(Paper No. 3328.)

“Pile Sinking by Means of a Hydraulic Jet at Moruya and Carrington Bridges, New South Wales.”

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THE difficulty frequently experienced in sinking screw-piles has, in some instances, led to the employment of a water-jet to facilitate the work of sinking, and communications¹ on the subject have appeared in the Proceedings of the Institution. The Author desires to acknowledge his indebtedness to these communications.

In the structures described in the following Paper the Author adopted cast-iron piles on account of their durability in teredo-infested salt water. The section of the Moruya River, at the point where the South Coast Road crosses it, shows soft granitic rock underlying sand and clay at depths varying between 4 feet and 36 feet, Fig 10, Plate 10. The bridge which carried the traffic up to the year 1889 consisted of sixteen timber spans of 50 feet each, supported on hardwood piles. In the new structure eighteen spans of 45 feet each and two spans of 25 feet each were adopted, as these spans admitted of the use of corbelled ironbark beams, and it was necessary to construct nineteen piers and two abutments. The deck is 18 feet in width between the curbs.

General Type of Pier Adopted.—Each pier consists of three cast-iron piles, 12 inches external and 10 inches internal diameter, braced as shown in Figs. 2, Plate 10. Each pile was cast in lengths of 12 feet or less to suit the conditions of sinking, and the connections between the lengths of pile were made by means of outside flanges thick enough to admit of the bolts being housed into them, so that after the bolts had been screwed up with a box-spanner they could be flushed over with Portland cement to protect them from the action of the salt water.

¹ Minutes of Proceedings Inst. C.E. Mr. Brunlees in Discussion on “Sinking Iron Columns,” vol. xxvii. p. 309, and “South Reserve Piers and Landing-Stags at Birkenhead,” by C. G. Smith, Stud. Inst. C.E., vol. 1. p. 164.

It was considered desirable to sink the piles of Piers 4 to 14 (thirty-three piles) to a depth of 18 feet to 37 feet, and to fix those of Piers 1, 2, 3, 15, 16, 17, 18, 19, and of the abutments, (thirty piles) in the rock, in holes excavated for the purpose. It is believed that the piles of Piers 4, and 9 to 14, reached the rock and rest upon it.

Type of Shoe.—The maximum load on each pier-pile in the finished structure amounts to 24 tons, with a full live-load of 84 lbs. per square foot of deck, and on the abutment-piles to 9 tons. Whilst the cast-iron columns with flanges, when sunk to a depth of 35 feet in sand, would probably sustain such a load safely, it was considered desirable to increase the bearing-surface by the addition of a shoe, which would also act against overturning in flood by resisting the lifting of the upstream piles. An experiment was made with a shoe of the form shown in Figs. 3, Plate 10, the cast-iron teeth being added to assist sinking in clay, or when decayed timber was met, when it was proposed to rotate the pile. In this shoe the central and only orifice was $2\frac{3}{4}$ inches in diameter; subsequently this shoe was abandoned in favour of that shown in Figs. 4, Plate 10, which is of a lighter and more simple pattern, it being found that the action of the central and radial water-jets alone was sufficient to sink the pile through the sand and a certain distance into the clay, making it unnecessary to provide teeth or rotating-gear.

Experiments were made to determine the most efficient system of orifices, and it was found that a central orifice of 2 inches diameter and four orifices of $\frac{1}{2}$ inch diameter, disposed as shown in Figs. 4, Plate 10, provided the most effective arrangement in the sand and soft clay with occasional sand-bands which were met with; but, as will be seen later, difficulties were encountered when the depth of clay to be penetrated exceeded 11 feet 6 inches, and the clay itself became more compact. Although the size of these orifices may be increased, with a corresponding increase in the pumping-power, no advantage is gained in sinking in sand, while the disturbance at the bottom is unnecessarily increased. On the other hand, the piles might be sunk successfully in sand with a smaller supply of water than that used at Moruya, for, in the course of experiments conducted by the Author, a pile was sunk 10 feet in compact sand with a high-pressure Mumford boiler-feed-pump delivering only 30 gallons per minute, and sinking was only stopped by the pile encountering a very stiff bed of clay. It would appear, however, that the plant about to be described fairly fulfilled the requirements as to efficiency and portability.

