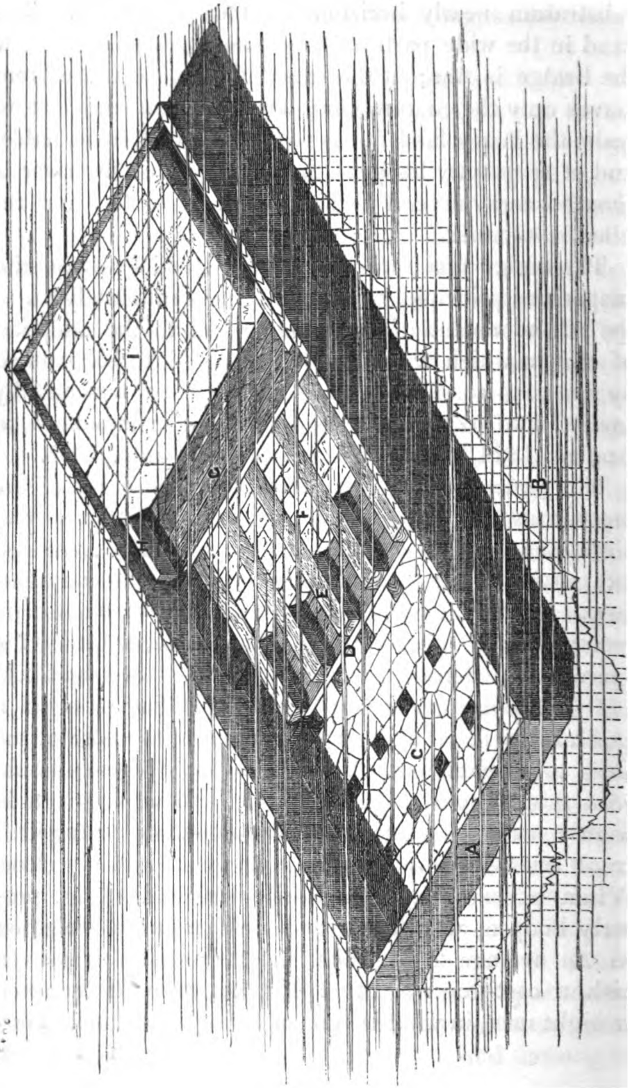
"By borings it appeared that the bed of the river was sand to a depth of 60 ft., the lofty lime rock on each shore dipping abruptly from high water, and forming a substratum nearly horizontal across the strait. The sand in the wide parts of the estuary above and below the bridge is fine; at the site of the bridge the current leaves only the coarser kind, but this is not sufficient to resist the heavy land floods to which the Plym is liable, and it frequently happens that the bed of the river is scoured away several feet in depth in winter, and refilled in summer."

The design first furnished by Mr. Rendel was on the suspension principle, but circumstances ultimately led to the abandonment of this design, and to the adoption of one in which the river was proposed to be spanned by five cast-iron arches, and this design was successfully carried into execution, the work being commenced in August, 1824, and the bridge opened in July, 1827.

It is unnecessary to give here any description of the superstructure of the bridge, our object being only to direct the reader's attention to the methods employed for putting in the foundations of the piers and abutments in such treacherous ground, and we cannot do better than to give Mr. Rendel's own account of the operations undertaken for this purpose. (See fig. 26.)

"We commenced by driving sheeting piles to a depth of 15 ft. around the whole area of the base of the piers and abutments. These piles are of beech plank, 4 in. thick, grooved to each other, and were driven in double leading frames fixed to temporary guide piles; great attention was paid to have them perfectly close. When pitched they were from 16 to 18 ft. long, properly hooped, and shod with plate-iron shoes, weighing on an average 2 lbs. each. These piles were driven with a cast-iron weight of 450 lbs., worked by seven or eight men, in what is termed a ringing engine. They

Fig. 26.



were driven several feet below low water, by means of punches.

"As these pilings were carried on, the sand was excavated from the space they inclosed to a depth of 5 or 6 ft. below the general level of the river, and from 9 to 10 ft. below the level of low water of ordinary tides.

"As these excavations proceeded, the ground was piled with whole timbers (B) of large Norway and small-sized Memel, and as many of beech as could be procured of the desired length; these piles, being properly shod and hooped, were driven from temporary stages fixed above high-water level, by weights varying according to the size of the pile from 10 to 15 cwt.; they were disposed in five rows, in the width of the foundations, from 4 ft. to 4 ft. 6 in. from centre to centre, and were driven till they did not sink more than one inch with eight blows of the 15-cwt. driver falling from a height of 25 ft., and then received twenty additional strokes with the same weight and fall.

"These piles, none of which were less than 35 ft. long, were driven to the level of the stage, and then punched to their proper depth. The punches used for the purpose were made of sound and well-seasoned elm, hooped throughout their length, and having at their lower ends a strong cast-iron ring about 18 in. wide; this ring had a thick partition plate cast in the middle of its width, which separated the head of the pile from the end of the punch; the lower end of the ring was cast a little conical, and the pile heads were made to fit it accurately. By this means the pile heads were but little injured, and the loss of momentum occasioned by the intervention of a punch was reduced to a mere trifle.

