The Author. had been found in the first experimental bay. The flat sheet-pile, guided only on one side, went out of line, and did not form a successful cut-off. The gauge-piles seemed to have rendered the driving accurate, and to have guided the intervening sheet-piles very closely. He had strong doubts whether piles guided on one side would have been successful. It was not anticipated that corrosion would take place to any serious extent, it having been generally found, he believed, that it did not occur in the case of iron buried in this way. Having had occasion to demolish structures of iron in the sea, he had found that while the upper portion of piles, especially the part within the tidal range, had corroded seriously, little or no deterioration had occurred in the part below the surface of the ground.

Correspondence.

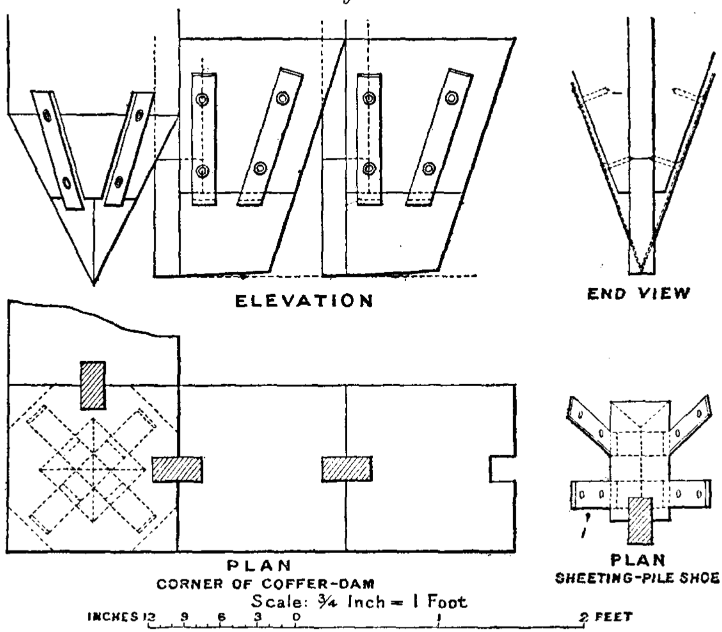
Mr. Brodie. Mr. JOHN S. BRODIE considered the Paper most interesting, as describing what was not only a structure for sea-defence, but also a work which presented to a large extent the problems involved in the construction of a water-tight dam for a reservoir on very pervious strata. It appeared that the borings taken originally at intervals of 600 feet were much too far apart. It was well known to those who had to carry out structures in the proximity of hæmatite deposits that the stratification was almost always very irregular, and borings at such a wide interval would be of little use when the work came to be executed. The experience gained in the actual construction of the Barrier fully bore out what might have been anticipated in this respect. It was open to criticism whether the cut-off under the centre of the clay embankment was really necessary. It must be remembered that the problem in this case was not simply to make a dam, as such, perfectly water-tight; for although a cut-off had been provided by means of a puddle trench tied into the clay, and by the timber and steel sheet-piling, yet, bearing in mind that mining-operations would be carried out under the surface of the foreshore to a depth of probably 10 to 15 fathoms, the water-tightness, either of the dam itself or of its key into the clay, by no means guaranteed the shutting-out of the sea from the mine-workings. Strata might exist underneath the clay bed—as in 1898 in connection with the original sea-wall—which would not be affected by the water-tightness of the dam or of the piling underneath it. It therefore appeared that an equally successful, and much less costly, plan would have been to rely on a properly constructed clay dam, protected on the outer side by the limestone rubble facing and by the irregular blockwork, to preserve the clay dam proper from the erosive action of the sea, and to rely upon the weight of this dam to cause the closure of any fissures which might develop far below the surface of the foreshore. By so doing, the two primary objects kept in view, namely, the flexibility of the Barrier to enable it to follow, without its own destruction, the gradual subsidence of the surface of the foreshore, and a compressive weight to consolidate the underlying strata of sand, would have been equally well secured at a much lower cost. It did not appear from the Paper for what practical purpose the four sluice-culverts had been introduced at all. When the sea-water had been drained from the 170 acres of reclaimed land, a much less sectional area of sluice than was provided by the four culverts would appear to be ample, and anyone with experience of tidal flaps or other mechanical expedients would much prefer to do without them altogether on an exposed foreshore such as this; or, at all events, to reduce the number to a minimum. Mr. Brodie.

