## CONSTRUCTION FEATURES OF CONCRETE SHIPS*

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*The Concrete.*—The concrete must be durable and impermeable to water; it must have a compressive strength of at least 4,000 lbs. per square inch at 28 days, and a minimum weight. To meet these conditions we have determined upon the use of a rich mortar mixture. Any standard Portland cement which will meet the specifications of the United States Government may be used, provided the fineness is increased so that at least 90 per cent. will pass a No. 200 sieve. For the present the maximum-size aggregate is limited to ½ inch. A sand and gravel or a volcanic ash or specially burned clay may be used.

The commercial future of the concrete ships is in large measure dependent upon obtaining a lightweight concrete. The strength and weight of one of these mixtures which meets our requirements is as follows: 1 part cement to 1 part special fused clay below ¼-inch size to 2 parts same aggregate between ¼ and ½-inch size, had a compressive strength of 3,380 lbs. per square inch at 7 days and 4,350 lbs. per square inch at 28 days. It weighed 106 lbs. per cubic foot in a saturated condition. With the use of this material the ratio of the dead-weight to total displacement will be 62 per cent. for the 3,500-ton ship as compared with 65 to 68 per cent. for a steel ship and 53 per cent. for a wood ship. No integral waterproofing compounds of any kind will be used in the mixtures.

*Reinforcing Steel.*—Reinforcing steel which we are using, other than fabric, is of rods or bars rolled from new billets to conform to the American Society for Testing Materials standard specifications for structural grade new billet steel. Plain round bars will be much easier to fabricate than deformed bars, but on account of the uncertainty of the effect of reversal of stress we are using deformed bars wherever the bond stress is high. The accurate bending of the reinforcing is one of the most difficult of all the construction problems. With a wall thickness of only 3½ to 4 inches, and two to three layers of steel, need for accurate bending of the steel can be readily appreciated. Furthermore, the curvature is constantly changing forward and aft in the vessel, which requires constant change in the location of the dogs on the bending table. The use of small steel is recommended, in that it is easier to spring into place if the bending is not accurately done.

With a very large quantity of steel, approximately equivalent to 10 per cent. of the carrying capacity of the ship, to be placed in a very small space in thin walls, there is much opportunity for the development of ingenious methods of fabricating the steel. Undoubtedly much time can be saved by pre-fabricating, at least in part, the steel of the frames and placing them in the ship as units. These frames may be as much as 54 feet in width and 35 feet in height, and they must be accurate to within a fraction of an inch. Through a length of 60 per cent. of the ship the shape of these frames is constantly changing. All the steel must be supported and secured so that it will not touch the form surface. Numerous methods have been suggested, and there are a number of chairs now on the market for supporting steel, but all of them have objectionable features.

A study has been made of welding methods and machines as a means of avoiding the lapping of the steel. The acetylene weld is rather uncertain and not satisfactory. The electric resistance weld appears to be the most promising and several machines of this type have been ordered and are now being tried out. It is not anticipated that welding any steel other than the main steel of the frames and possibly the main longitudinal steel will be required.

*Mixing and Placing Concrete.*—Rich mortar mixtures will be used, and they must be carefully proportioned and mixed in order to insure the quality of concrete necessary. Special attention should be given to the selection of the mixer, as all mixers of common types will not thoroughly mix mortars. The concrete should not be transported from the mixer and deposited directly into the forms in continuous operation or in large batches, on account of the danger of not having it thoroughly worked into place about the reinforcing steel. For the present it is required that all concrete shall be shoveled into the forms in order to insure its deposit in small batches and its thorough working into place.

It is preferable to place the concrete as one continuous operation in order to avoid construction joints. This will require approximately three days (of 24 hours each) for a 3,500-ton ship and six days for a 7,500-ton ship. No trouble is anticipated in working the concrete thoroughly around and through the reinforcing. The rich mortar mixture proposed is quite fluid, even though it is not mixed to a wet consistency, and with a slight tapping of the forms it settles readily into place about the steel. A number of test panels have been made, and the results in all cases have been entirely satisfactory. It is very different to make a construction joint in a section in which is embedded a large quantity of steel. Most leakage troubles occur at construction joints. The uncertainty of the bond obtained at construction joints is also objectionable on account of the large shear stresses. Several mechanical methods of placing mortar and concrete have received consideration, but the results of investigations do not up to the present warrant their use.

*Durability of a Concrete Ship?*—If durability is to be obtained, special attention must be given to many elements of the ship. The most serious problem is to provide means of adequately protecting the steel from corrosion. There is a large quantity of steel embedded in the concrete and much of it cannot be covered by more than ⅝ inches of mortar. This of itself will not protect the concrete, particularly in the interior and in the upper portions of the hull. There are two means of allaying, if not wholly preventing, the corrosion of the steel. The steel may be galvanized or painted with some protecting medium which will not appreciably affect the bond, or the concrete may be coated with some thoroughly impervious membrane which will prevent both air and water from reaching the steel. A large number of tests are being made, and it is quite possible both methods of protection will be tried. The results are promising and a satisfactory protection should be developed.

Another possibly disintegrating element which may have great importance is the effect of constant reversal of stress, as the ship alternately is subjected to hogging and sagging stresses in a heavy sea. Our allowable steel stresses are such as to cause the concrete to crack. No trouble from chemical disintegration is anticipated except as the hull may be seriously abraded. Sugar and certain vegetable oils, such as the cocoanut and peanut oil, will disintegrate the concrete if it is exposed for an appreciable length of time. If the ships are to be used in this class of trade, a protective paint coating should be applied to the inner surface of the hull.

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