|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Draught of Waler.** | **Sagging.** | | | | **‘ Hogging.** | | | |
| **Maximum Compressive Stress.** | **Maximum Tensile Stress.** | **E by Strain Indicator.** | **E by Deflec­tion over the whole length.** | **Maximum Compressive Stress.** | **Maximum Tensile Stress.** | **E by Strain Indicator.** | **E by Deflec­tion over the whole length.** |
| Fcet. ' 6 | 1∙7 | 2∙3 | 12,100 | 1I,8oo | I ∙o | •9 |  |  |
| 5 | **2** \*9 | 37 | 12,100 | **12,000** | 2∙7 | 2∙6 | 16,000 | 11,800 |
| 4. | 41 | 5\*4 | 11,400 | 11,400 | 4∙2 | 4∙o | i5.ιoo | 10,800 |
| 3 | **5∙2** | 6-6 | 11,400 | **11,500** | 5∙3 | 5∙o | 13,000 | 10,400 |
| *2* | **60** | 77 | 10,800 | 11,100  10,600 | 6∙1 | 5-8 | 12,700 | 9,600 |
| I | 6\*5 | 8-4 | 10,700 | 6 6 | 64 | 12,700 | 9,900 |
| Dry | 67 | 8-6 | 10,200 | 10,300 | 6∙8 | 6∙6 | 11,800 | 9,800 |

*Note.—*The maximum stresses above are approximate, and are recorded in order that the given by *y = a* sin πt where Tι is the variation of E with the stress in the material may be seen. Tons per square-inch units are 41

employed.

the values for E found from the dock experiments. The maximum stresses were as follows :■—

|  |  |  |
| --- | --- | --- |
| Condition. | Stress—Tons per Square Inch. | |
|  | Keel. | Deck. |
| Maximum observed stresses |  |  |
| when hogging ....  Maximum observed stresses | 2 ∙9 c. | 2·0 T. |
| when sagging .... Calculated stress (sagging) when in a wave hollow of height | 5·4 T. | 2∙5 C. |
| 1/20th length .... | 7·1 T. | 5·3 C. |
| C. = Compressive | T. == Tensile. |  |

It appears from these experiments that (at least in ships of similar character to H.M.S. “Wolf”) the stresses corresponding to any particular external conditions closely agree with those calculated from the usual theory of bending; on the other hand the waves encountered during the sea trials were such that the maximum stress then obtained was considerably less than that in the condition assumed for the standard calculations. Finally, the material of the ship was subjected in dock to a tensile stress of nearly 9 tons and a compressive stress of nearly 7 tons per sq. in. without distress.

While dealing with longitudinal bending, some of the refinements suggested for calculating stresses 'among waves may be cited, although the additional labour involved in their application has prevented their introduction in general practice.

Since the distribution of pressure in the water of a wave system differs from that in still water, the buoyancy of a vessel or the resultant vertical thrust of the water is then not equal to the weight of the water displaced; and the position of the ship when in equilibrium, and the stresses upon it are changed in consequence. By assuming the pressure at any point of the water to be in accordance with the trochoidal theory of wave motion, and undisturbed by the intrusion of the ship, the equilibrium position can be obtained and the modified stresses evaluated. This process was first applied to ships by Mr W. E. Smith *(Trans. I.N.A.,* 1883), who obtained the arithmetical sum of the sagging and hogging moments on vessels placed in the trough and on the crest of a wave, thereby eliminating the effect of the distribution of weight; and compared it with the sum of the moments as ordinarily obtained. The correction for the ships considered involved a reduction of the bending moment to about 5/8 of the value calculated in the ordinary manner, and in a torpedo-boat destroyer a reduction of about 10 % has been obtained. This reduction increases as the draught and fullness of the ships are increased, and the bending moment on a square-bilged ship deeply immersed is almost uninfluenced by wave motion, since the reduction in orbital motion at considerable depths below the surface ensures the bottom of a fairly deep ship being in comparatively undisturbed water.