Mr. W. Dyce Cay observed that the necessity for the Barrier to possess some power of adjustment to meet subsidence accounted for the large body of clay in the embankment, which was otherwise undesirable, as it might be damaged by atmospheric action; and this mass had probably led to the puddle wall being made unusually thin. Having had some experience of forming a cut-off in difficult ground, he would have preferred a double row of sheet-piling with a clay puddle wall between the rows. He had used this system in restoring the dock-entrance at Arbroath, which had sunk into quicksand; the borings showing 23 feet of soft sand below the sill-level, then 10 feet of coarse sand and gravel, and then sandstone rock. The following was a description of the procedure adopted. He surrounded the site with a single-skin pine dam, like a large caisson, 79 feet by 64 feet inside horizontally, the sheet-piles before being driven being made up into panels of three, each 2 feet 9 inches wide by 11 inches thick, and 41 feet long. These drove well, except in some cases where obstructions such as boulders or ruins of old works were met with. He tried the water-jet, but in this case it did not prove to be of much advantage. The caisson was, however, well shored inside, additional sheeting was driven behind the defective piles, and he was enabled, after pumping it dry, to get out the main part of the ruins. Then a "blow in" occurred, and he had to use diving-apparatus to remove the remainder. The ruins having been removed, the interior of the caisson was dredged to $17\frac{1}{2}$ feet below the sill, and the Mr. Cay.

Mr. Cay. pit was filled up with clay puddle into which bearing-piles were driven 4 feet apart between centres; and two rows of sheet-piling, 8 feet between centres of the rows, were driven across the work, forming a cut-off under the sill. Then, the piles having been sawn off at the level of the top of the clay, and the whole covered with a sheet of jute cloth, concreting under water was proceeded with up to a certain level, the concrete being carried 5 feet deeper so as to form a tongue between the sheet-piling rows of the cut-off. When this had set, the work was proceeded with by working half tide to half tide, powerful pumps belonging to a salvage-company being used to empty the caisson on the fall of the tide. Some leaks occurred, which were built into tubes and ultimately plugged. On visiting Hodbarrow he had been much interested in the arrangement of the pell-mell concrete wave-breaker blocks, and he hoped the Author would give an authoritative description or sketch of it, which would doubtless be interesting to foreign members. It appeared to him that the lowest course, instead of having the base of its blocks horizontal, had each of the blocks canted in one direction, say from right to left, until its sides were inclined at an angle of 30° to the perpendicular in the longitudinal direction of the Barrier; then those of the course above it were canted in the opposite direction, making a similar but opposite angle with the vertical; and the next course reverted to the same direction of cant as the first, and so on: the slope of the work facing the sea being always maintained at 1 horizontal to 1 vertical. He supposed the reason for the adoption of this class of blockwork was that the waves might be absorbed as well as broken, so that no spray might fall on the clay embankment behind the bulwark.

Mr. Clark. Mr. ALEXANDER CLARK remarked that the description given of the experimental piling recalled methods adopted on other works. In the coffer-dams used in connection with the foundations of Putney bridge, which had been designed by him, it had been noted at the beginning of the work that, if a single coffer-dam was to be successful, great attention must be paid to the proper formation of the groove and to the design of the shoe of the sheet-pile. *Figs. 14* showed the formation of the corners of the dams and the adjacent sheet-piles. The 2-inch square plug on the front of the shoe was needed to clear out the open groove left in the pile previously driven. The material was packed very firmly, and on no account must this part of the shoe be brought to a point, as very small stones getting into the groove would lead to the bursting asunder of the timber. The tongue throughout must also be made as tight a fit as possible, no play being allowed. The bevel or "lead" at the point of the pile had also been carefully studied so as to cause each pile to draw tightly alongside the pile previously driven. The piles in these coffer-dams were 45 to 50 feet long and about 14 inches square, the tongues being 4 inches by 2 inches, and the groove in the piles 2 inches square. They were driven in bays of 12 to 15 feet, a sheet-pile being driven on each side of the guide-pile, all leading towards those already driven until the key-pile was reached. This was made of the exact dimensions to suit the space, was sharpened only crosswise to the dam, and had no lead to either side. The system had been so Mr. Clark.

