(*Paper No. 1765.*)

"Note on the Friction of Timber Piles in Clay."

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THE frictional resistance to motion of piles in different soils is not easily ascertained or well known. The difficulty arises from the fact that when piles are once driven in the foundations of bridges, &c., no occasion, as a rule, occurs by which their adhesion can be afterwards determined. In isolated cases, where foundations have failed, an approximate connection has been formed between the superincumbent weight and the frictional resistance of the piles; these cases, though not numerous, afford some information on the subject. Direct experiments are also but few, so that the data from which to obtain a correct knowledge are not ample. As a small contribution the Author submits the present short note of several observations.

The removal of a cofferdam of whole-timber piles at Hull gave the opportunity for taking the observations.

Previous to the extension of the Albert dock westward a circular cofferdam was driven at the west end of the dock, to keep out the water from the new works. This dam consisted of two rows of whole-timber piles, 5 feet apart, the radius of the outer row being 205 feet. The intervening space was filled with puddled clay to above high-water mark. The dam was made in 1874, and the piles, after remaining in the ground five years, were drawn in January and February 1880.

The nature of the strata at the site of the dam is shown in Plate 11, from which it will be seen that the clay was reached at a depth of 28 feet below the level of the quay. This was a compact bluish clay, and above it there were from 3 to 5 feet of peat, above which again were silt and sand. The west end of the Albert dock was finished with a pitched slope at an inclination of 3 to 1, and the dam was driven into this slope, the points of the piles entering the ground at about the level of the peat, or slightly above. Thus the piles may be considered as having been chiefly in the stiff blue clay. Before the piles were drawn the clay puddle between the two rows was removed to as low a point as possible, which was about 13 feet below the level of the quay, or rather under high-

water mark of ordinary neap tides. The clay puddle that could not be removed would increase to a small extent the frictional resistance to drawing. The clay having been got out the piles were drawn, commencing at the north end of the dam.

A "cat-head" was used to draw the piles. This consisted of a framework of whole timbers, to the cross-head of which was fixed the tackle for lifting—a pair of blocks and six-part chain. The free end of the chain was led round the barrel of a winch, capable of being worked by single or double purchase. The whole of the apparatus stood upon a platform upon the heads of the piles, and was shifted southwards as the piles northward were drawn. To the lower pulley-block a heavy sling-chain was attached, and this was slung round the pile to be drawn and secured with wedges.

The power exerted by one, two, or more men working at the apparatus was previously ascertained by allowing them to lift certain known dead weights with the winch and tackle, under exactly the same conditions as those under which they were used in drawing the piles of the dam. The radius of the handle of the winch was 18 inches, and it was found that the extreme power which a man could put into the machine throughout the revolution was 27 lbs. effective. That is to say, the extreme weight that could be raised by one man, together with the friction of the apparatus, was represented by 27 lbs. at the handle. The same men employed in drawing the dam worked the winch to ascertain the weights lifted; these were as follow:—

Number of Men.	Single Purchase.	Double Purchase.
	Tons. cwt.	Tons. cwt.
1	2 10	9 10
2	4 0	15 0
3	6 0	22 10
4	7 10	28 0
5	9 10	35 10
6	11 0	41 0

The winch was generally used in double purchase, and in commencing to draw a pile perhaps three men were first put at the handle. If they could not move the pile four were tried, and if these could not do it then five, and so on. Suppose, for instance, five men were able to draw the pile, while four could not; the ganger in charge would enter in his book, kept for the purpose, whether the pile which would not move with four men at the handle, moved easily or otherwise when five were tried. Three degrees were used to designate the difficulty in drawing, viz., "easy," "hard," and "very hard," and against each pile in the

book was entered the corresponding degree of difficulty experienced in drawing it. Thus, knowing the extreme loads that four and five men could lift, it was possible to estimate approximately the actual pull required to draw the pile. It would have been easy with a dynamometer to have had the exact pull registered in every case; but such an instrument was not available, and the Author had to be contented with the approximate estimate. The results, though not pretending to great accuracy, are perhaps as useful as if they did; for in any case where the knowledge of the friction in earth is required, it is sufficient to be able to estimate to within a few tons.

