ON THE INFLUENCE OF STIFFNESS AND LOCATION OF SHEAR CENTRE IN THE DYNAMICS OF A CONTAINERSHIP.

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Introduction

In applying a unified dynamic theory in evaluating the responses of flexible ships, it is assumed that the hull may be mathematically modelled as a non-uniform Timoshenko beam [1-6]. The use of this theory has allowed investigations to be made of antisymmetric ship response in regular [1,3] and irregular [5,6] waves. It has also admitted the possibility of investigating such matters as

(i) the large effects of warping stiffness [1,2,3,6], and

(ii) the number of principal modes to be used in the summations of the responses, so as to ensure adequate convergence [1,4,5].

During these investigations it has been noticed that in the range of significant wave encounter frequency substantial differences arise, as between the response predictions made when the hull is assumed to be flexible and those from an equivalent rigid body theory. This paper discusses these differences and presents a sensitivity analysis of

(i) various stiffness properties associated with lateral bending and twisting of the flexible hull, and

(ii) shear distances, $\bar{z}$, (i.e. the distance by which the shear centre of a slice lies below the centre of mass).

In the rigid body analysis, the ideas of hull stiffness and shear distance are irrelevant.

Influence of stiffness

For the containership hull [1,3] under consideration, differences between the responses calculated from the 'rigid-' and 'unified dynamic' theories [6] have previously been attributed to the low natural frequencies of the hull. These are of the same order as the dominant wave frequency. It may be argued that, were the natural frequencies sufficiently high, the two theories should be in reasonably good agreement with one another. Indeed, the higher the natural frequencies, the more rigid is the hull.

To illustrate the implications of this argument the natural frequencies and responses are determined for the containership travelling with a forward speed of 26 knots in bow waves (i.e. with a heading angle, $\chi=135^{\circ}$) of unit amplitude. In order to examine the effects of stiffening the hull through flexural rigidity $EI(x)$, warping stiffness $C_1(x)$, and torsional stiffness $C(x)$, the original values (Case O) are increased by factors of 10 (Case A), 20 (Case B), 40 (Case C) and 80 (Case D). The values of all the remaining structural properties of the flexible hull remained those of Case O. (Results for the rigid body are referred to as those of Case R.)

The corresponding natural frequencies of the dry hull are given in Table I and the response amplitude operators for amidships lateral bending moment $|M(\ell/2)|$ and twisting moment $|T(\ell/2)|$ are shown in Figures 1(a) and (b) respectively. The peaks at resonances of low order disappear to the right due

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Table I Dry hull natural frequencies (rad/s) with increasing stiffnesses. The shear distance $\bar{z}(x)$ remains fixed as in Case 0.

Mode r	Case 0 rigidities x1	Case A rigidities x10	Case B rigidities x20	Case C rigidities x40	Case D rigidities x80
3	2.231	6.976	9.727	13.265	15.657
4	3.888	10.408	12.702	14.516	17.216
5	7.540	18.343	21.343	23.856	26.935
6	10.649	23.475	26.306	28.129	29.248

Table II Dry hull natural frequencies (rad/s) with varying shear distance $\bar{z}(x)$. The hull stiffness values are those in Case 0.

Mode r	Case 0 (original $\bar{z}$)	Case 1 (original $\bar{z}$)/2	Case 2 (original $\bar{z}$)/4	Case 3 (original $\bar{z}$)/8	Case 4 (original $\bar{z}$)/16
3	2.231	2.477	2.550	2.569	2.574
4	3.888	5.279	6.272	6.828	7.094
5	7.540	10.102	9.034	8.339	8.046
6	10.649	10.518	12.051	13.227	13.863

to increases in the natural frequencies of the dry hull. A gradual increase is observed in the 'coupled' amidship bending moment response $|M(\ell/2)|$ at about ω_e=1 rad/s with increasing stiffness and even with the excessive stiffnesses of Case D the value appears to be limited to about 250 MNm. By contrast, the amidship twisting response amplitude operator $|T(\ell/2)|$ shows an initial small decrease and then remains unaffected by subsequent increases in stiffness.

It must be remembered that changing the stiffnesses also changes the mode shapes with the result that different modal combinations occur in the predicted responses.

Influence of shear centre

This investigation was initiated because large differences had been found between the magnitudes of twisting moment response amplitude operators found for the containership by the theory of a flexible hull on the one hand and that of rigid hull on the other. Differences found in the corresponding response amplitude operators of lateral bending moment could be reduced by the inclusion of additional modes [5,6] but this did not seem to affect the twisting moment results. Notice that the rigid body theory cannot make any allowance for the location of the shear centre; indeed the theory does not depend in any way on the concept of a shear centre.

The influence of the location of the shear centre is examined by reducing the shear distance $\bar{z}(x)$ proportionally along the length of the containership. Cases 1,2,3 and 4 refer to $\bar{z}(x)$ distributions reduced 2, 4, 8 and 16 times by reference to Case 0. In every case the mass axis remains fixed relative to an equilibrium system of axes [1]. Case R remains that of the rigid hull. The corresponding dry hull natural frequencies are presented in Table II, from which it will be seen that the overall changes in values are not particularly large. Despite this, some important changes occur in the sequence of the principal modes.