Plant used for Sinking Piles.—The water-jet was supplied by

a Worthington pump, having two steam-cylinders 10 inches in diameter and 10 inches stroke, and two water-cylinders 6 inches in diameter and 10 inches stroke, capable of delivering 250 gallons of water per minute, and working up to a pressure of 160 lbs. per square inch. Steam was supplied by a 12-HP. vertical boiler with four tubes, working at a pressure of 80 lbs. per square inch. A 6-inch armoured rubber suction-hose was used, and the delivery-end was connected to a length of 5-inch steel pipe laid in a convenient position along the edge of the pontoon which carried the plant; from this steel pipe branched four connections, one 4 inches, one $2\frac{1}{2}$ inches, and two $1\frac{1}{2}$ inch in diameter, while a spring-valve was provided to prevent sudden shocks to the pump. The intermediate connection between the head of the pile and this steel main was made by a 4-inch armoured rubber suction-hose, a steel U-piece being provided at the head of the pile, Figs. 6, Plate 10. The U-piece was fixed in a gland to admit of the pile being rotated if necessary. The water was pumped into the pile itself, no internal pipe being used. A Marsh air-compressor, having a steam-cylinder 10 inches in diameter and an air-cylinder 10 inches in diameter and 12 inches stroke, was fed from the same boiler as the Worthington pump and supplied air for the air-lock. The air-lock consisted of a steel cylinder 3 feet 6 inches in internal diameter, built in one 5-foot and two 10-foot segments, with an upper chamber, 4 feet 6 inches in diameter and 6 feet in height, having attachments for both the 4-inch water-delivery from the Worthington pump and the 2-inch air-delivery from the Marsh compressor, Figs. 8, Plate 10. A steam-winch, with an independent 6-HP. boiler, and a 3-ton hand-winch were used for hoisting.

Of this plant the Worthington pump and the winches alone were sufficient for the general work of sinking the piles, the air-lock and compressor being for the special purpose of removing timber which, it was anticipated, might be met with embedded in the sand, and also to reach the rock in which the piles of Piers 1 to 3 and 15 to 19, and those of the abutments, were fixed.

Temporary Structures.—As it was necessary to provide for traffic during the progress of the work, the new bridge was built in two sections, and a side-track, 17 feet in width, supported on timber piles, was constructed before each section of the old structure was removed. The hardwood piles of this side track, sixty in number, were each sunk a distance of 16 feet, on an average, by means of a jet, the water being carried down the side of the pile in a 2-inch pipe, and thence into a $1\frac{3}{4}$ -inch auger-hole in the point of the pile,

as shown in Figs. 6, Plate 10. This arrangement was adopted, as it was found that unless the jet was kept central, and following the direction of the axis of the pile, straight sinking could not be attained, the pile following the direction of the jet. The average time occupied in sinking each pile, after it was placed in position, was 4 minutes, being the actual time in motion; and as the piles were supported and lowered from a derrick, no pile-frame being necessary, little delay was occasioned by shifting gear. The pump-gauges indicated a pressure of 5 lbs. to 7 lbs. per square inch, except when clay bands were met, when the pressure would run up to 30 or 40 lbs. per square inch. The piles were of hardwood, 14 inches in diameter at one end, 9 inches in diameter at the other, and 40 feet in length, and weighed $1\frac{1}{4}$ ton each. No additional weight was needed to sink them, and directly the pump was stopped the pile set firmly in whatever position it happened to be at the time. No test was made of the sustaining power of these piles; they supported the load of 10 tons each which came upon them, in conjunction with the vibration caused by the traffic passing over a rough deck, without movement, and it would appear that the sand settled round them, in a short time, as firmly as if it had not been disturbed. It is probable that a number of these piles reached the clay, and in some cases penetrated the upper soft portion of it for some distance; at the north end of the bridge, where little or no sand was encountered, they were sunk into clay as far as the jet would take them.

