to keep these stresses at a minimum it was specified that the pile should only be lifted at points one-fifth of their length from each end. No piles were cracked while being properly handled. The few piles that were cracked by accidents were discarded. The piles were cast in pairs and the concreting of a pair once started was continued without interruption until completed. Three feet of the reinforcing rods were allowed to project out of the head of the pile for bonding into the superstructure. No shoes were used on the pile points, the concrete, heavily reinforced, being formed to a blunt point.

As a pier with vertical piles only has small lateral stiffness, bracing piles were driven at an angle of one horizontal to three vertical, and in order to increase the

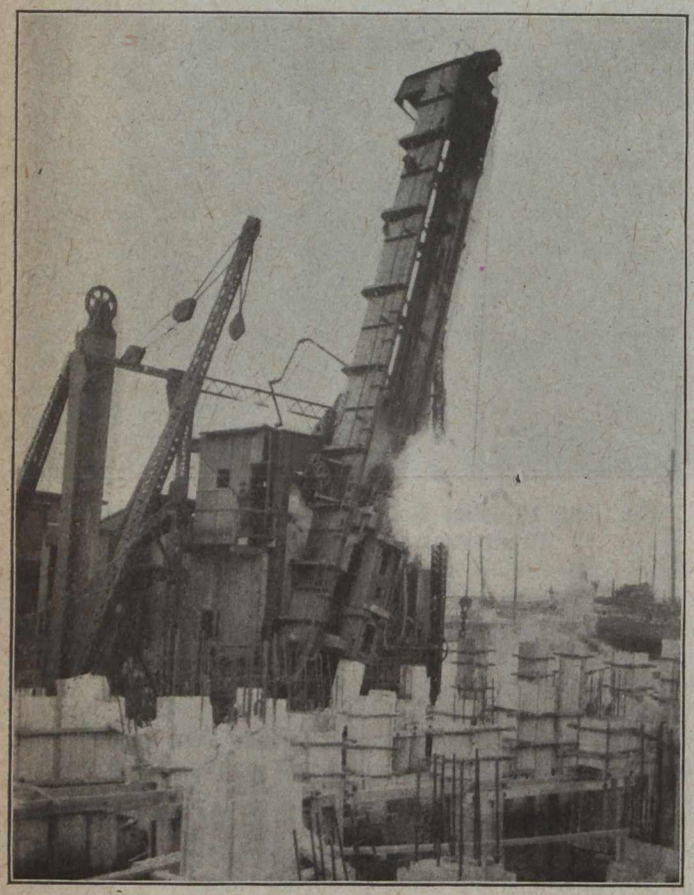

Fig. No. 11—Pier No. 2—Driving Batter Pile

stiffness of these raking piles they were cast with sufficient camber that when driven and built into the pier with their convex side upwards and under an axial load of 80 tons, the stresses on the cross-section of the concrete due to this load, plus the bending moment stresses due to the weight of the pile, would be uniform. The amount of camber required varied from 2 ins. in a 45-ft. pile to 5½ ins. in a pile 75 ft. long.

Each bent consists of 33 vertical piles and six brace piles, three of which latter lean towards the north side and three towards the south side of the pier. The vertical piles are driven singly and in groups according to the concentration of the loads from the superstructure, and the brace piles are driven in such positions that their heads were built up along with the group of piles under each shed column. The bents were driven 18 ft. centre to centre. The total number of brace piles used in the work is 238.

As the piles ranged from 12 to 23 tons in weight, special pile-driving apparatus had to be built to handle them. This apparatus was placed on a strongly built wooden scow 112 feet long overall by 56 feet wide over spud leads and 12 feet deep at the bow.

The drums and machinery for handling the piles in the leads and operating the hammer are supported on a heavy structural steel carriage, mounted on rollers which travel on a track, and the whole is moved by means of a rack and pinion drive. The front of the carriage is provided with two heavy girders. The upper girder carries a trunnion bearing which supports the weight of the leads, while on the lower girder is a specially designed cross-head attached to the leads in such a way that they are held firmly. Trunnion bearing and cross-head are connected to independent screw shafts driven by an engine; hence simultaneous operation of both shafts will move the leads laterally across the carriage, while operation of either shaft alone will cant them. In this way a transverse motion of eight feet as well as a fore and aft play of seven feet is provided and canting of the leads to take care of the brace piles is also made possible.

Largest Pile Hammer of Its Kind

Two forward spuds and one stern spud, each provided with an independent engine, hold the driver in position when in action. These spud engines are controlled by the engineer in his position in the travelling leads carriage by means of levers. The pile hammer used was a double-acting steam hammer made by the Union Iron Works, of Hoboken, N.J. The combined weight of hammer, follower and follower guide is about 16 tons. The cylinder has a diameter of 14 ins. and a stroke of 36 ins. The weight of the piston and ram is 4,150 lbs. With a mean effective steam pressure of 80 lbs. per square inch in the cylinder, the hammer is rated to develop 3,916,000 foot-lbs. per minute when the hammer is striking 80 blows per minute.

Owing to the fact that this was the largest hammer of its kind ever built, considerable trouble was experienced at first in its use, and it was not until June, 1913, that the last of the hammer difficulties were overcome and the driving of the piles could proceed without interruption by serious breakdowns of the hammer.

Two 30-ton derricks were placed at the forward corners of the scow for handling the piles to the leads from the scows on which they were brought up to the work.

Three separate cushions were used between the concrete and the ram of the hammer. On top of the pile was placed 3 ins. of spruce planking on which rested a cast steel follower about 4 ft. high, consisting of a hollow cylinder with top and bottom flanges, the bottom flange having eight holes through which the rods projecting from pile head passed. The top flange had formed on its upper side a rectangular depression in which was placed a hardwood block about 15 ins. thick, bound round with a heavy steel band. This block received the direct blows of the hammer and had to be frequently renewed.

From 200 to 1,800 Blows

The materials through which the piles were driven consisted of from 5 to 27 feet of soft mud and from 2 to 12 feet of hard clay, gravel and stones overlying the rock. The weight of the pile and hammer was sufficient to penetrate the soft mud, while from 200 to 1,800 blows were required to drive the pile to refusal. Although the driving was very hard, the last few inches of penetration being at the rate of 1 inch to 30 or 40 blows, the pile heads suffered practically no damage. Nine piles, at various times, were pulled up after having been driven