wharf encased in 1 : 2 : 4 concrete. Four years after the wharf was built it was found that the steel was badly corroded above high water mark, even where protected with 2½ inches of concrete. Three-sixteenths inch round lacing was practically corroded away. Below mean tide level no signs of corrosion were found. A reinforced concrete lighthouse, built in 1908 in the Malacca Straits, in which the steel had a covering of from 1½ to 2½ inches of concrete, was found in 1914 to be so much corroded from low water of neap tides to 85 feet above

Fig. No. 3—Furness Withy Pier—Tipping Steel Cylinder into Water

high water of spring tides, that extensive repairs had to be carried out. The corrosion in this case may have been helped by vibration caused by wind and wave action, as the structure is reported to have been rather light.

Mr. Ellis also mentioned several reinforced concrete wharves which he had examined in the East, all of which showed more or less corrosive action taking place above high water level. In one case so bad was the corrosion that the concrete had flaked off the underside of the deck beams, leaving the tension steel entirely exposed.

The disintegration or disruption of the concrete above high water level is apparently due to the absorption by the concrete of salt water carried in suspension in the air, which moisture eventually finds its way to the steel and causes the corrosion. High temperatures are favorable to this action. To prevent, or at least retard, this action taking place, it is necessary to have the reinforcing steel covered by an ample thickness of concrete of maximum density, which means generous designing in the size of members, securely tieing the reinforcing steel in its proper place before the concrete is poured so that it will not be pushed aside by the liquid concrete, but be properly embedded where intended, the careful selection of materials, and possibly the painting of all concrete surfaces above high water mark with waterproof paint.

In some cases failure of reinforced concrete structures has taken place between low and high water levels before any signs of disintegration appeared above high water. In cold climates this type of failure is usually due to the mechanical action of frost freezing the water absorbed by the concrete, and thus bursting the outer skin of concrete, aided by the abrasion of the concrete by floating ice and the chemical action of the sea-water on the interior concrete. This chemical action is particularly severe on concrete from which the outer surface has been removed by frost or other means, even when the temperature is low. In certain cases, however, failure between tides has been due to the fact that low water brace members were introduced which necessitated the pouring of the concrete above that level "in situ." Concrete which is allowed to come in contact with sea-water while setting does not have the same power of resistance against the chemical action of the water as concrete which has matured on shore, and, therefore, so far as possible, precast members should be used to at least extreme high-water level.

The mechanical action of frost and ice may be prevented by protecting the concrete surfaces between tides with timber sheathing. Concrete bridge piers in this country which have been so protected have been found in perfect condition under the planking after 25 years' service.

It will thus be seen that the use of reinforced concrete in marine works is attended by some risk, and that protective measures must be taken to preserve its life. This does not mean that reinforced concrete should not be used for harbor works any more than that structural steel should not be used for making bridges. Both are vulnerable, but both can be protected.

It may now be of interest to consider for a few minutes some of the uses to which reinforced concrete has been put in various harbors. The following descriptions have been derived from articles and papers published in technical journals and proceedings of technical societies, with the exception of the works in Halifax, with which the author was connected:—

One of the first uses made of reinforced concrete was in the manufacture of concrete piles to take the place of timber piles, which are so vulnerable to the ravages of the teredo and limnoria. The first piles made were, as a rule, comparatively small, being not more than 12

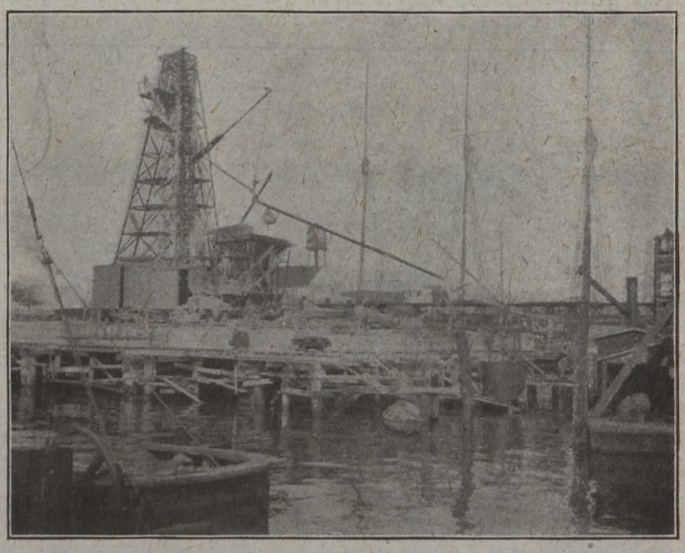

Fig. No. 4—Furness Withy Pier—Concreting Plant

inches, round or square, and their life in consequence did not prove long.

When in England in 1914 the author was informed by one of the foremost concrete engineers in London that he had just completed the rebuilding, from low water level up, of the majority of the concrete piles which supported a reinforced concrete pier built in 1903. Reinforced concrete piles are still being used in English ports, large numbers of 14-inch and 16-inch piles having been used in the improvement works of the Port of