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◉ 論 文

Effect of Trim Variations on the Ship Structural Responses

Young-Sub Kwon*

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트림변화가 선체 구조응답에의 미치는 영향

권 영 섭

Key Words : Trim(트림), Mass distribution(질량분포), Hydroelasticity analysis(유체탄성 동역학적 해석)

초 록

트림변화에 의해서 발생하는 선체 구조응답을 고찰, 계산 결과를 요약하였다. 본 고찰로부터 같은 크기의 선수, 선미 트림상태일지라도 많은 차이를 보였다. 이에는 중량분포의 효과가 특히 크게 작용함을 밝히었다.

1. Introduction

The phenomenon of trim may well be considered along the same line with mass distribution. But, then, it would be extremely complicated to deal with both aspects together. Moreover, trim, itself, is another critical factor affecting the behaviour and safety of a ship. Most of the researches on the effect of trim are concerned with stability and the results are widely known to naval architects as well as ship operators. In the present investigation, the efforts are directed on the effects of trim on the longitudinal strength of the (trimmed) hull.

In seems true that, even if the knowledge we have got at hand on the effect of trim on the directional/course stability is important, that is all really matter of degree[1] in general. In fact, most ships would sail with an (slight) inclination of the keel rather than with even keel**. Furthermore, the ship's master would willingly try to take advantage of changing the trim if necessary. Therefore, apart from its effects on stability, it is nece-

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* Research Student, dept. of Mech. Eng., Brunel Univ., Uxbridge, Middx., UB8.3PH, U.K.

** Many of the causes of trim, such as liquids consumption, ballasting, excessive solar heating and even a change in density of the surrounding water, are well known. However, there is evidence that in some occasions the causes for a ship to trim are not clear[2]. In this context it is anticipated that sludges accumulated in the ballast tanks, juddering cargoes are some of the reasons which could hinder from identifying trim.

ssary to establish the importance of the changes occurring in the wave induced loads along the hull due to the effects of trim.

2. Present Investigation

The aim of this research is to provide practical design/operational information concerning the influence of trim, as a extension of studying the effect of mass distribution variation, on the structural responeses of a ship in waves. In fact, many argue that trim is a decisive factor for safe operation of ships, but its apparent effect on the wave and stillwater loads that the ship should embrace has little been investigated.

To achieve the aim of the present investigation, systematic manipulation of relevant data should be simulated and examined for a tanker with various speeds load conditions and seaways. It is anticipated that this kind of systematic approach is quite effective to produce practical information in need. The linear hydroelasticity analysis(Sec. 3) laid down by Bishop and Price[3)] has been applied, utilizing the existing numerical methods[4,5)]. The primary results relating to mode shapes, principal coordinates of distortion modes, resonance frequencies, etc., are not discussed as the space is limited. Also, the results of bending moment are only included in discussion, except for stillwater loads.

2.1 Model ship

A tanker(VLCC) in fully loaded condition was used as a model ship in the present investigation and the hull structure is idealised as a non-uniform beam with varying properties along its length which is divided into 20 slices of the same thickness. The general characteristics and some of input data are listed in Table 1. Original mass and buoyancy distributions for the loading condition are shown in Fig. 1 together with those of various trim conditions to be investigated.

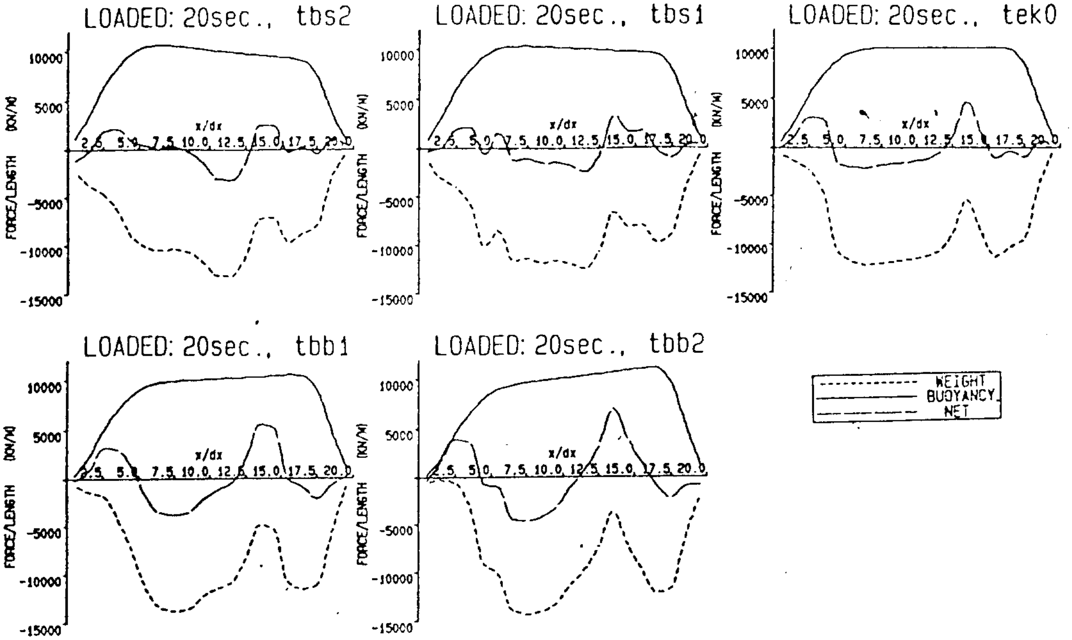

Fig. 1 Distributions of mass buoyancy and net upward force along the hull for rarious trim conditions