The corresponding response amplitudes $|M(\ell/2)|$ and $|T(\ell/2)|$ are shown in Figures 2(a)and (b) respectively. The agreement between $|M(\ell/2)|$ in the two theories improves as $\bar{z}\to 0$ and is better than that obtained when only stiffness is changed (see Figure 1(e)). The twisting moment response amplitude amidships $|T(\ell/2)|$ also tends to approach that predicted by the rigid body analysis when the shear distance is decreased. The same observations can be made for the distributions of lateral bending moment and twisting moment amplitudes along the hull as shown in Figures 2(c) and (d) for a particular frequency of encounter, ω_e=1.22 rad/s.

Conclusions

For symmetric responses of a ship in waves, increasing stiffness increases the natural frequencies of the flexible hull and, in the range of dominant wave frequency, the rigid and flexible response predictions are in reasonable agreement [7]. For antisymmetric responses, however, the position is not so straightforward. It has been shown in this paper that the value of the shear distance $\bar{z}$ is a very important parameter in determining the distribution of twisting moment response along the hull. The implications of this are far-reaching, especially in model tests involving antisymmetric responses; for merely assuming that the hull is stiff (i.e. that it has high natural frequencies) leaves open the question of shear distance. In order to fit essential test equipment, it is common practice to give ship models open deck sections and this has a marked influence on the positions of the shear centre along the hull. It would therefore appear that any comparison between theoretical predictions and experimentally measured results should require that shear distance is included in the analysis as in the unified theory of a flexible hull.

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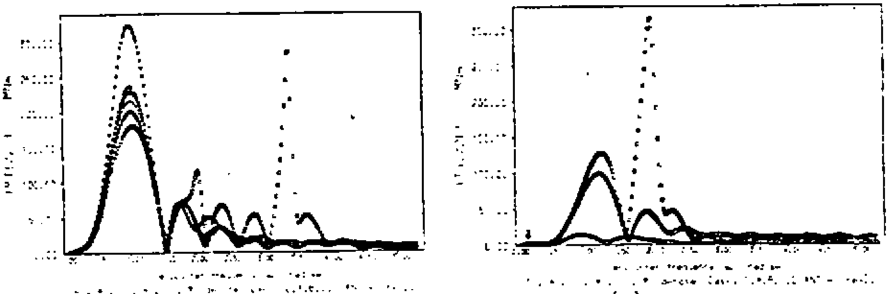

(a) (b)

Figure 1. Results for a large containership travelling at 13.38 m/s in sinusoidal waves of unit amplitude and heading angle $\chi=135^{\circ}$.
(a) Amplitude of horizontal bending moment amidships, and
(b) Amplitude of twisting moment amidships,
as functions of encounter frequency. The cases are those of Table I.

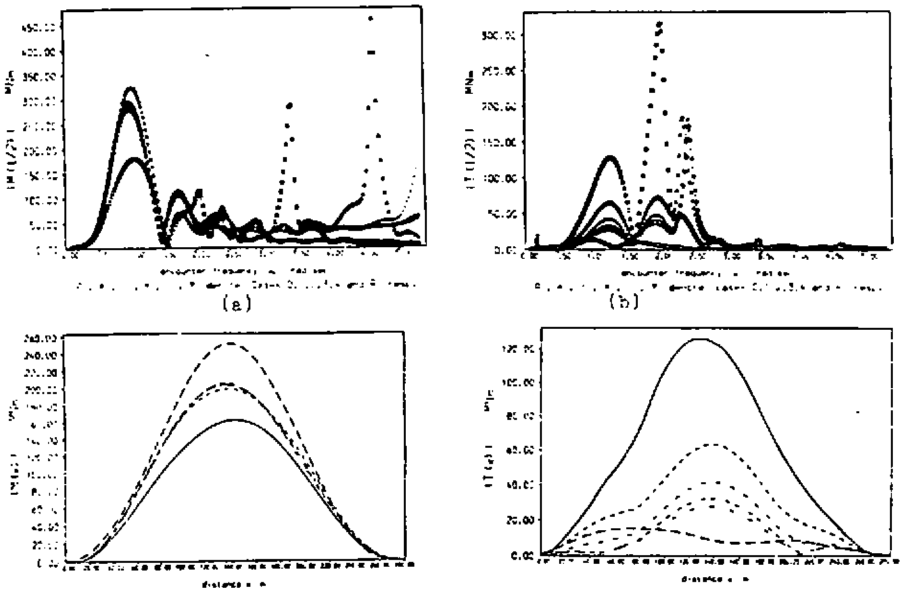

Figure 2. (a) and (b) correspond to the results given in figure 1, but for the cases of Table II. Distributions of amplitude of (c) horizontal bending moment and (d) twisting moment for the cases of Table II.

————————	Case 0	— · —— · —	Case 3
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— · — · —	Case 2	—— —— ——	Case R