Figs. 14.

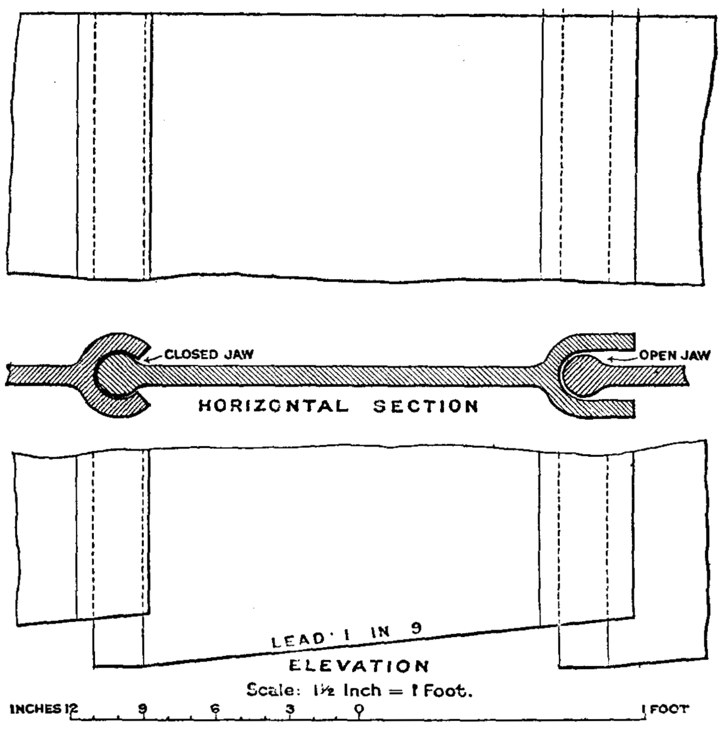


PUTNEY BRIDGE: PILING OF COFFER-DAM.

successful at Putney that the same design had been followed in the foundations of the Battersea bridge, and it had also been adopted for the foundations of the new Kew bridge, by permission of the engineer. In all these cases it had been found well suited to the work, the foundations being in sand, gravel, and clay. There was no drawing in the Paper showing the amount of lead given to the sheet-piling at Hodbarrow, but in Figs. 11, Plate 5, the sheet-piling (which was also tongued and grooved) was shown with diamond-pointed piles. These points did not seem suitable for drawing the piles together so as to make tight joints. In difficult

Mr. Clark. ground it was well not to be encumbered with gauge-piles driven into their permanent position, because there was no flexibility to meet emergencies, and, if there was any part of contractors' work which required provision for contingencies, it was certainly pile-driving. Driving permanent gauge-piles at first necessitated having special sizes for the key-pile on every division, and these were very difficult to get with iron or steel piling. When, however, a gauge-pile was driven temporarily, a uniform size of sheet-pile could be used without any key-pile, as the gauge-pile could be driven permanently into its place after the sheet-piling had been brought up to it. In using iron or steel in that way it was difficult to ensure filling the space accurately; whereas with timber it was not difficult to form a pile tapered or parallel to fill any opening. It would seem to be better to have as few key-piles as possible when steel was the material used. By using a temporary gauge-pile in the manner indicated above, the sheet-piles could be used continuously with far less danger of getting out of line, and with more facility for making a correction, should the pile twist on meeting an obstacle in driving. A good form of steel or cast-iron sheet-pile was shown in *Figs. 15.* It consisted of a solid plate of the required length, about $\frac{3}{4}$ inch thick, having the leading side swelled out to the form of a bead about $1\frac{3}{4}$ inch or 2 inches in diameter, and the other side formed into a jaw or clip to embrace the bead of the pile behind. The jaw at the back of the pile might either have parallel sides or be made so as almost to encircle the bead of the pile behind, and the piles should be made to fit tightly together when driving, without any allowance for play beyond that necessitated by the roughness of the castings, just as the tongues of timber sheet-piles were made to fill perfectly the spaces in the grooves. The closed jaw was preferable if the nature of the ground would allow of its being used, but it might be well to have a few piles with open jaws on the ground in case any correction in plumbing were required. It was mentioned in the Paper that the engines used for driving this piling were of the ordinary type, and subsequently the difficulties experienced with the attachments of the gear were referred to. The ordinary type of pile-driving machinery was of such ancient date that the difficulties connected with its use were almost forgotten. A piling-ram, such as the Lacour or other steam-cylinder design, gave no trouble with monkey-eyes, gauge-bolts and cotters, as the tongue of the ram passed through the leaders and had a very light and simple fastening behind it, which was scarcely ever known to give way. The Lacour machine could strike twenty to thirty strokes per minute at any distance between 1 inch and 6 to 8 feet, according to the length of the ram. When the ram was once set on the top of the pile, it followed it downwards without any further trouble. The original difficulties with this machine were the breaking of the three-way cock and the bursting of the flexible tube; but these difficulties were very slight in view of the amount of work done, and they had long since been overcome. It was not evident from the description why the sheet-piling should have been cut into half-lengths. It was usually preferred to have the piles as long as possible if the length was not altogether inconvenient, as Mr. Clark.