In addition to the observation on the pull required to draw the pile, the length and scantling of each pile were taken, and also the depth to which it had been driven in the ground. These were all the observations required.

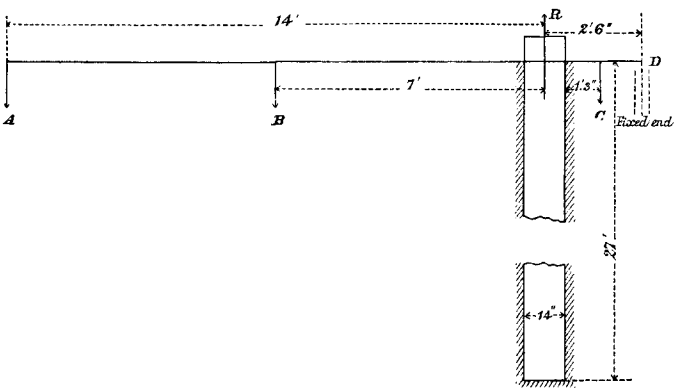
Four hundred and twenty piles were drawn, upon which three hundred observations were taken. The length varied between 20 feet and 49 feet, a few of the short piles being used in the south end of the dam, where it met the pitched slope of the side of the dock. The average length of all was 40 feet. The average scantling was $12\frac{1}{2}$ inches square = 156 square inches, the sizes varying between 12 inches by 10 inches = 120 square inches, and 15 inches by 14 inches = 210 square inches. The depths to which the piles were driven in the ground ranged between 6 feet and 30 feet, the average being $18\frac{1}{4}$ feet. The average superficial area of pile below the ground line was 76 feet.

As the piles were not tongued and grooved, but simply driven close together, and as they were drawn consecutively, only two sides of each pile would have to be taken in estimating the area to which the friction in the soil was due. The average area below ground being 76 square feet, half of this, or 38 square feet, will be subject to friction. The gross resistance, as measured by the pull required to draw three hundred piles, was 33·87 tons per pile. From this must be deducted two items, the weight of the pile and the power required to overcome the suction. For the piles of average scantling, $12\frac{1}{2}$ inches square, there will be required a maximum pull of 156 × 15 lbs. = 2,340 lbs. to overcome the resistance of suction, taking the worst condition, viz., that of a perfect vacuum. The weight of the pile containing 44 cubic feet may be taken at 1 ton. Thus, making allowance for these items, the net frictional resistance of the soil will be 31·82 tons per pile; and this, on an area of 38 superficial feet, gives 1,875 lbs. as the coefficient of friction per square foot in contact with the soil.

The piles were of ordinary rough Memel balk timber. With sawn timber there would probably be a slight reduction in the friction.

In other soils, and with a surface other than timber, the coefficient would be different. During the progress of a 14-inch boring for water the Author observed what force was required to press down the tube lining the hole. This lining was of iron tubing, 14 inches in diameter, and $\frac{1}{16}$ inch thick. The bottom of the tube had reached a depth of 24 feet, and the boring tool was working at a depth of 28 feet, having passed through 20 feet of made ground and 8 feet of silty clay. The hole having been cleaned out, the tube was forced down as follows (Fig. 1):—

FIG. 1.



A = weight of two men = 3 cwt.
B = weight of 14 feet, length of four planks 12½ inches by 3 inches = 7 cwt.
C = weight of 2 feet 6 inches length of same planks = 1¼ cwt.
R = the resistance opposed by the tube.

The end D of the planks being anchored down, it follows from the above that R = 47 cwt. The depth being 27 feet, and the diameter 14 inches, the superficial area in contact with the earth = 100 square feet; so that the skin friction of the tube in this light earth amounted to 0·47 cwt. per square foot = 53 lbs.