2.2 Seaway

When the response in an irregular seaway is to be investigated, it is known to be practical and quite common to employ wave energy spectra representing relevant real sea states. There are, nowadays, a variety of proposed wave spectra[3] and one of the most frequently used form is referred to as the ISSC spectrum which is used in this work.

Table 1 also shows the input values of statistical parameters of the spectrum, i.e. characteristic wave period(T_1) and significant wave height($H_{1/3}$). The values assigned to these parameters, as well as ship's speed-though the highest speed included seems rather high for tanker ships,—reflect an attempt to simulat rather moderate operating conditions for this ship and examine their influence.

Table 1 General characteristics and input data

Item	Value	Remarks
Principal dimensions		Fully loaded
Length	348.358	(m)
Beam	51.8	(m)
Draft	19.58	(m)
Displacement	2.79194(E6)	(kN)
Ship speed	6,8,10	(m/s)
	(11.66,15.54,19.43)	(Knots)
Heading angle	180	(deg.) Head sea
Sea spectra		ISSC
($H_{1/3}$)	6.0,6.0,6.0	(m)
(T_1)	7.72,9.46,10.92	(s)
Mod. of Elasticity	2.07070(E8)	(kN/m^2)
Mod. of Rigidity	8.28269(E7)	(kN/m^2)
No. of modes	5	3 distortion modes

3. On the Hydroelasticity Theory of Ships

"… But a ship is not really a rigid structure and, as we show in this book, this has some profound consequences which cannot easily be ignored—particularly when one considers the stresses and strains of the hull in a confused sea."

The above quotation is taken from the preface of the book entitled 'Hydroelasticity of ships', appeared in 1979, by the late Professor Bishop and Professor Price[3]. They have given not only momentum but, also, ever increasing power to the, then, new study of hydroelasticity theory of ships. In this paper, no attempt will be made to illustrate this theory from its concept in detail, as a good deal of references are available in literature on the subject(e.g. 6—10). In addition, hydroelasticity theory is, rather, active in its applications to naval architecture and marine engineering(and it certainly will be for quite long time to come, as Professor Bishop claimed in a reply to discussion[11]). Nevertheless, it might be of general interest to point out, at least briefly, its basic particulars. Note that the subject would be restricted to the two-dimensional linear symmetric steady state response, whereas other advanced applications have already been achieved(e.g. 7,9. 12).

The concept of the theory is based on the fact that, as shown in the previous quote, a ship is not really a rigid structure. Efforts are focused to derive a unified dynamic analysis for the hull responses instead of the traditional treatment which, artificially, splits into two main categories : hydrodynamics and strength. This is a very crucial step bringing radical changes in the means of thinking about and tackling the problem of ship dynamic analysis rationally. A modal analysis is employed to take account of hull flexibility(distortions) and bodily motions. It was necessary to introduce the concept of 'dry modes' in order to, properly, account for the mutual interactions among inertial, hydrodynamic and elastic forces.

The 'dry modes' analysis provides the principal modes and corresponding natural frequencies of the ship in vacuo. For this, the complex hull is idealised as a non-uniform free-free Timoshenko beam, divided into an appropriate number of segments and the Prohl-Myklestad finite difference method technique is used to obtain the solutions. In short, this is the process to solve the undamped free vibrations of a non-uniform beam. Then follows the determination of the two-dimensional hydrodynamic properties of the hull sections, using Lewis or multiparameter conformal transformations, fluid restoring forces and applied wave forces in conjunction with the strip theory. Allowance for structural damping is also made in this stage. Note the the approach appears to offer success in the estimation of the generalised forces, particularly in the lowest modes we are interested in.

The equations of motion are expressed in the Lagrangian form with frequency dependent system matrices and the solution for (steady state) harmonic wave excitation is obtained in terms of the principal coordinates of the dry hull. Since the principal modes (and modal responses) are known, responses such as displacement, bending moment and shearing force at any section along the hull can be computed by modal synthesis.

Although the above summary description appears rather simplified, it should be noted that it covers a good deal of background in mathematical formulation as well as conventional theories on seakeeping and structural analysis.

4. Descriptions of Trim Conditions Considered

In the present study two different cases of each trim condition-trim by the stem (tbs1, tbs2) and trim by the bow (tbb1, tbb2)-are investigated and compared to the evenkeel condition(tek0). Particulars are listed in Table 2. As can be seen, the magnitude of trim between tbs1 and tbb1 and between tbs2 and tbb2 is identical.

