Towards the end of the period dealt with, however, the detailed planning referred to by Mr. Thompson had become much more general. His discussion of the possibility of starting excavation at the High wall was interesting. It was tried more than once, and in one case certainly with disastrous economic results. American practice was almost always to follow the coal down from the outcrop and put up with the loss of the two advantages which Mr. Thompson had accurately indicated. That enabled working to be continued to any depth warranted by the plant available when the work started, or which might be made available later, and it had been found profitable in practice on many occasions to continue working much beyond the line of high wall originally adopted on the plans.

Costs varied so widely that any figures given would be misleading and would require a considerable Paper to themselves to enable them to be studied and assessed at their true weight. The ratios and the depth of the high wall also varied so much with different geological conditions that it was impossible to give any general figures. Sites were worked with depth-ratios at the finished high walls of up to 20 : 1, whilst others could not be taken to anything like that figure, sometimes because of physical conditions and sometimes because suitable plant just was not available.

Paper No. 5498.

"Shear Stresses in Reinforced Concrete with particular reference to Concrete Ships." †

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Mr. G. A. Maunsell observed that the problem dealt with by the Author had reference more particularly to the shear stresses developed in the sides of concrete ships due to the longitudinal hogging and sagging which occurred when navigating in rough water. Stresses set up in the longitudinal side walls of floating docks were caused by the hogging and sagging which occurred when towing in rough water, and were also caused by inequalities of longitudinal loading which took place when docking ships in calm water. The shear stresses set up from the latter cause were, as a rule, less severe than those which might be set up from the former and were not aggravated by continual and rapid alternations.

Therefore a floating dock which is designed for stationary use in a port

† J. Instn Civ. Engrs, vol. 26 (1945–46), p. 377 (May 1946).

need not be given such great longitudinal strength as had to be provided in one which was intended to be towed about in the open sea. Most of the reinforced-concrete docks which Mr. Maunsell had built for the Admiralty during the war were, however, intended to be towed across the oceans and their longitudinal side walls had to be made strong enough to bear the severe alternating shear stresses set up by waves.

In designing those docks, 3 : 1 gravel concrete of the highest quality was alone specified, vertical reinforcing-bars sufficient to carry the calculated shear were provided, and a double layer of horizontal reinforcement was also furnished. The horizontal reinforcement was intended primarily to resist the hydrostatic bending moment which arose when immersing the dock for docking purposes, so that, when a dock was being towed at sea, the horizontal wall reinforcement was in part available to act in combination with the vertical shear bars so as to provide the equivalent of those diagonal shear bars, the superior effectiveness of which had been pointed out by the Author.

In calculating the amount of vertical shear force which a vertical section of reinforced-concrete wall might safely sustain, the Code of Practice allowed up to 480 lb. per square inch, but in the floating dock design alluded to above a shear stress of 250 lb. per square inch was rarely exceeded. That compared with the figure of 600 lb. per square inch which the Author stated should be allowed in the case of concrete ship sides, although it was not quite clear whether he intended such a high value to be used with the lightweight concrete mentioned by him.

The Author had indicated that the so-called shear stress could be resolved into a diagonal compressive stress in the concrete combined with a diagonal tensile stress at right angles which was taken care of by the reinforcing steel bars provided for that purpose. That being so, the question arose why it was necessary to limit the compressive stress set up in the concrete to 250 lb., 480 lb. or 600 lb. per square inch when the compressive stress normally permissible in the same material was 1,000 lb. or 1,200 lb. per square inch.

The answer appeared to be that shear stresses set up in the web of a comparatively thin deep vertical beam such as the vertical side of a ship or of a floating dock, were accompanied by secondary stresses in planes perpendicular to the wall plane, and such stresses tended to disrupt locally or buckle a thin wall of that kind lacking side support.

Evidently, therefore, it was the inherent lateral weakness of a thin wall which rendered it necessary to keep the compression due to shear stresses down to one-half, or less than half, the value permissible in normal compression.

Looked at in that way, the Code of Practice value of 480 lb. per square inch calculated on the concrete area of high-grade concrete might be regarded as correct, and in Mr. Maunsell's opinion a shear stress of greater magnitude could not prudently be permitted; indeed, the stress of 480 lb. per square inch could only be employed in cases where ample diagonal or the equivalent of diagonal steel reinforcement was provided, and also only in cases where the concrete itself had a high Young's modulus and was of the most dense and substantial quality.

If the concrete was not of the highest grade, or if the concrete, even though of high grade, was subject to alternating shear stresses, a lower shear stress than 480 lb. per square inch seemed to be indicated. That would involve the consequence that a reinforced-concrete ship or floating dock would inevitably weigh more than a steel ship or a steel floating dock of equal capacity—a fact which involved the further consequence of presenting an almost fatal objection against the use of reinforced concrete for building ships' hulls.

In the case of floating docks that objection also existed, but it was less serious and could, in fact, be more than compensated for in other directions.

The Author, in reply, observed that he did not think that the disparity between allowable concrete web shear stresses and allowable compressive stresses usually required by regulations was intended, as Mr. Maunsell had suggested, to deal with web buckling. Webs in building beams were comparatively robust and totally unlikely to buckle and it was for them that the allowable low shear stress was intended. The Author had endeavoured to make clear, in the Paper, that low allowable shear stresses were intended to deal with the comparatively ineffective action of the shear reinforcement in eliminating cracks. In brief, the Paper went to show that if high shear stresses had to be used, they were perfectly satisfactory, provided that reduced shear stresses were used in the shear steel, particularly of the stirrup type.