Several examples of the friction of soils on piles and piers are recorded in the Minutes of Proceedings.[1]

[1] *Vide* vol. xli., p. 197; vol. xlii., p. 217; vol. l., p. 122; vol. liv., p. 95; and vol. lxi., p. 192.

In close connection with this subject is the relation between the energy imparted to a pile in driving and the weight it will afterwards carry, or the force required to draw it, if it be assumed that friction only is the resistance to motion in each case. The Author has deduced a simple formula for ascertaining the extreme load that could be carried by a pile after a definite amount of driving.

If P = the extreme resistance of the pile in tons,

x = the energy of the last blow, in foot-tons = the product of the weight of the monkey into the height of fall,

y = the "set" of the pile at the last blow, in feet, then the formula is:—

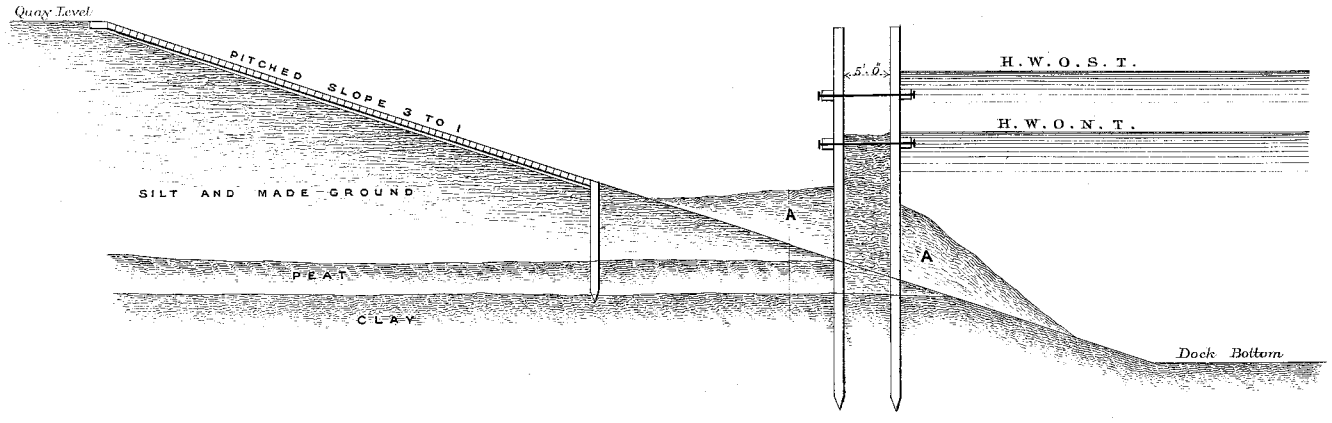
$$y = \frac{x}{P} - \frac{P}{500}.$$

The piles in the dam were driven with a 1-ton monkey falling 5 to 6 feet, and the set of the pile under the last blow varied between $\frac{1}{2}$ and $\frac{3}{4}$ inch.

Applying these quantities to the preceding formula, the extreme resistance is from 35 to 45 tons, while the average resistance to the drawing of the piles was actually something under 34 tons—a result which shows that the formula is tolerably correct for the extreme supporting power of a pile in its worst condition, that of resistance by lateral friction only.