Fig. 1 shows distributions of mass buoyancy and net upward force curves along the hull for each condition. The way of redistributing the mass to achieve the proposes trim condition should be noted. This is important, because different mass distributions could result in the same degree of trim. That is, given a ship, either in ballast or fully loaded, the trim changes only with the variation of first moment of mass. Therefore, the variations of radius of gyration (or second moment of mass) in the forebdy and/or aftbody, which affect the responses of the ship, will not change the degree of trim as long as the first moment of mass is not changed. Meanwhile, it can be conjectured intuitively (and also from Fig. 1) that masses are shifted in the regions, in general, of the first and the third quarters(from A. P.) to achieve trim by the stem and of the second and the fourth(or last) quarters to get trim by the bow. Therefore, although detalis related to shift of mass along the hull might affect the resu-

Table 2 Particulars of the cases

	tbs2	tbs1	tek0	tbb1	tbb2	Unit
Total Weight	2893.9	2794.8	2795.6	2797.0	2797.1	(x100) MN
XCG	173.96	177.51	181.42	185.34	188.89	m
Total Buoyancy	2796.6	2794.6	2793.0	2794.4	2796.5	(x1000) MN
XCB	173.68	177.59	181.47	185.33	188.86	m
Amount of Trim	−1.016	−0.508	0.0	0.508	1.016	deg.
Total Trim	−6.178	−3.089	0.0	3.090	6.178	m

lts, the probable resultant trands, if any, would not be much changed.

4.1 Some notes on the effects of hydrodynamic forces and mass distribution on trim conditions

Although the main interest is to comparing the results of bending moments between the various trim conditions including level trim, the effect of variation in the hydrodynamic forces can not be entirely disregarded in a discussion. Changes in hull form under the waterline due to trim will change hydrodynamic forces. For better understanding of the effect of trim (by the bow), two hypothetical simulations(designated as tmte10, tmte 20 respectively) are considered together with level trim (tmte00, identical with tek0) and trim by the bow (tmte30, identical with tbb1) conditions in order to differentiate between the effects due to changes in the underwater hull form and in the mass distribution-both of which comprised in a trim. The way of preparing the two hypothetical data sets is

(1) assuming the mass distribution not changed, but the underwater hull form changed to match the supposed trim, (tmte10)

(2) assuming the hull form itself not changed, but the mass distribution changed to match the supposed trim.(tmte20)

The most interesting point of these purly hypothetical assumptions is to allow inspection of the effects of hydrodynamic properties and mass distribution sepqrately. In other words, by comparing the results of these cases, the property-either mass or hydrodynamic-which affects the results more can be idenified.

The select results of heave and pitch motion RAOs, bending moment and shearing force RAOs and their RMS values are shown in Fig. 2(a, b), (c, d) and (e), respectively for a forward speed of U=6m/s. They reveal that the effect of variation in the mass distribution is much more significant than that in hydrodynamic properties induced by trim. It is interesting to note that this reverses at relatively short waves and the effects of hydrodynamic properties and more dominant. This is also considered by the results of RMS values showing that the effect of mass dominates as T_1 increases. From this limited study it can be summarised that, although the role of hydrodynamic forces could be a matter of importance, the effect of mass distribution are mare critical while trim is varied.

5. Results and Discussion

5.1 Dry hull characteristics-*Natural Frequencies*

The result in Table 2 show an increase in the natural frequencies as the mass distribution varies so as to cause the ship to trim by the bow. Such a tendency could be anticipated as consistent, as far as the influence line is referred to(13). But, at the same time, it would not be necessarily so, because, mass distribution can be manipulated so as to produce different dry hull result for the equivalent trim condition. One of this example may be seen with tbb1 in the present result.

Table 3 Natural frequencies of dry hull

Case	Natural frequencies(rad/sec)		
	Mode 2	Mode 3	Mode 4
tbs2	3.590	8.820	15.273
tbs1	3.666	9.116	15.749
tek0	3.987	9.896	16.314
tbb1	3.983	9.790	16.180
tbb2	4.126	10.282	16.490

5.2 Still-water loads

One of the most interesting features in the still-water bending moment(SWBM, Fig. 3(a)) is that the trim by the bow causes both sagging and