"The next operation was to cut off the bearing piles to their proper depth, and to pave and grout the spaces between them. The usual mode of cofferdams was manifestly inapplicable to such a bed of sand; I therefore, in an early stage of the works, proposed to the contractors that the pile heads should be levelled, and the spaces between them paved by means of a diving-bell. To save expense this bell was made of wood, and, with the necessary machinery, was finished and put to work within six weeks from the time it was determined on; with its assistance the works were carried on with expedition and success; when in operation it contained two men, who, being provided with the necessary instruments for cutting off the piles, paving the spaces between them, &c., continued at work for four hours, when they were relieved by two others.

"As much depended on the regularity with which the pile heads were levelled, great care was bestowed on this part of the work. It was accomplished in the following manner:—The four angular piles of each foundation being cut as low as the water would permit, were accurately levelled from a plug on the shore to ascertain how much each had to be reduced to bring it to its proper level; on each of these piles was marked the portion remaining to be cut by the bell men, which being done, all the remaining piles were levelled from them by means of a spirit level, accurately adjusted in a piece of wood, sufficiently long to be applied to three piles at a time. The paving (c) between the pile heads was performed in an equally simple and satisfactory manner."

This diving-bell was made of two thicknesses of 1½ in. well-seasoned elm boards; the whole surface between the inner and outer case being covered with double flannel saturated in a composition of beeswax, and every precaution being taken to render the joints water-tight. The diving-bell was suspended from a carriage mounted on a travelling frame, working on a temporary stage formed about 15 ft. above high water; and by means of the combined action of the upper and lower gauge-trees it was moved with great celerity to any part of the foundations. Detailed descriptions of the construction of the diving-bell, and the arrangement of the machinery for working it, are given in the original paper, to which we would refer the reader for further details respecting this portion of the work.

"The foundations being prepared, and guides fixed to the plank piles, caissons were floated off from the the shore with one, and, in some instances, two courses of masonry (I), and sunk. The greatest success attended these operations, from the care that was taken to get the foundations perfectly level; of course the heads of the plank piles were not cut off until the caissons were sunk.

"The bottoms of the caissons were made of beech plank and beams; the bottom plank (D) was 4 in. thick, and laid in the transverse direction of the pier, across which the beams (E), 12 in. by 8 in., were placed so as to correspond with the rows of piles in the foundation. The spaces between the beams were filled with masonry (F) set in pozzuolana mortar, and grouted; and a flooring of 3 in. plank (G), closely jointed and well caulked, so as to be perfectly water-tight, covered the masonry and beams. The top and bottom planks were trenailed to the beams, and the whole strengthened by a strong frame of beech (H), a foot square, surrounding the bottom and fastened to it by strong screw bolts and trenails.

"The upper surfaces of the beams of this frame were grooved to receive a strong tongue fitting a corresponding groove in the bottom beams of the sides and ends of the caissons, which were made in the usual way, and connected to the bottom by strong lewes irons fitted to cast-iron boxes firmly fixed in the bottom planking. The lewes irons were fixed about 8 ft. apart, and were easily removed when the masonry was brought up to the height of the caisson. The introduction of the tongue in the bottom beams of the caisson proved of the greatest utility, as it prevented leaks from the slight sinkage of the bottom between the lewes irons, which it is impossible to prevent when the caisson grounds.

"The caissons were furnished with sluices, and made 15 ft. high, which gave the masons an opportunity of working about five hours each tide on an average of neaps and springs."

During the erection of the bridge it was found that a gradual scour of the bed of the river was taking place, and that some protective measures were necessary, in addition to the sheet piling, to prevent the undermining of the foundations. Mr. Rendel therefore determined on forming an artificial bed to the full extent to which the natural one was removed, with clay, from 18 in. to 2 ft. thick, covered with rubble stone of all sizes from 200 lbs. each downwards. This plan was put in execution, and succeeded perfectly. To quote Mr. Rendel's words:—"By this union of materials an indestructible bed has been produced. The clay shields the natural bed from the current, whilst at the same time it forms a tenacious cement in which the stone buries itself, and which is hardened by the volume of water constantly pressing on it. In six months after this work was finished, I ascertained that sea-weeds were growing on its surface, and that it was sufficiently firm to resist an oyster dredge."

CHAPTER VII.

COFFERDAMS.

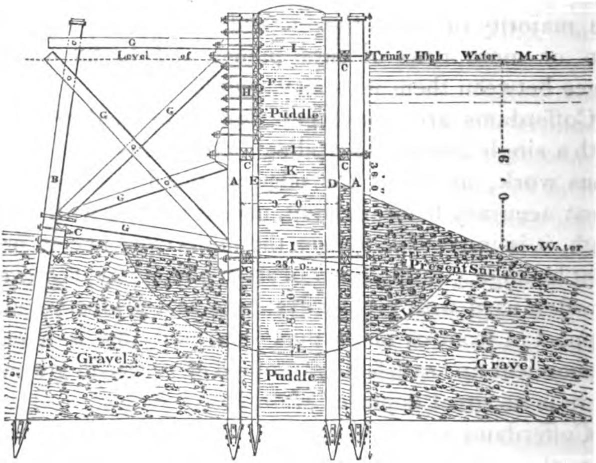
A COFFERDAM may be described as a water-tight wall, constructed round the site of any work for the purpose of laying dry the bottom by pumping out the water from the area thus inclosed.