Sinking Piles of Piers 4 to 14.—The position of each pile having been fixed, borings were taken with an iron pipe 2 inches in diameter, which, coupled to the pump, penetrated the sand with the greatest ease, enabling any change in the strata, or the presence of any obstruction, to be accurately located. During the sinking of eleven of the piles, drift timber was encountered embedded in the sand, and where this timber consisted only of small branches, or even heavier timber well riddled by *Cobra*, no difficulty was experienced in sinking the pile through it, for it would appear that the action of the jet caused the sand, for some distance round the pile-shoe, to become fluid, so that the timber was easily pushed aside or broken. When, however, heavy sound logs were met with, it was necessary to use the air-lock, as described later, to clear a passage for the pile. In the case of the remaining twenty-two piles, no obstacle was encountered.

The guides consisted of four hardwood timbers, faced with iron plates, and fixed as shown in Fig. 5, Plate 10, to bear upon the flanges of the pile; it was found advisable to have these guides as

long as could be conveniently arranged (20 feet in this case), and, although an average length of 30 feet of pile was sufficient to reach the required depth and finish at water-level, an additional length of 15 feet, in five segments, was added, so that the guides might still be effective when the required depth of sinking was approached. The use of short lengths for the upper portion of the column gave a better bearing against the guides than if the flanges were less frequent, and additional weight, obtained by working with a long column, facilitated sinking when stiff strata or any obstruction was encountered. The removal of a portion of the guides enabled the air-lock cylinder to be introduced in place of the pile if necessary. The Worthington pump was capable of working up to a pressure of 160 lbs. per square inch, but directly it was set in motion the pile was found to penetrate the sand rapidly, although the pressure on the water-gauge would only range between 5 lbs. and 7 lbs. per square inch; and it was found necessary to support the weight of the pile by a steel rope from the derrick, and so control the sinking by paying out from a hand-winch. So low was the pressure needed for sinking in sand that the column of water in the pipe would, by its own pressure, escape from the shoe in jerks, thus causing a partial vacuum in the head of the pile, so that if plain rubber delivery-hose was used for the water-supply, as was done at first, it would constantly collapse near the head of the pile, filling again as the pump supplied the void. This constant "breathing" of the hose wore it out, and was the cause of the adoption of the suction-hose for delivery which has already been referred to. It will be seen, therefore, that, had a large supply of water at a fair pressure been available, from such a source, for instance, as a town water-supply, it might well have been used for sinking the piles, and the pumping-plant dispensed with; such a system would, however, necessitate the work being carried on in a continuous line from the source of supply, which is not necessary with a portable plant such as that described.

The time occupied in sinking a pile through the sand overlying the clay, an average depth of 14 feet, after it was placed in position, averaged 6 minutes, inclusive of the time occupied in shifting the gear. The actual rate of movement was about 8 feet per minute, but this was always regulated by the check-rope, so as to prevent any sudden run of the pile taking it out of position. No appreciable variation was found in the speed or ease of sinking in sand at various depths, until the clay was reached, nor was any great difference noticed at the Carrington Bridge, where similar piles were sunk in sand by the same

process to a depth of 20 feet. It is of importance to notice, however, that the fact of the sand being covered by water makes sinking much easier than if the surface is dry; so much is this the case that when the sand was exposed at low-tide it was found desirable to excavate a channel to the point where a pile was to be sunk, and so flood the surface round the pile. When the clay was met with, the pile stopped suddenly and the pressure of the water in the delivery-hose rose to 40 lbs. or 50 lbs. per square inch and higher, the limit not being recorded, as the gauge did not register above 50 lbs. per square inch. As it was necessary to continue sinking, the weight on the pile was increased (by pulling down with a winch) to about 10 tons, the pump being kept steadily at work; after a lapse of 5 minutes to 10 minutes the pile would sink 6 inches to 9 inches. This operation was repeated until the penetration became very slow, which occurred after an average depth of 11 feet 6 inches of clay had been passed through. There is no doubt that this limit to sinking in the clay may be attributed to three causes:—(1) The compact nature of the clay met with at that depth; (2) the resistance caused by the strata closing in under the flange-joints of the pile; (3) the failure of the shoe to clear well. In the case of the piles (twelve in number) of Piers 5 to 8 inclusive, the average depth of 9 feet 3 inches which they reached in the clay, under a 10-ton load and the action of the pump, was considered sufficient, on account of their position in the current of the river. These piles were loaded as described later to test their bearing-power only, but in the case of the piles (eighteen in number) of Piers 9 to 14 inclusive it was considered desirable to press the sinking as far as possible, and with this object in view the pumping was continued until an average depth of 13 feet 8 inches in clay was reached, under the 10-ton load, and movement practically ceased. The pump was, however, kept working for 2 hours to 3 hours longer, and additional loading up to 32 tons per pile was applied, which produced an average additional penetration of 4 feet 4 inches, making a total depth in the clay of 18 feet, on an average, for each of the eighteen piles. The clay, which was several times exposed and examined during the operations with the air-lock, was of a compact nature, with some sand-veins near the top, but stiff and tough below. The Author is of opinion that for sinking in clay the shoe used at Moruya, which was designed for sinking in sand, could be modified with advantage; for it would seem that the action of the jet softened and wore away the clay, but that the hole made had a less diameter than the shoe, upon the