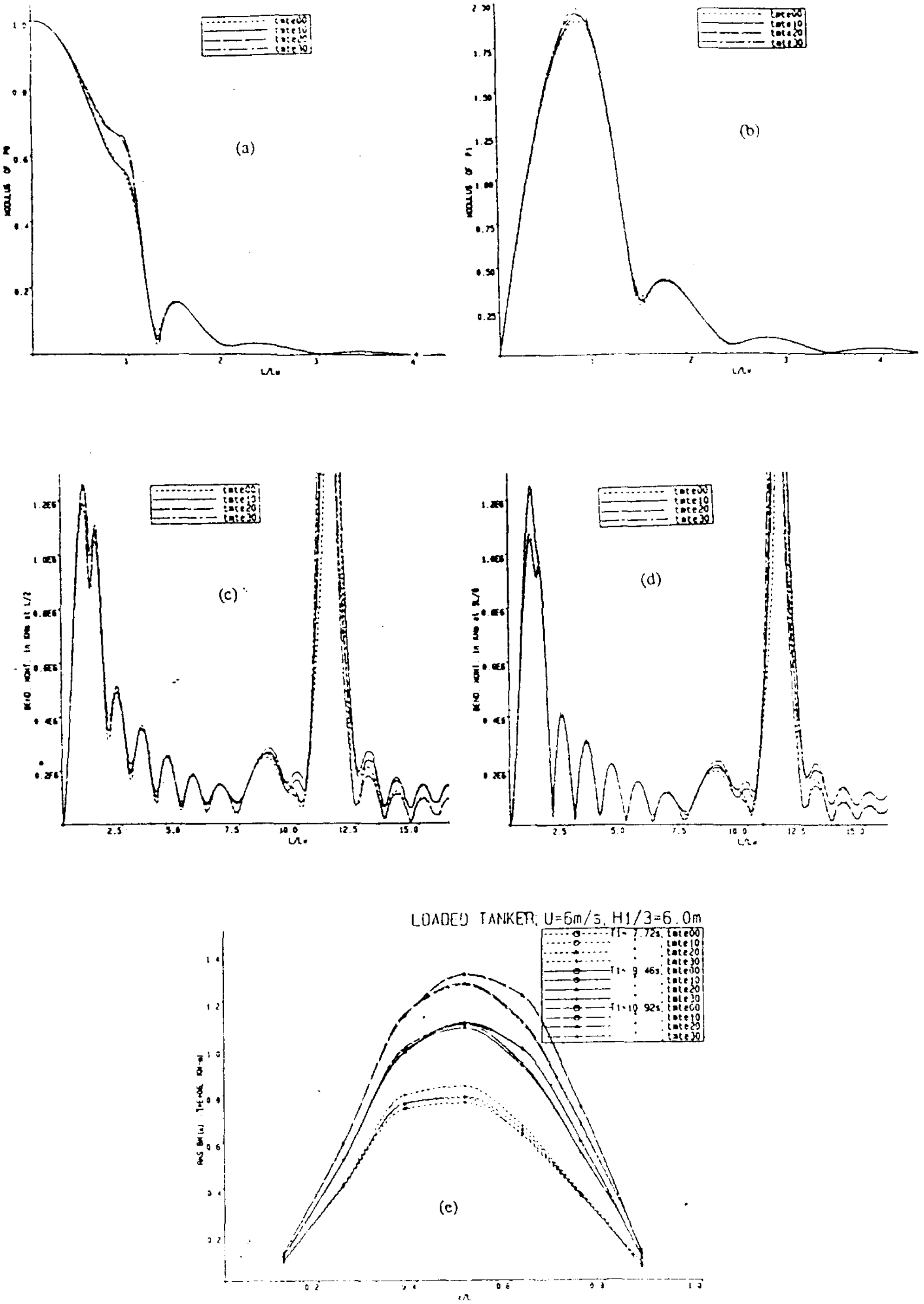

Fig. 2 Effect of changes in hull form and mass distribution due to trim
(a) mode 0 ; heave (b) mode 1 ; pitch (c) BM RAO at L/2 (d) BM RAO at 5L/8

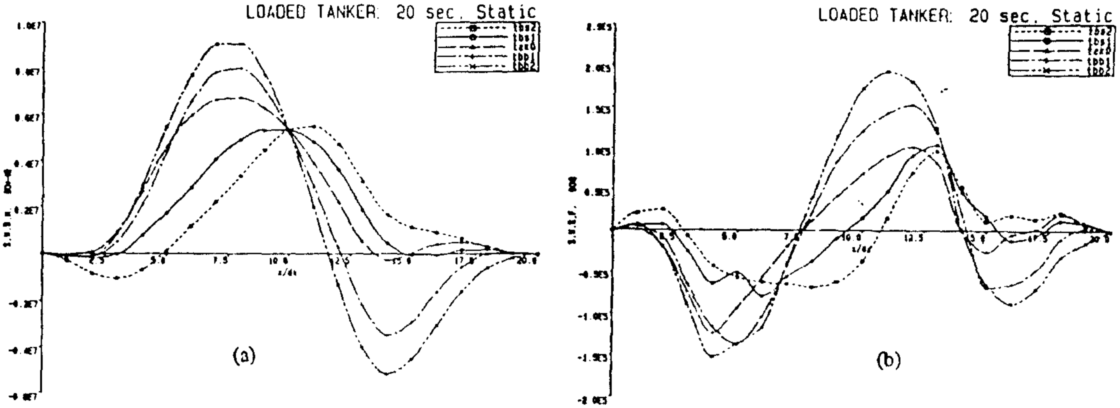

Fig. 3 Variations of still-water loads due to trim
(a) SWBM (b) SWSF

hogging SWBMs to increase significantly. In particular, it is notable that the hogging bending moment around 0.7L becomes as significant as the maximum sagging moment with increased trim by the bow. On the other hand, as the ship becomes trimmed by the stem (from even keel condition) the variation of the maximum value is smaller, but its location along the hull shifts forwards. Throughout the conditions, the SWBM amidships dose not change but the variations at 0.3L−0.4L and 0.60L−0.76L are quite considerable between the conditions.