In some situations this may be effected by earthen dams, by bags of clay piled on each other, or by rough caissons, without top or bottom, filled with clay, and sunk in line round the space to be inclosed; but in the majority of cases the method adopted is to drive two or more rows of close piling, and to fill up the space between them with clay puddle.

Cofferdams are sometimes formed in shallow water with a single row of sheet piling; but this is very precarious work, as unless the piles are fitted together with great accuracy before driving, and are driven with great truth, it is impossible to keep the joints close and to prevent leakage. A single row of sheet piling may, however, be often used with great advantage as a protection and support in front of an earthen dam, and this is a very economical and satisfactory method of proceeding where there is no great depth of water.

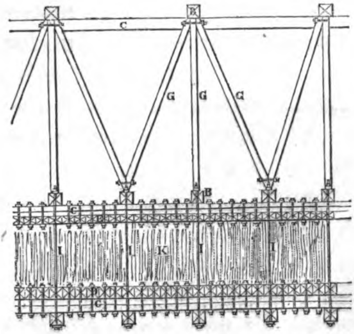
Cofferdams are subject to heavy external pressure from the water round them, which would crush them in were they not very firmly strutted. In cofferdams in-closing a small area, as, for instance, the site of the pier of a bridge, the strutting is placed from side to side, in the manner that will give the greatest facility for carrying on the work, the struts being gradually removed as the latter proceeds. In constructing dams in front of a wharf wall, or similar work, the strutting requires to be effected in a different manner, and the plan usually adopted is to form a series of buttresses, or counterforts, at short intervals, from which the intermediate portions of the dam can be strutted, with raking horizontal struts. The strength given to these counterforts must of course depend on the amount of pressure to come on the dam. The counterforts of the cofferdam used in the construction of the river wall at the Houses of Parliament (see figs. 27 and 28), are formed

Fig. 27.



Section of the Cofferdam used in the construction of the river wall at the Houses of Parliament.

Fig. 28.

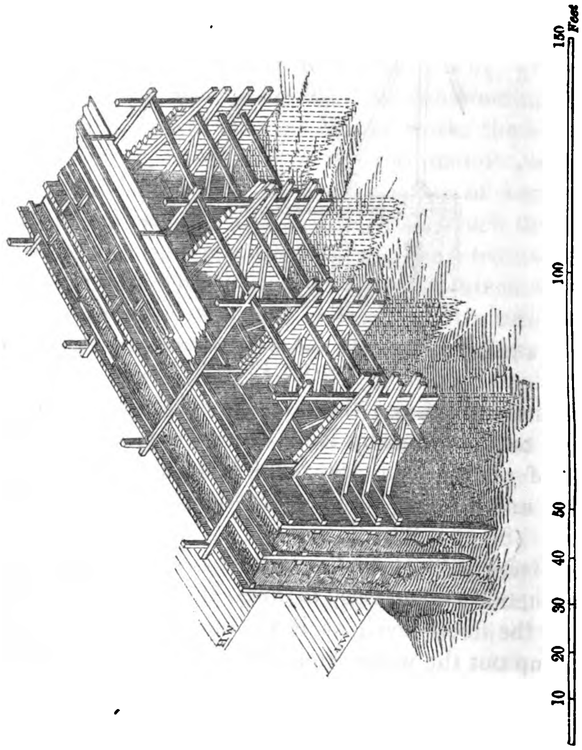


Plan of a part of the Cofferdam used in the construction of the river wall at the Houses of Parliament.

of skeleton framing; those of the cofferdam at the entrance to the Grimsby New Docks are constructed of rows of piles driven close, and brought home to each other, and to the body of the dam, by strong screw bolts. (See fig. 29.)

In rivers subject to heavy freshes it is common, in constructing cofferdams, to keep the top of the dams below the flood level, as it is generally less expensive to pump out the water from the interior of the dam occasionally, than to construct and maintain a dam which should sustain the pressure of the flood waters; and it is always advisable to provide every dam with a sluice, by means of which the water can be admitted, if there is any fear of injury from a sudden fresh, or from any other cause. In tidal waters the operation of *closing* a dam is sometimes rather hazardous (unless it can be performed at low water), from the tide falling outside, without the dead water inside being able to escape sufficiently quickly through the sluices to maintain an equilibrium; and, unless the piles and puddle wall are

Fig. 29.



View of part of the Cofferdam, Grimsby New Docks.

sufficiently strong to resist this outward pressure, the work will be violently strained, and often permanently injured. Where the site to be inclosed is above the level of low water, *half-tide dams* are sometimes resorted to. A half-tide dam is one which is covered and filled at every tide, and emptied by sluices at low water, the available working hours lasting from the time the bottom runs dry until the flood tide reaches the top of the dam.