edge of which the pile remained supported until the added weight broke down the resistance. The substitution of internal screwed joints for the external flange-joints used to connect the piles would be found of advantage in deep sinking.

Use of the Air-lock.—As already stated, it was decided to secure the piles of both abutments and of Piers 1, 2, 3, 15, 16, 17, 18 and 19, in the rock, an operation which, in the case of the piers, would, on account of the overlying sand, involve considerable expense in the construction of cofferdams. It was thought necessary to provide the steel cylinder and air-lock, already described, for the purpose of removing drift which might be encountered when sinking the piles of Piers 4 to 14, and it was intended to reach the rock in which the piles had to be fixed by sinking the cylinder through the sand by the pneumatic process in the usual way. Before carrying out this portion of the work it was decided to attempt to sink the cylinder in the same manner as the piles of Piers 4 to 14, by means of a water-jet; and with this object a cast-iron door, having a central and radial orifices like the pile-shoes and designed to open inwards, was provided to close the bottom of the cylinder. On starting operations, the Resident Engineer (Mr. Beynon Reed) discarded this door or shoe, with the satisfactory result that the cylinder, with open bottom and closed top, sank rapidly through the sand when the pump was started, reaching the rock or clay without difficulty. After this first trial the six piles of Piers 2 and 3 were placed as follows:—

Sufficient length of steel cylinder to reach from rock-level to 6 feet or more above high-water level was built, with the air-lock on top, on the spot where the pile was to be fixed, the door at the bottom of the air-lock was left open, and the top door was shut, while the 4-inch delivery-pipe from the pump was attached to the connection provided for it in the top of the air-lock. The pump being started, the water rose in the cylinder until it had attained sufficient head to overcome the resistance of the sand, when it escaped from the bottom with a rush, the cylinder at the same time sinking about 2 feet. It was a very rare occurrence for the water to reach the door at the top of the cylinder, and when it did so the pressure never exceeded 10 lbs. per square inch. Pumping was continued until the rock was reached, when the supply-pipe was uncoupled and its connection closed; the air-pipe from the Marsh compressor was then attached, two men entered the lock, and the water was expelled by the air-pressure in the usual way.