The still-water shearing force(SWSF) dose not display a typical variation with peaks at both quarter lengths due to the given loading conditions (Fig. 3(b)). It is quite notable that trim by the bow produces the maximum value at 0.5L−0.6L. At L/4 the magnitude tends to increase with increasing trim by the bow. The magnitudes at around 3L/4, where the tendency is similar to that at L/4, would not be significant throughout the conditions considered.

Finally, it is noted that as trim varies, the results of both magnitudes and locations (e.g. where the maximum occurs) show consistent trends for SWBM and SWSF respectively. As far as still-water loads are concemed, it is obvious that magnitudes increase with increasing trim by the bow.

5.3 Ship motions-*Rigid Body Modes*

First of all, increasing trim by the bow results in bigger magnitudes for both heave and pitch motions(Figs. 4,5). Note, in particular, that the difference in the magnitudes of heave mode between two opposite conditions considered is enormous. In pitch mode, however, as ship's speed increases the difference in magnitude decreases. In addition, free pitching period is increased with increasing trim by the bow (Table 4). It is noted that the results of even keel condition are in-between for all the cases and the results display a consistent trend.

Table 4 Ship-wave matching frequencies(rad/sec)

	tbs2	tbsl	tek0	tbbl	tbb2
6m/s	0.39	0.39	0.39	0.39	0.39
8m/s	0.39	0.39	0.39	0.39	0.38
10m/s	0.40	0.39	0.39	0.38	0.37