The principal difficulties in the construction of coffer-dams may be thus briefly stated :—

1st. To obtain a firm foothold for the piles, which, in either rock or mud, is a matter of great difficulty.

2nd. To prevent leakage between the surface of the ground and the bottom of the puddle.

3rd. To prevent leakage through the puddle wall.

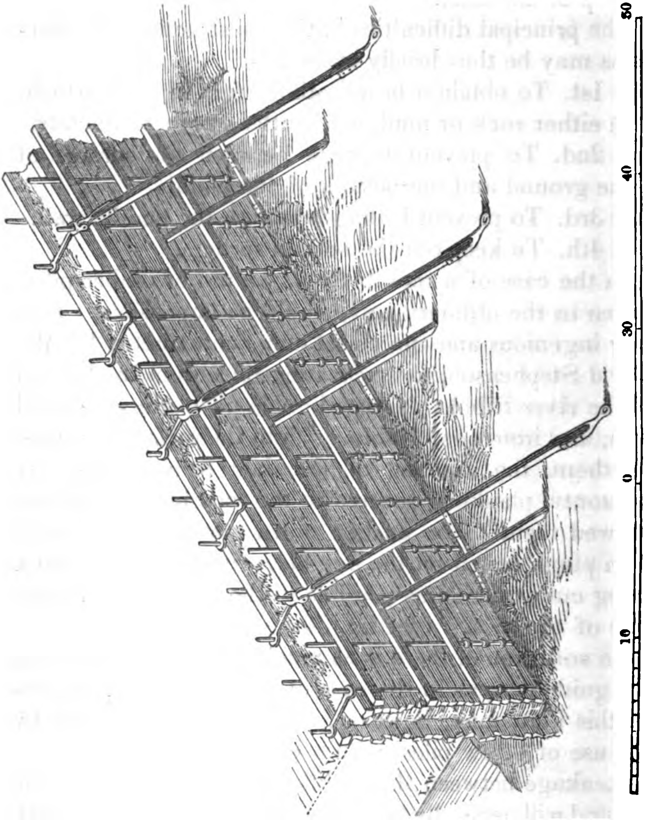
4th. To keep out the bottom springs.

In the case of a rock bottom, the use of timber piles, driven in the ordinary way, would be impossible. In a very ingenious and successful dam, constructed by Mr. David Stephenson, for excavating rock from the bottom of the river Ribble, the usual guide piles are dispensed with, and iron rods, "jumped" into the rock, substituted for them, the sheeting of the dam being formed by horizontal planking, secured to the rods by rings, which allowed them to be pushed down into the water, until each plank rested on the one below it, the bottom plank being cut as nearly as possible to the profile of the surface of the rock. (See fig. 30.)

In soft ground there is as much difficulty in securing the guide piles as in the case of a rock bottom. Cases of this kind may, however, be successfully treated by the use of screw piles, with a broad flange.

Leakage between the puddle and the surface of the ground will generally take place, unless all the loose, soft, or porous surface soil be carefully removed by dredging before any of the puddle is put in. This dredging may be done before or after the piles are driven; the best plan is to dredge for a portion of the depth required before commencing the driving, which is much eased thereby, and afterwards to dredge out a trench

Fig. 30.



View of part of the Cofferdam, River Ribble.

between the rows of piles, sufficiently deep to allow the puddle to lie well below the ground line.

Leakage through the puddle wall itself may arise from various causes, but may generally be prevented by careful work, and selection of good materials. In the first place the piles should be all fitted to each other before driving, and should be truly and carefully driven; next, the framing and strutting should be sufficiently strong to prevent any straining or movement under the varying pressure to which the dam may be exposed by alternations in the height of the water. And lastly, the material used for puddle should be such as will settle down into a solid mass, and should be carefully punned in thin layers, so as to ensure that no vacuities are left in any part. For this reason it is desirable, when the piles have been driven between double walings, to remove the inside wales after the piles are home, as any projections of this kind increase the difficulty of punning the puddle. In order to resist the evil effects which might arise from the swelling of the puddle, the inner and outer rows of piles are usually connected with iron bolts passing through the piles, and secured by nuts with iron plates and large wooden washers, to prevent the former from being drawn into the piles by the extreme pressure. These tie bolts are often found to be very troublesome sources of leakage, as the water soaks in round the bolt holes, and it is difficult to keep the puddle from settling away from the bolts, and leaving a channel for the passage of water through the dam. In the Grimsby dam this is guarded against in a very effective manner. The dam consists of a double puddle wall, inclosed by three rows of piling, and the tie bolts only pass through half the total thickness of the dam, and are fixed, breaking joint with each other, so that no water can find its way through from this cause.

Leakage from bottom springs, where the ground is porous, can scarcely be prevented. The best course to adopt is, to put in a layer of béton over the whole area inclosed by the dam, and so soon as this has set, there will be no difficulty in keeping the dam dry. This is a much less anxious course than to attempt to keep down the water by dint of constant pumping; and the béton, extending for some distance round the base of the work, forms a valuable protection against any scouring action.