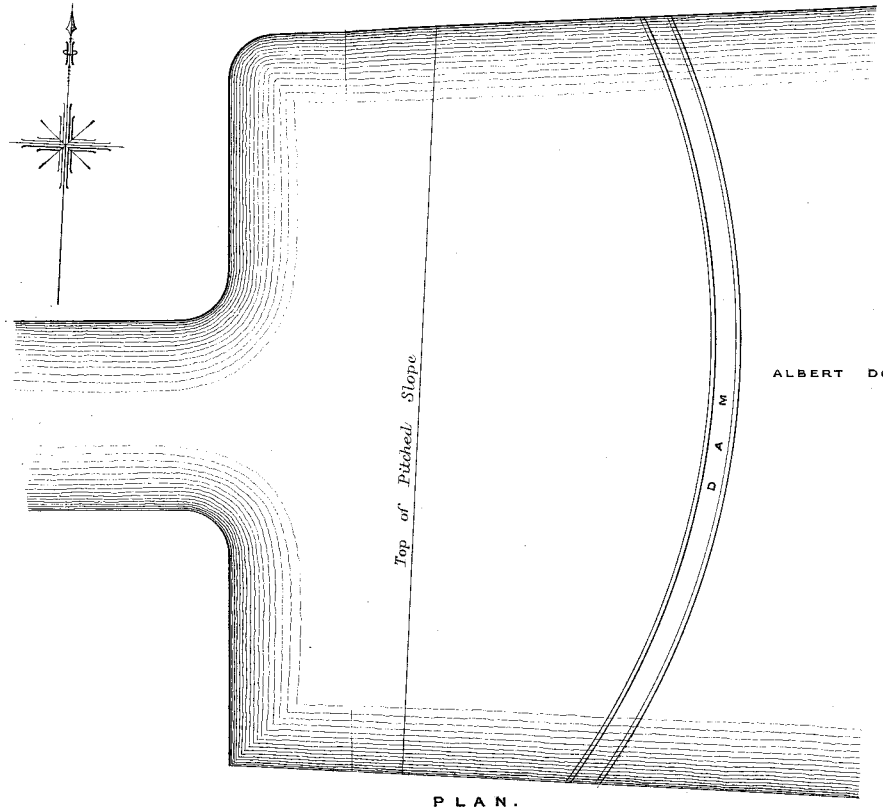
This communication is illustrated by two tracings, from which Plate 11 has been prepared.

FRICTION OF TIMBER PILES IN CLAY.



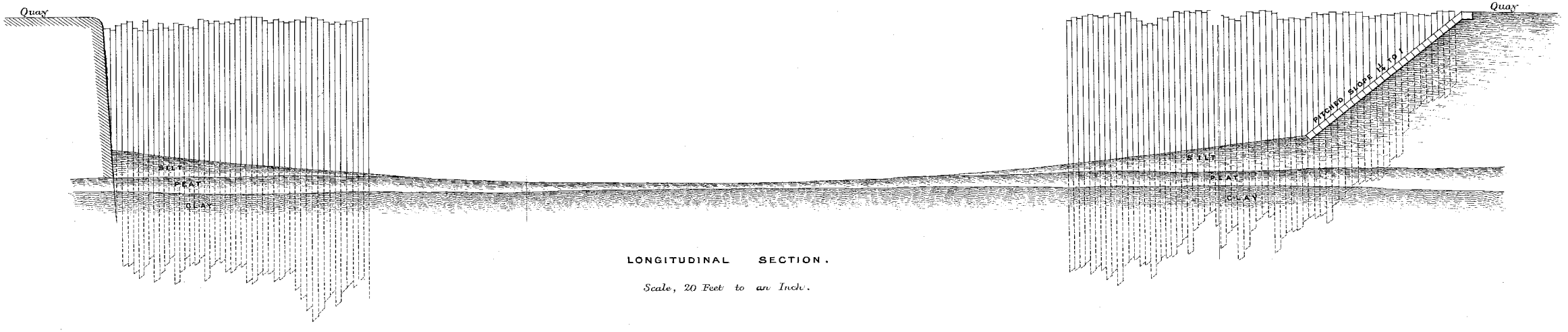
CROSS SECTION.

Note: *The Banks A.A were tipped after the Dam was driven.*



PLAN.

Scale, 50 Feet to an Inch.



LONGITUDINAL SECTION.

Scale, 20 Feet to an Inch.