The results of the bending moment RAOs at 5

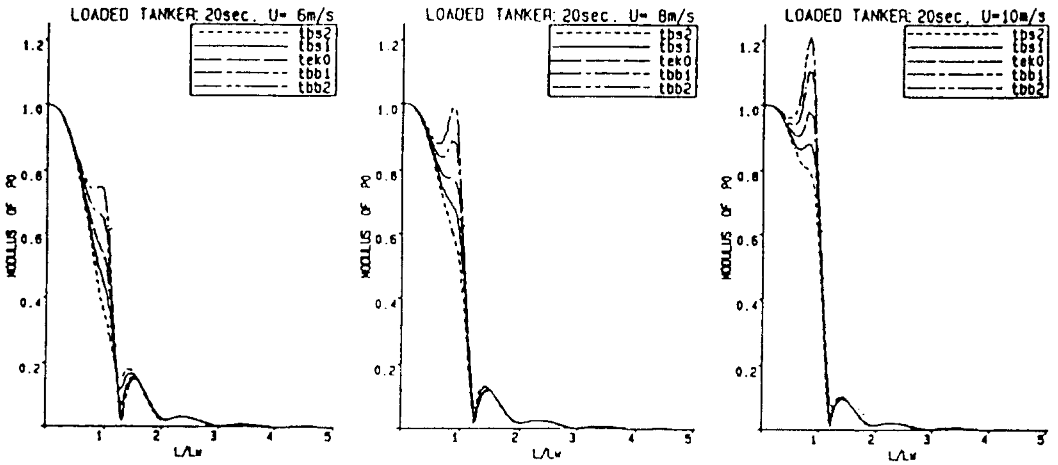

Fig. 4 Principal coordinate of mode 0 ; heave

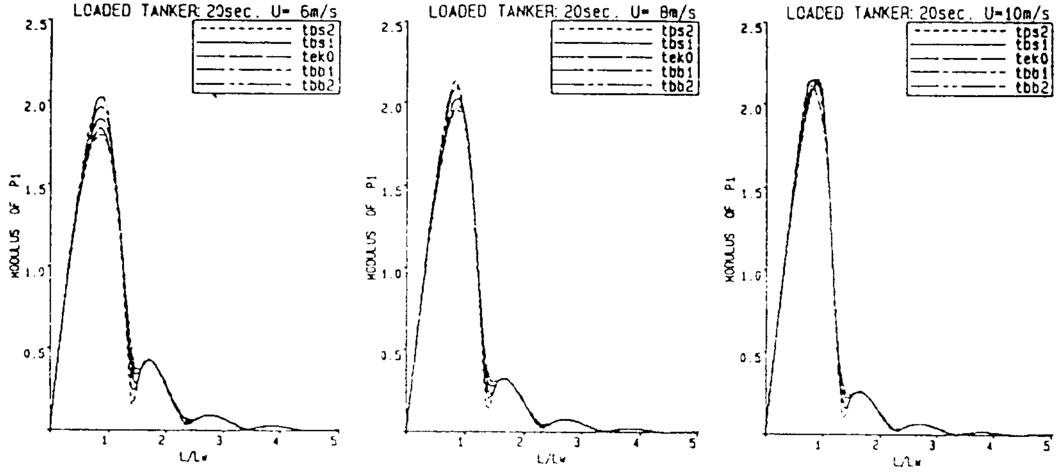

Fig. 5 Principal coordinate of mode 1 ; pitch

locations along the ship are shown in Figs. 6 and 7 for 2 different speeds respectively. To begin with, at the longer waves, say $L/L_W<1.46$ when ship's speed $U=6$m/s (and $L/L_W<1.33$ when $U=10$m/s) the BM increases with increasing trim by the stern at all the sections examined. In this wave range, it is interesting to note the appearance of double peaks(14), particularly, in the aftbody including amidships, becoming more evident as bow downs and as the ship's speed increases. At other short waves, on the other hand, trim by the bow produces, in general, larger BM than trim by the stern. in the latter case, one may observe some exceptions in the forebody of the hull for waves between $L/L_W=2$ and wavelength at which resonance occurs, but the differences between the results are small. At resonance and further shorter waves, on the other hand, where the trend follows dominant one(i.e. BM increases as bow downs), the differences are relativel large in the fo-