It is not uncommon for ground, which appears perfectly firm and sound, to overlie a water-bearing stratum receiving the drainage of elevated land. Where this occurs, the effect is, that on the area being laid dry, and the firm superstratum *thinned* by excavation, the upward pressure of the sub-water will blow up the work, unless the springs are tapped, and the water allowed to rise and flow over the bottom of the dam. This evil may be guarded against by excavating small portions at a time—putting in the masonry of one section before the excavation for the next is commenced, taking care, at the same time, to weight the ground, to balance the upward pressure as much as possible.

The first step to be taken in forming a cofferdam (after the ground has been prepared by dredging) is to drive guide piles, at short intervals, along the line of the dam and to bolt on to them horizontal timbers, called walings, to guide the sheeting piles in their descent. The guide piles are always of whole timbers the walings generally of half balks. The guide piles are usually placed about 10 ft. apart in the length of the dam. If the sheet piles are of whole balks, the wales may be bolted on each side of the guide piles, so that the latter become portions of the sheeting; but if the sheeting piles are half balks, or planks only, the wales are both bolted on the inside of the guide piles, a sheet pile being driven first behind each guide pile, to keep the wales at the proper distance from each other. This is in some respects a better plan than the former, because it is not always possible, in pitching the guide piles, to keep them perfectly in line, and an opportunity is thus afforded of blocking out the guides, so that the wales and sheeting piles shall be perfectly true. These two systems of construction will be well understood by comparing fig. 31, and fig. 32, which show the construction of the dam used at the entrance of the St. Katherine's Docks, with the section of the cofferdam used at the Houses of Parliament (fig. 27, p. 106).

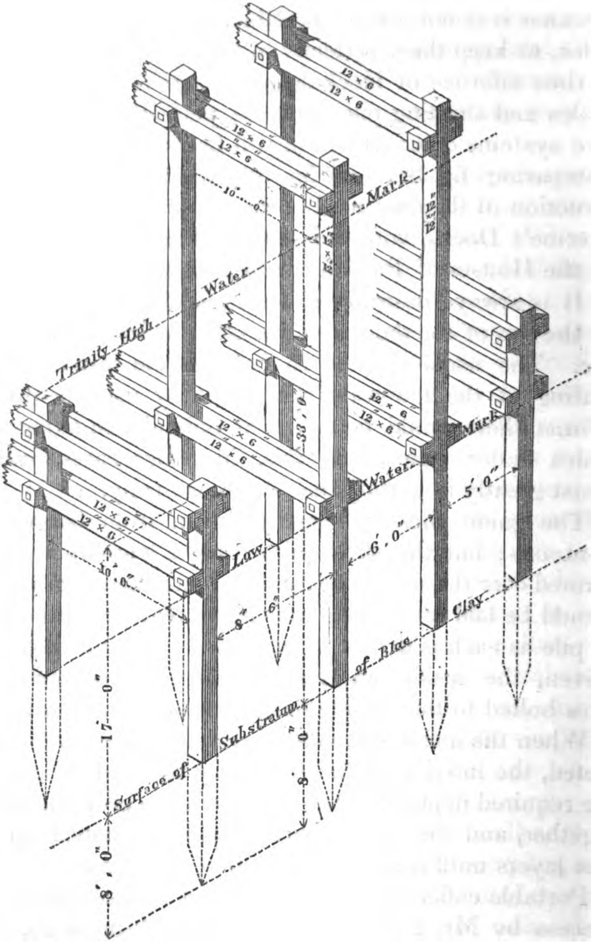
It is always desirable to have two tiers of wales, one at the top of the dam, and the other as low as practicable. The usual plan is to bolt on the lower tier of waling at the low-water line; but by using a diving helmet there would be no great difficulty in fixing the wales under water, and this, in many cases, would assist greatly in getting the piles down truly.

The guide piles are usually driven from barges or pontoons; but the sheet piles from a temporary stage formed over the site of the dam, and on which a gangway should be laid for shifting the engine regularly from pile to pile as each is driven in succession. As the piles are driven, the inside wales should be removed, and the piles bolted to the outside wales with strong screw bolts.

When the inside and outside rows of piling are completed, the interior of the dam may be dredged out to the required depth, the tie bolts put in to keep the sides together, and the puddle thrown in and punned up in thin layers until it reaches the top of the dam.

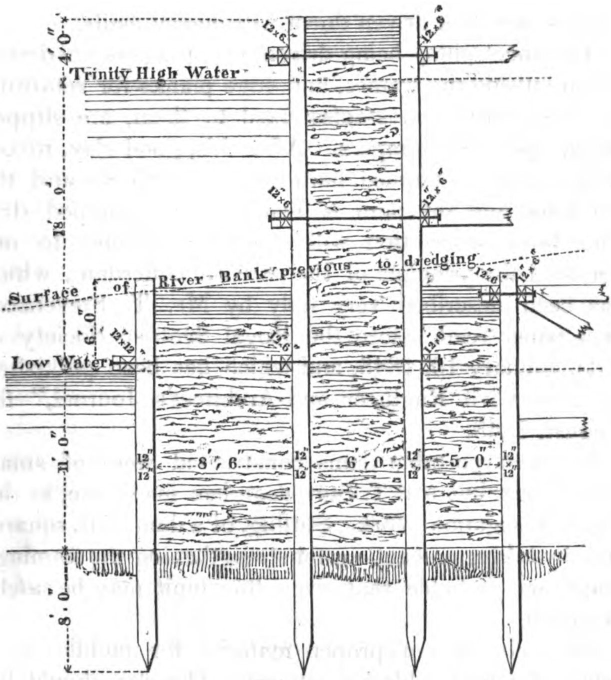
Portable cofferdams have been used of late with great success by Mr. Thomas Stevenson, of Edinburgh, for harbour and marine works, in situations where, from the nature of the bottom, or the exposed position of the

Fig. 31.