In the foregoing the vessel is assumed to occupy at every instant a horizontal position on the wave with the correct displacement; a ship proceeding perpendicularly to the crests of a wave system will, however, undergo heaving and pitching oscillations which lead to a further modification in the bending moment obtained (see paper by T. C. Read, *Trans. I.N.A.,* 1890). Considering first the effect of pitching only, imagine the ship at her proper displacement (allowance being made for the altered buoyancy of the wave system as before), but momentarily out of her correct trim; the longitudinal restoring couple, due to the wedges of immersion and emersion, is balanced by the moment of the reversed mass-accelerations of the component parts. If the ship is longitudinally symmetrical about her midship section, one half of the moment of the restoring forces and one half of the moment of the reversed mass-accelerations about amidships are due to the forward end, and one half to the after end. These moments are therefore equal and opposite for each half of the ship and have no influence on the midship bending moment. It appears, therefore, that in the majority of ships whose departure from longitudinal symmetry is slight, pitching has little effect on the amount of the maximum longitudinal bending moment ; nevertheless it considerably increases the bending moments near the ends.

The effect of heaving is investigated by obtaining the positions of equilibrium of the C.G. of the ship when on wave crest and in wave trough; intermediate positions of equilibrium are assumed to be

apparent semi-period of the wave. On taking into account the mass of the ship, assumed originally stationary, the height of the C.G. above its mean position becomes

ν Tl2 ( . *ΙΓt* T . *1Γt }* “ ^rPj2-rp2 } Simp \*ρ Sl∏rp > ) where T =7r^^ = period of dip in still water;

W is the displacement, and *p* the tons per foot immersion; the re­sistance to vertical motion being neglected. When T and Ti are nearly equal, allowance has to be made for the resistance by using a process of graphic integration. On applying the correction to two vessels, and comparing the bending moments in their positions of the wave, given by the formula, with those in the equilibrium position, the effect on the maximum hogging moment was found small; but the sagging moment of a moderately fine vessel was increased by over 20%, and that of a full vessel by about 10%.

Allowance has also been made for the effect of the superposed heaving, pitching and rolling oscillations undergone by a ship moving obliquely across the crests of a wave system (see papers by Captain Kriloff, *Trans. I.N.A.,* 1896 and 1898).

The maximum calculated stress on vessels inclined to considerable angles of heel has been found in some instances to be slightly greater than that for the upright condition; and the stress on the material towards the ends is then usually more nearly equal to that amidships.

In addition to the direct stresses on keel, bottom, and upper works resulting from longitudinal bending, shearing stresses are experienced which in some cases are of appreciable magnitude. The in-

FAs tensity of shear stress in the side plating is equal to ; where F is the shearing force over the transverse section, Az the moment about the neutral axis of the sectional area above or below a hori- zontal line through the point considered, and *t* the thickness of side plating. This stress is usually greatest at or near a quarter of the length from either end and at the height of the neutral axis, since here F and Az respectively attain their maximum values. In some cases the thickness of plating and arrangement of riveting have to be specially considered in relation to these shearing stresses.

The stresses due to transverse bending are not, in general, capable of definite determination; as, however, they are frequently severe when the ship is in dry dock, and may also attain considerable magnitude during heavy rolling, a means of comparing the transverse strength of vessels is of some interest. A transverse bulkhead forms a region of almost infinite transverse stiffness, and it is therefore difficult in ships internally subdivided by numerous bulkheads, to determine how far the stresses at intermediate sections are influenced by the neighbour­ing bulkheads. In many vessels carrying cargo, however, in which trans- verse bulkheads are widely spaced, a section midway along a hold may be so far removed from all bulkheads as to be uninfluenced by their local support; and the following method has been proposed for comparing the transverse strengths of such ships:

A frame and a strip of plating one frame space in width are regarded as a stiff inextensible bar subjected to the known external forces and to the unknown tension, shearing force, and bending moment, at any fixed point.

Let OP (fig. 60) be a portion of the framing under consideration, O being the keel, and *Ox, Oy,* horizontal and vertical axes.

On consideration of the forces on the arc OQ, which are in