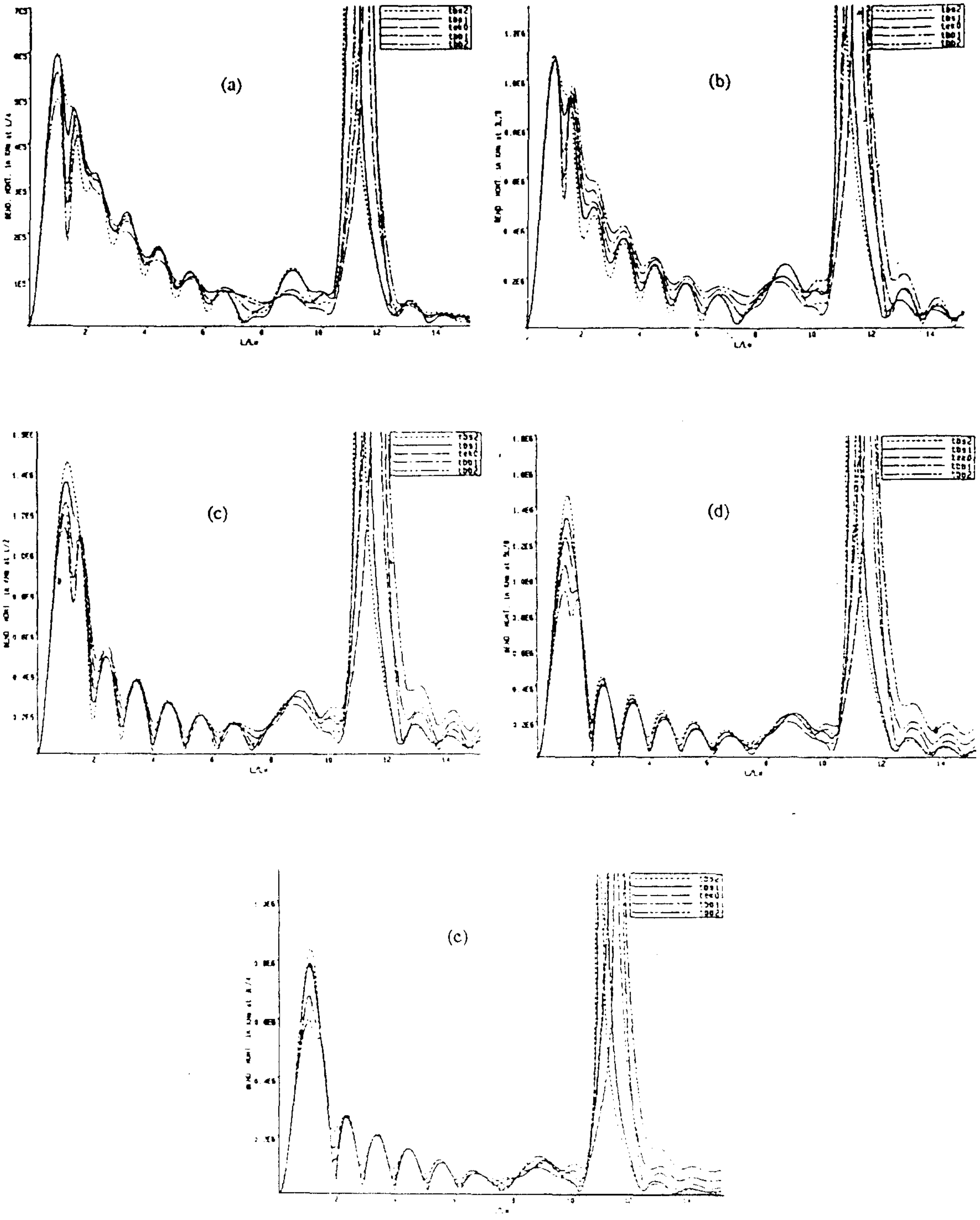

Fig. 6 Variations of bending moment RAOs due to trim, U=6m/s

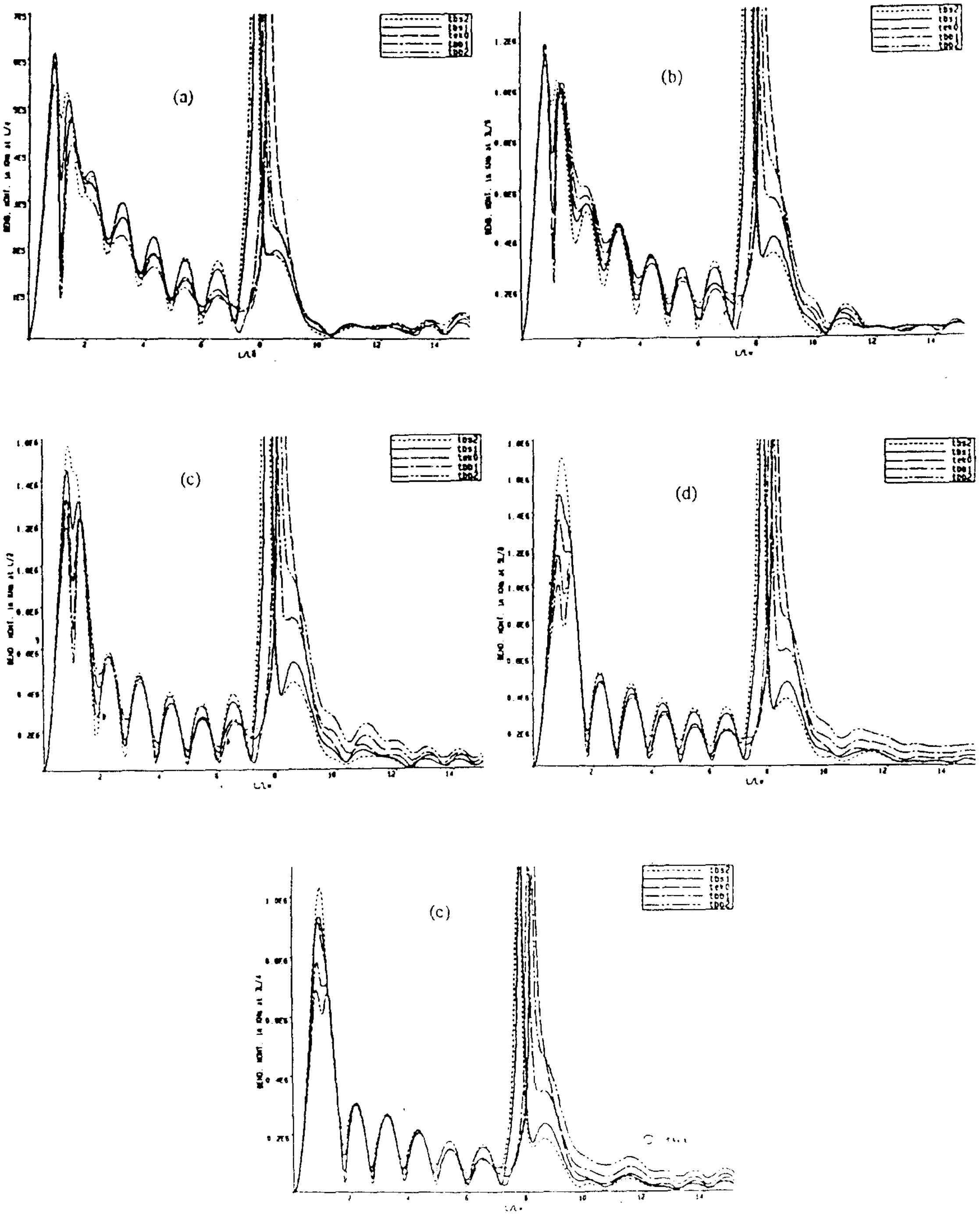

Fig. 7 Variations of bending moment RAOs due to trim, U=10m/s

rebody. As a reference, the resonant (wave) frequencies for mode 2 are shown in Table 5.

Table 5 Resonant (wave) frequencies(rad/sec)

	tbs2	tbsl	tek0	tbbl	tbb2
6m/s	1.39	1.39	1.43	1.42	1.43
8m/s	1.26	1.27	1.30	1.29	1.30
10m/s	1.17	1.17	1.20	1.19	1.20

5.5 RMS values of bending moment

The RMS BM distributions along the hull for the various conditions are shown in Figs. 8−10 for ship's speed U=6, 8, 10m/s respectively. Each one is comprised with 3 figures for different T_1 values. First note that the even keel condition (tek0) is, by and large, the most favorite condition amongst others as far as BMs along the hull are concerned. Nevertheless, with light trim by the bow(tbbl) and increasing T_1 slightly smaller BMs (than tek0), particularly at the forebody, are obtained. On the Other hand, the largest BM is attained when trimmed by the stern(tbs2) in most seaways considered except when U=6m/s and 10m/s and T_1=7.72s. In these cases, the condition of trim by the bow (tbb2) results in the largest BM.