Figs. 15.



they could thus be more easily controlled and kept in place in driving. There was also a great saving in time by not having to stop work in order to fix on the upper portion of the pile, and considerably more rigidity resulted in the whole structure. The necessity for the use of a dolly was not obvious. Possibly the construction of the piling machines had not admitted of the use of hanging leaders for driving piles below the level of the staging on which the piling-machinery was placed, but no details were given of this staging, and therefore it

Mr. Clark. was difficult to conjecture why there should have been a dolly at all. As a general rule, fully one-half of the effect of the stroke was lost by the intervention of a dolly, and in very hard driving the proportion would be still greater.

Mr. Robinson. Mr. JOHN ROBINSON had been favourably impressed, on visiting the Hodbarrow works, by the admirable arrangements for manufacturing, stacking, and depositing on the sea-face of the Barrier, the large concrete blocks to act as wave-breakers; but it was really the steel sheet-piling in which he was interested, as he had had experience himself with cast-iron sheet-piling in connection with new dock-works. He thought that perhaps steel sheet-piling had some advantage in driving over the cast-iron kind he had used, which had bulb-shaped tongues passing down a groove in the adjoining pile, allowing of considerable play. He did not feel sure that the steel had much advantage, and his choice of steel or cast-iron would depend on the nature of the resistances to be encountered. But to get any kind of pile, whether steel, cast-iron, or pitch-pine, to penetrate hard boulder clay, gravel with water-worn stones, or slag, was very difficult and troublesome. In closing a sea-embankment it was advisable to choose for the purpose a place some distance away from the deepest portion, and, if possible, where the ground would not be injuriously affected by scour. The forming of an artificial floor, capable of resisting erosion, on the site proposed for closing, as had been done at Hodbarrow, and closing the gap afterwards with heavy material, was to be commended. On inspecting the Barrier since its completion, he had observed that it was water-tight, with green-sward on the inner slope; and, although there had been stormy weather recently, he could not see that either the limestone or the concrete blocks on the sea-slope had sustained any damage. It would have been quite different had the clay hearting or the backing with clay been omitted, as the tide, on rising after the closing of the Barrier, would have flowed through the rubble or slag, carrying portions of it away inwards, and a similar thing would have occurred on the ebbing of the tide, doing damage to a less extent. He noticed that in addition to the culverts a steam-pump had been provided for lifting water over the Barrier.

Mr. Siccama. Mr. H. T. H. SICCAMA remarked that it was a well-known fact that the driving of piles through layers of compact sand or gravel was difficult and unsatisfactory, as the resistance and the friction increased as the piles were multiplied. As foundations for heavy structures they were not trustworthy in such soils, as often nothing on the surface indicated whether they were properly driven, or shivered, or deflected. If they were driven with the assistance of the water-jet the sand was churned up, and in settling it left a space beneath the cap-sills or timber flooring which might lead to disaster. The steel sheet-piling also, in this case, seemed to have been warped and disjointed on passing through the sand. It had lately been reported that in the harbour-works at Rotterdam, where timber piles had to be driven through a layer of coarse sand, tipped in only shortly before to cover fascine-beds, some of the piles, which were drawn owing to their not having been driven true, were found to be not only split and shivered, but were charred, and caught fire on being exposed to the air. It would be interesting to know whether the Author had noticed similar results. If not, it might be that pitch-pine was less liable to such accidents than the Baltic timber used for the piles at Rotterdam. Mr. Siccama.