In the case of Piers 2 and 3, where no clay was met with,

examination of the bottom of the cylinder showed the rock to be quite clear of sand, and it was only necessary to excavate a hole 3 feet to 5 feet deep, in the rock, to receive the cast-iron pile. Owing to the small diameter of the cylinder used (3 feet 6 inches) this hole was excavated near one side of the cylinder, so that room remained for a man to stand at one side of a pile placed in the hole. The material excavated from the rock was removed through the air-lock and the cylinder was filled with water to the level of the river, the water being put in from the top to prevent sand entering with it; both air-lock doors were then opened and the necessary length of pile to reach from the bottom of the hole in the rock to water-level was lowered into place. In this case no shoes were fixed to the piles, the flanges of which were the same as the others used in the bridge, and the air-lock doors were circular and of sufficient diameter to admit of the pile-flanges passing through them. It was necessary to place in position only such length of pile as was sufficient to clear water-level, but not so long as to reach within a few feet of the bottom door of the air-lock; for if the top of the pile reached the air-lock door it would be impossible for men to enter to complete the work. The pile being roughly in position, the water was again expelled, and two men, entering the cylinder, plumbed the pile and fixed it in the rock with fine concrete. The water was then re-admitted, and after the lapse of sufficient time to allow the concrete to set, the pump was again applied and the cylinder was lifted with ease from its position, the sand running back into its place, completing the operation. It is difficult to convey in a detailed working description of the process, an idea of its speed and efficiency. The water-pressure required to sink the cylinder rarely exceeded 5 lbs. per square inch, and the time which elapsed from the starting of the pump until the men were standing on the rock below 9 feet of sand and 5 feet of water, was only about 30 minutes to 45 minutes. The small size of the cylinder used necessitated that a small slight man should do the work below, but there is no doubt that a cylinder 4 feet in diameter would have been sunk easily with the same pump. On the economy of the process as compared with building a cofferdam it is unnecessary to comment. At Piers 15, 16 and 17, where clay was encountered, the material was excavated under air-pressure and was sent up through the air-lock in the usual way. In the case of two of the piles of Pier 5, it was ascertained by sounding that heavy timber was embedded in the sand in the position to be occupied by the pile, and the cylinder was sunk in the manner already described until

the timber was reached, when, the air-lock being applied, a man descended and cut a passage for the pile, which was then sunk by means of the water-jet.

Testing Sustaining Power of Piles.—It has been stated that the full load (dead and live) on each pier-pile was estimated at 24 tons. This load is based on an assumption of a live-load of 84 lbs. per square foot of deck-area, which is generally adopted as a standard by the Public Works Department of the State of New South Wales, but is rarely met with in country districts. In the case of the piles of Piers 5 to 8 inclusive (twelve piles in all), the sinking had stopped in clay, and, as the action of the water-jet was to soften and carry away the material below the pile-shoe, it was thought desirable to test the sustaining power in each case; a load of 28 tons per pile was accordingly applied, and was left in position for a period of between 24 hours and 48 hours, or longer in cases where the yield or set reached a maximum. The downwards pull applied when sinking these piles was 10 tons, and it was found that the set under 28 tons was, on an average, 4 inches. The minimum set was $2\frac{3}{4}$ inches; in this case the pumping had been continued for 12 minutes after the pile failed to move under the 10-ton load, $5\frac{1}{2}$ weeks had elapsed between the date of sinking the pile and that of applying the test-load, and the sinking was through 12 feet of sand and 4 feet 3 inches of clay. The maximum set was $10\frac{1}{2}$ inches; in this case the pumping had been continued for $2\frac{1}{2}$ hours after the pile failed to move under the 10-ton load, only 12 hours had elapsed between the time of sinking and the application of the test-load, and the sinking included 13 feet in sand and 11 feet in clay. In general, it was found that the set under the test-load increased with the proportion of clay sunk through, and with the time pumping was continued after the 10-ton load failed to move the pile; while the longer the pile was left before being tested, the less it moved.

On the completion of sinking and testing, the whole of the piles were filled with fine concrete, the object being not only to stiffen the pile but also to prevent the circulation of water, and the possible deterioration of the pile, in the event of any water finding access through the joints; the bracing was then fixed, and the superstructure completed. In the case of some of the piers, however, owing to the bracing not being ready, the superstructure was completed before the piers were braced, but the incomplete work withstood a serious flood without damage.

The Moruya Bridge was opened in 1900, and has since carried a fairly heavy traffic, and been subjected to a flood which rafted

timber heavily against it, but up to the present time (November, 1901) no signs of movement or subsidence have been detected.

Carrington Bridge.—This bridge, like the Moruya Bridge, was erected to replace an old structure. It carries the road-traffic from Newcastle to the Dyke, on which is situated the hydraulic plant for loading vessels with coal. The new bridge has nine spans of 30 feet and one span of 35 feet, all of ironbark beams, with a 24-foot roadway, and one footpath 6 feet in width. The piers consist of cast-iron piles similar to those at Moruya, but there are five piles in each pier, the two outer piles being 1 foot in diameter and the three inner piles 9 inches in diameter, all having shoes of the same size and shape as those shown in Figs. 4, Plate 10. Reference is made to this bridge on account of the sinking being wholly in sand, and also on account of the different method adopted of testing the piles. There are forty-five iron piles in the bridge, those in the abutments, ten in number, being of timber, and, assuming a live-load of 84 lbs. per square foot of deck, the estimated load on each pile is 15 tons. All the iron piles were sunk by the hydraulic process exactly as at Moruya, to a very uniform depth of about 20 feet, in fine sand containing some layers of shells. The work was done by contract, and the plant used was not so complete or convenient as that described as used at Moruya, but the water delivery was about the same, and the sinking was very quick and easy; many of these piles were sunk in 4 minutes from the time of starting, little timber being encountered.