St. Katherine's Docks.

Fig. 32.



St. Katherine's Docks.

work, the construction of an ordinary cofferdam would be impossible. These portable dams have two tiers of wales securely framed to uprights at the angles; the upper and lower tiers being bound together by long bolts. Each dam, therefore, consists of two sets of framed walings, one for the outside, the other for the inside of the dam. These frames are floated to the site of the work, and placed in the required position, the one frame inside the other; and the sheet piles, which fill up the space between the inside and the outside frames, are then driven down with heavy malls.

The sheet piling being driven, iron jumpers are driven down outside the frames, and edge planks for retaining the clay, with iron staples fixed to them, are slipped down upon the jumpers. After this, good clay, mixed with gravel, is punned hard between the piles and the planking, and the dam is ready to be pumped dry. This brief description will enable the reader to understand the principle of the portable cofferdam, which has been described very fully by Mr. T. Stevenson, in a paper read before the Royal Scottish Society of Arts, January 10, 1848, and which has been published in the "Civil Engineer and Architect's Journal," for August, 1848.

The first portable dams constructed were of small dimensions, but Mr. T. Stevenson has made use, at the Forth Navigation Works, Stirling, of a dam 35ft. square, and, by taking precautions for strengthening the framing, it appears probable that even this limit may be safely exceeded.

The selection of proper material for puddle is a point of considerable importance. The clay should be thoroughly worked up with gravel before being thrown into the dam; this lessens the tendency to cracking, and makes a much more compact and binding mass than clay alone. Marl, when chopped up small and well punned, answers exceedingly well; as also chalk, if the lumps are not too large. The great point of importance is to leave no large lumps, but to break up the material very small before using it, and to pun it up carefully, so that no vacuities may be left in any part.

We have already spoken of the danger of drawing the piles of cofferdams for the sake of obtaining the timber and iron, which would otherwise be wasted. We need here only repeat the caution, and would most earnestly endeavour to impress its importance on the minds of those engaged in works of this kind.

We have now glanced at the principal points of importance in the construction of cofferdams; there are, of course, a variety of minor details of practical importance, but of a nature to be learnt much better by personal inspection of works in actual progress than by any verbal description. In this, as well as in the preceding chapters of our work, our object has been, not to supersede the necessity for personal observation, but to teach the student how and what to observe, and by laying down first principles to which he may constantly recur, to enable him to understand the object of what he sees going forward in his visits to engineering works, and to judge for himself how far the means employed are suited to the end proposed.

In conclusion, we shall briefly describe a few of the best cofferdams that have been constructed in this country, and would recommend the student to examine attentively the respective systems of construction employed. It would be also productive of much practical benefit to model these dams to a large scale, as the construction of such models is a valuable practical lesson, and the experience gained by so doing will tell with great advantage when the student has the management of such works thrown into his hands for the first time.

(The figures referred to below have all been inserted previously.)

The first dam we propose to describe is that constructed by Mr. Thomas Telford in front of the entrance lock of the St. Katherine's Docks, of which the general construction is shown in fig. 31 and fig. 32. Fig. 31 is a perspective view of one bay of the dam, showing the guide piles with the walings bolted on, preparatory to the driving of the sheet piling; fig. 32 shows a section of the dam when complete, with the inner walings removed. We cannot better describe the dam than by an extract[a] from the specification of the work, which fully explains its construction.

"St. Katherine's Docks.

"Specification for the cofferdam for the entrance lock, to be 207 ft. long, and of the form represented in the drawings.

"The principal dam to be made of two rows of piles, at a distance of 6 ft. apart, of Memel or Dantzic timber 12 in. square; also an outer row of piles of the same timber 12 in. square, at 8½ ft. from the main dam. An inner row to be driven, to strengthen the foot of the main dam, at 5 ft. from it, of fir timber 12 in. square; the piles to be driven 8 ft. below the lowest part of the lock. All the piles to be perfectly straight, and parallel on two sides, and shod with wrought-iron shoes not less than 15 lbs. each; strong iron hoops also to the heads, the iron 4 in. broad by 1 in. The gauge piles to be driven opposite each other at the distance of 10 ft. apart, and their heads, when driven, to be 4 ft. above high-water mark of an 18-ft. tide; when they are driven to the proper depth, two rows of temporary double

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[a] Published in the "Civil Engineer and Architect's Journal," November, 1839.