Mr. JOHN STRAIN remarked that the works were unique, and well designed for the object in view. The feature of the design was its elasticity, to provide against subsidence, or "draw," due to mineral workings. The engineers had evidently had to feel their way in dealing with this difficult problem; and the Author had frankly recounted the failures made before reaching success. The lesson to be taken from this work was the value of steel sheet-piling as against timber, for either temporary or permanent coffer-dam work. Had steel been used from the beginning, instead of timber and puddle, it would probably have saved much money—and certainly much anxiety. It would add much to the value of the Paper if the cost of the work described were stated against the "Quantities of principal materials used" on p. 189. It would also have added to the interest of the Paper had the Author given some rough estimate of the quantity of ore which the works would render available. Mr. Strain.

The AUTHOR, in reply, remarked that the cut-off under the centre of the embankment was necessary to give security against percolation through the pervious strata immediately underlying the Barrier. After the closing of the Barrier, a spring or runnel of sea-water, which had existed in the mine in the line of the inrush of 1898, gradually became less in volume, and it had since ceased to flow. It would be noticed that there would be no mining-operations in the immediate vicinity of the worst ground, the Barrier having been purposely kept away from the scene of operations here (Fig. 1, Plate 4). The sluices provided for the draining-off of water accumulated behind the Barrier were no more than sufficient, having in view the very heavy local rainfall (45 inches per annum), and the facts that one day's abnormally heavy rain would cause a serious accumulation, and that it was possible to keep the sluices open only for a The Author.

The Author. comparatively short period, as they had to be closed well in advance of the rising tide. The arrangement of the wave-breaker blocks was substantially as described by Mr. Dyce Cay, save that the slope was $1\frac{1}{2}$ to 1, and had been adopted for the reasons surmised by him. It had been found quite satisfactory in attaining the objects in view, no heavy water finding its way to the upper surface of the embankment in any storm that had yet been experienced. The timber sheet-piling forming the western portion of the cut-off was provided with shoes somewhat similar to those described by Mr. Clark, only the gauge- and key-piles being diamond-pointed. The timber sheet-piling shown in Fig. 11, Plate 5, referred to by Mr. Clark, was only a small boxing to confine a narrow gully of silt. In the steel piling the system adopted after trial, namely alternate gauge- and sheet-, or gauge- and key-piles, if that term was preferred, had been found to give very satisfactory results. How accurately the piles as a whole had been driven might be inferred from the fact that in only one case in the whole length of $\frac{7}{8}$ mile had it been necessary to use a special closing-pile. The pumping-arrangements for lifting water over the Barrier, referred to by Mr. Robinson, had been provided by the Mining Company, the directors fearing that, in the event of trade disputes with the miners, the culverts might possibly be tampered with. In the case of the Barrier the piles—with the exception of those under the culverts, as to whose satisfactory driving there was no doubt—had not been driven as foundations to the structure but to form a water-tight cut-off. The pitch-pine piles had driven satisfactorily through the sand; it was in the bed of hard gravel, as mentioned on p. 165, that difficulties had been experienced. Though the Author had found many piles split and burred he had not come across any instance of charring. The cost of the Barrier had been mentioned by Mr. Matthews in the discussion, and the quantity of ore available from the newly-enclosed area might be gathered from Mr. Vaughan's statement that the company would be kept going for 30 years or more, and from the average annual output mentioned in the Paper (p. 157).

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27 March, 1906.

Sir ALEXANDER RICHARDSON BINNIE, President, in the Chair.

The discussion upon Mr. Shelford Bidwell's Paper, "The Outer Barrier, Hodbarrow Iron Mines," occupied the evening.