At the time the contract was let for this work, the Moruya Bridge was not sufficiently far advanced to enable a definite test of the sustaining power of the piles to be specified, nor had the Author any other data on the subject to act as a guide. It was anticipated, however, that very little settlement would occur in these piles, as the sand, being very fine, would probably run in under the shoe and flanges, quickly assuming its original position, and would prove very unyielding; on the other hand, the contractor frequently hung the piles up and adjusted them to an exact level to save fitting-pieces, continuing the pumping the while to keep the sand fluid—a system not to be encouraged, as it would appear to increase the risk of a void under the shoe. It was decided to weight some of the piles to 18 tons, and the first two piles so tested gave no sign of yielding although the load was left on for several days; in the case of two other piles, however, where the depth had been adjusted by the means already referred to, yields of $1\frac{1}{2}$ inch and 2 inches respectively were recorded under

the load. As this yield was very small and evidently due to the disturbance of the sand only, and the cost of loading was considerable, experiments were made to ascertain whether the desired result could not be obtained equally well by giving each pile a few light blows with a pile-engine which was available. A timber head was placed on the piles to protect them from injury, and twenty blows were given with a 25-cwt. monkey, the drop being gradually increased from 3 feet to 5 feet. The whole of the piles were treated in this manner with very uniform results, the general set being about $2\frac{1}{2}$ inches, and the maximum set in any case $3\frac{1}{2}$ inches, and it was found, on placing the 18-ton test-load on several of the piles after they had been tested with the monkey, that no further subsidence could be obtained. On the other hand, when the monkey-test was applied to the piles which had previously been loaded, a further set was obtained to an extent sufficient to satisfy the Author that for the purpose of settling the piles the monkey-test was not only the cheaper but also the more reliable of the two. A sum of 20s. per pile was paid for making this monkey-test, but the actual cost was under 15s. per pile.

The Carrington Bridge was completed and opened in August, 1900, and has since carried a heavy and continuous traffic. In no case has the slightest subsidence of the piles occurred.

Since the conditions as to situation, rates for carriage, and labour vary so much, the Author does not propose to give a detailed account of the cost of the pile-sinking, but hopes that the particulars given as to plant, etc., will enable a satisfactory estimate to be made to suit individual cases. It may be stated, however, that the total cost of Moruya Bridge was £9,403 6s. 6d., or £10·78 per foot run of structure (about 12s. per square foot of deck). The metal work in the piers weighed 138 tons, and cost £1,975 delivered, or £14·3 per ton. The timber in the superstructure, 3,875 lineal feet round, and 10,150 cubic feet hewn, sawn and planed, cost £1,690, leaving a sum of £5,738 for plant, sinking the piles, working and erecting the timber in the superstructure, providing, erecting, and taking down the temporary bridge, dismantling the old bridge, completing the approaches, and supervision.

The cost of the Carrington Bridge was £4,725, or £15·3 per foot run of structure (about 10s. per square foot of deck), but any comparison with the Moruya Bridge is difficult, for while the Carrington Bridge is wider, it is much more conveniently situated for supply of material and labour.

These works were designed and carried out by the Author

under the direction of Mr. R. R. P. Hickson, M. Inst. C.E., then Under Secretary for Public Works and Commissioner for Roads, New South Wales, and the Author is indebted to the present Under Secretary for Public Works, Mr. J. Davis, M. Inst. C.E., for permission to communicate the results.

The Paper is accompanied by a sheet of tracings, from which Plate 10 has been prepared.

PILE-SINKING AT MORUYA BRIDGE.
NEW SOUTH WALES.

PLATE 10.

Fig. 1.