walings, 12 in. by 6 in., to be bolted to them, the upper one to be 1 ft. above high-water mark, and the other as low as the tide will admit, allowing a space of not less than 12 in. wide between the wale pieces for the piles to fill up the bays between the gauge piles; the bolts to be 1½ in. square, iron, 3 ft. long in the clear, and to pass through the walings and the piles, and also two pieces of timber, 6 in. thick, to be placed under the head and nut of each bolt; the remainder of the piles to fill up the bays are to be driven truly, and each bay keyed in with wedge piles to make the dam water-tight. When all the piles are driven, the temporary walings to be taken off; the joints between the piles of the outer row of the main dam to be caulked where necessary with tarred oakum; three rows of permanent single walings are then to be put on, as shown on the drawings, of timber, 12 in. by 6 in., and in length not less than 20 ft., the two rows of piles to be tied together with screwed bolts, and nuts, with plates, to pass through the walings and piles, and also the two pieces of timber; the bolts to be of the best scrap iron, 2 in. diameter, and proper lengths; the distance between the bolts at the bottom tier is not to exceed 5 ft., the middle tier 7 ft., and the top 10 ft. The dam is then to be filled with good clay to the level of 3 ft. above the bottom tier of the bolts, and from thence to 3 ft. above high water of a spring tide, with bricks laid in sand.

"The gauge piles for the outer rows to be driven 10 ft. apart, and the heads when driven to be 6 ft. above low-water mark of spring tide; two rows of temporary walings, 12 in. by 6 in., to be bolted to the gauge piles, the same as to the main dam, leaving sufficient space between the wales for the piles to fill up the bays, the same as above; the temporary walings are then to be removed, and one of 12 in. square to be put on, as shown by the drawing, and bolted, as above, so as to secure the piles to the main dam, the bolts not to exceed the distance of 5 ft. apart, and every second bolt to pass through the two rows of main-dam piles and walings. This dam is then to be filled in with clay, as above; the inner row of piles, at the distance of 5 ft. from the main dam, to have a double waling, 12 in. by 6 in., bolted within one foot of the top, and to be firmly braced from the inside, and the top part of the dam must be tied to the shore with chains, to prevent its going outwards at low water.

* * * *

A circular trunk, 3 ft. diameter, with sluices for letting the tide flow in and out, is to be placed through the dam. The mud, gravel, and other matter now upon the space where the cofferdam is to be constructed, is to be removed by the contractor, to the level of 12 ft. below low-water mark of a spring tide, and in a uniform inclination to the lowest part of the bed of the river opposite the said cofferdam."

The dam just described is a very strong one, and capable of resisting very great pressure without injury. Our next example, viz., the cofferdam for the river wall of the new Houses of Parliament, is one of a totally different construction, the piling and puddle wall depending entirely for support upon the counterforts and strutting (see figs. 27 and 28).

The following description of the work is extracted from the "Minutes of Proceedings of the Institution of Civil Engineers, February 11, 1840."

"The mud at the site of the works varied much in depth and in consistency, but beneath it is a bed of red gravel and sharp sand, averaging 14 feet in thickness, laying over a stratum of stiff clay, into which the piles are driven to a depth of 2 ft. To facilitate the driving of the piles, a curved trench, 27 ft. wide by 8 ft. deep, was dredged in the line of the dam. The main piles (A) of Memel fir, 36 ft. long by 1 ft. square, were then driven, leaving their tops 4½ feet above the Trinity high-water mark of ordinary spring tides. The waling pieces (C) were then attached, and the outer sheet piles (D) of whole timber, 36 ft. long by 13 inches square, sawn square on all sides, so as to insure the joints being close when driven and bolted to the waling. The inner sheet piles (E) of half timber were then driven to the same depth as the others; the space above them was made up with horizontal pieces (F), bedded down to them, and secured with bolts to the furring pieces (H) inserted above the waling at each gauge pile. The whole length of the dam was secured by diagonal braces (G), extending back to the old river wall[a], against which they were abutted. The outer and inner rows of piles were secured together by three rows of wrought-iron bolts (I), the lower being 2½ in. diameter, and the two upper rows 2 in. diameter. The whole of the piles being driven, the space between was cleared out down to the clay substratum, and then filled up with stiff clay mixed with a portion of gravel; a portion of the excavated matter was then laid on both sides of the dam to protect the piling from injury.

"The first pile was driven on the 1st of September, 1837, and the dam was closed on the 24th of December, 1838. The extreme length of the cofferdam

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[a] In the plan and section here given, the struts are shown as abutting on the brace piles (B), the extension of the bracing to the old wall being omitted.

along the river face is 920 ft., and the ends return at an angle until they meet with and enter the old river wall at a distance of about 200 ft. from the face of the dam."

The cofferdam constructed at the entrance of the Grimsby Docks, of which, by permission of the Institution of Civil Engineers, we are enabled to give a perspective diagram, fig. 29, taken from the drawings presented to the Institution by Mr. Charles Neate to accompany his memoir on that work, is one of the most important dams that has ever been constructed. It stands in deep water, five-eighths of a mile from the high water margin of the shore, and is entirely self-supported. Its length is 1500 ft., and it supports at high water a head of water of 25 ft., whilst the excavation behind it is carried to 11 ft. below low water.

The form of the dam is that of a circular curve, with a versed sine of 200 feet, or nearly one-fifth of the span. The body of the dam is formed by a triple row of whole timber sheet piling, which receives support from counterforts of close piled whole timber, driven at intervals of 25 ft. throughout its whole length. The through bolts are made to break joint and terminate at the middle row of piling, so that no water can pass along them through the dam. In the middle row of piles, wrought-iron longitudinal ties are substituted for timber walings, by which means an uninterrupted surface is left on the piles against which the puddle could be compactly punned.

The execution of the work is fully equal to its design, and it has been emphatically declared to be the longest, the deepest, the strongest, and the tightest dam ever constructed.

A full detailed description, accompanied by engravings, will be shortly published in the "Minutes of Proceedings of the Institution of Civil Engineers for 1850."

We have only space for one more illustration of our subject, viz., the cofferdam constructed by Mr. David Stevenson for excavating rock in the river Ribble.

The peculiarity of this dam consists in its having been constructed on a rock bottom without guide or sheet piles, the sides of the dam being formed of edge planks, secured by staples to iron rods, jumped into the rock and kept in their position by raking stays placed inside the dam.

The following description is extracted from the "Transactions of the Institution of Civil Engineers," Vol. III. (See fig. 30.)

"It will be seen that the cofferdam consists of a double row of iron rods 2½ in. diameter placed 3 ft. apart, the spaces between the rods which form each row being 3 ft. also. On the inner side of each row of rods, linings of 3 in. Memel planking are placed; and the space between these linings of planking, which form the two sides of the cofferdam is carefully filled with well-wrought clay puddle. The sides of the dam are kept together by bars of iron connected to two horizontal wale pieces of Memel timber, measuring 10 in. by 6 in. placed on the outside of the iron rods. These iron bars pass horizontally through the heart of the puddle at proper intervals, and serve to counteract the tendency which the puddle exerts to force the iron rods and planking outwards, and thus to derange the whole structure. A row of strong stays placed 18 ft. apart from centre to centre, as shown in the plate, is also applied to the inside of the dam. To avoid interrupting the navigation as well as for greater safety, the dams were stayed entirely from the inside. These stays, as shown in the drawing, have joints at the upper extremities, and being simply slipped over the tops of the iron rods and kept in their places by *cotters*, their lower ends which rest on the bottom can be moved either horizontally or vertically, and thus be easily adapted to the level of the rock. The shorter stays applied in the first instance can be removed as the work proceeds, by simply driving out the *cotters* at the tops of the iron rods, and their places supplied by longer stays resting on the bottom of the excavation. A sluice at the level of low water, which can be opened so as to admit the water and prevent the dangerous consequences of a sudden rising of the river while the interior of the dam is empty, two cast-iron pumps of 12 in. bore, with their gearing, and a steam engine of 10-horse power for pumping the dams dry, complete the whole apparatus.

" In constructing the dams according to this design, the most tedious parts of the operation were those of fixing the iron rods into the bed of the river, and securing the lower tier of planking which rested on the irregular surface of the rock. The manner in which these operations were effected I shall endeavour briefly to explain.

" In order to fix the iron rods, a jumper point was first worked on the end of each of them. They were then successively *jumped* into the bed of the river to depths varying from 12 in. to 18 in., according to the soundness or hardness of the rock, by labourers who worked from punts moored in the line of the dam, three or four men being employed at each rod. Gauges were used for enabling the workmen to *enter* the rods properly, so that they might retain a nearly perpendicular position when fixed, and also for the purpose of preserving the proper line of the dam and placing the rods at equal distances apart. No other fixture than that produced by simply jumping the rods into the rock was applied, but this was necessarily a tedious process, from the difficulty of working in a rapid run of water, and from the repeated interruptions which occurred, occasioned by the rise of the tides and by land floods. When a sufficient length of rods had been fixed in the manner described, the lower tiers of planking, which were to be placed below the level of the water, were secured to the iron rods by clasps of iron, as shown in the drawings, and slipped down into their places one above another. The under edge of the lowest tier of planking, the fitting of which often occasioned much trouble, was cut previously to being put down, as nearly as possible to suit the inequalities of the rock which were ascertained approximately by measuring from the surface of the water down the iron rods to the bed of the river. The plank being then lowered into its place, a small iron rod, with a hooked end which could go under the plank, was used for finding what parts of it did not touch the rock, and this having been ascertained, the plank was raised and again cut. This operation was repeated two or three times, until a near approach to the contour of the rock was obtained. The lower edge of the plank was then cut with the adze in a bevelled or wedge-shaped form, and the plank being finally lowered into its place in the bottom, was beaten down by blows from a heavy mallet upon an upright piece of wood resting upon the upper edge of the plank, and extending above the upper surface of the water, and the sharp bevelled edge yielding to the blows, sank into the smaller irregularities of the rock, and thus ultimately, as experience proved, formed, in connection with the puddle behind it, a perfectly water-tight joint. The planks above low water had no fixture to the iron rods, and were kept in their places simply by the pressure of the puddle in the inside of the dam."

INDEX.

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