In addition, it should be noted that the maximum (and significant) BMs occur around amidships with the curves shifting aftwards and forwards from it as the bow and the stern downs respectively. Bearing in mind that masses are shifted and increased in the region-roughly speaking-of the first and the third quarters(from A.P.) for trim aft and of the second and the fourth (or last) quarters for trim by the bow, such a result confirms that increase of mass increases the bending moment in the region engaged[15,16]. Then, further examination of this feature may be made in this context ; at 3L/8 and 7L/8 the BMs for the trim by the bow condition are larger than those for trim by the stem and at L/8 and 5L/8 it is opposite. These features are generally applicable throughout the variations of ship's speed and characteristic wave period. Finally, note that the changes in the results from even keel to the light trim by the bow are rather smaall ; whereas the equivalent, light trim by the stem tbsl, gives rise to large differences.

In spite of some exceptions, it can be said with confidence that the results reveal a trend for the magnitude of RMS BM in the following order :

tbs2>tbsl>tbb2>tbbl = tek0

Form the additional polts prepared to help identifying the results of various trim conditions with respect to T_1 for U=6 and 10m/s(Figs. 11 and 12 respectively), one may, at first, note that the differences of the BM results between tbsl and tek0 and between tbbl and tbb2 are much greater than those between tbs2 and tbsl or between tek0 and tbbl. That is to say, a slight trim by the stern results in large increases with small variations for further trim by the stern. Whereas, more trim by the bow is required to produce large increases. Meanwhile, as T_1 increases, the results of each trim condition increase more for trim by the stem compared to trim by the bow. This trend is mainly due to double peaks at around the ship-wave matching region which becomes distinguished as bow downs(see Figs. 6 and 7). However, note that when T_1 is small, tbb2 produces the most unfavorable results of BM. Finally, the effect of speed variation seems, in general, to be rather insignificant as far as RMS BM is concerned.

5.6 General discussion

Ship Motions

The differences in the (small) magnitudes between the conditions are insignificant in the relatively high vave frequency range. However, in the

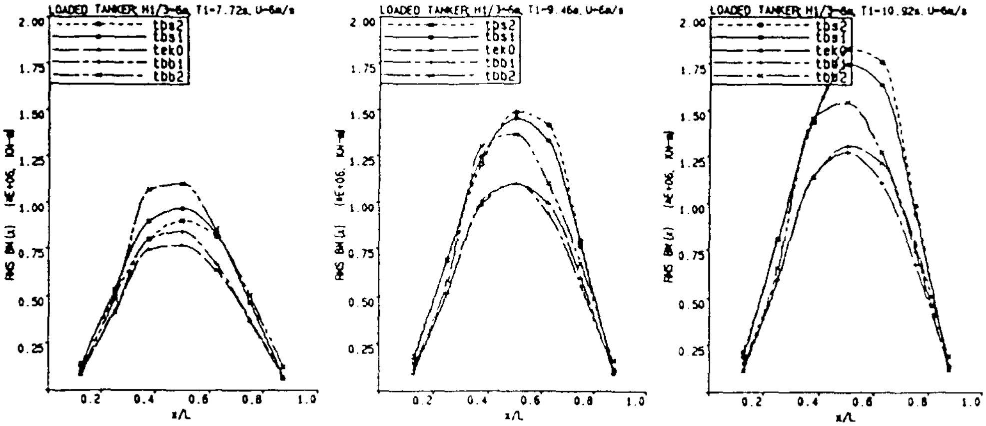

Fig. 8 Comparison of RMS BM(x) between trim conditions, U=6m/s

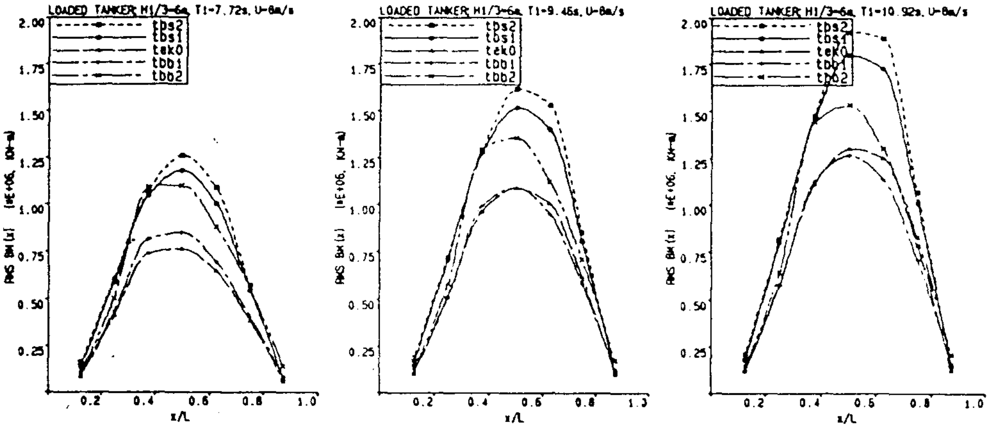

Fig. 9 Comparison of RMS BM(x) between trim conditions, U=8m/s

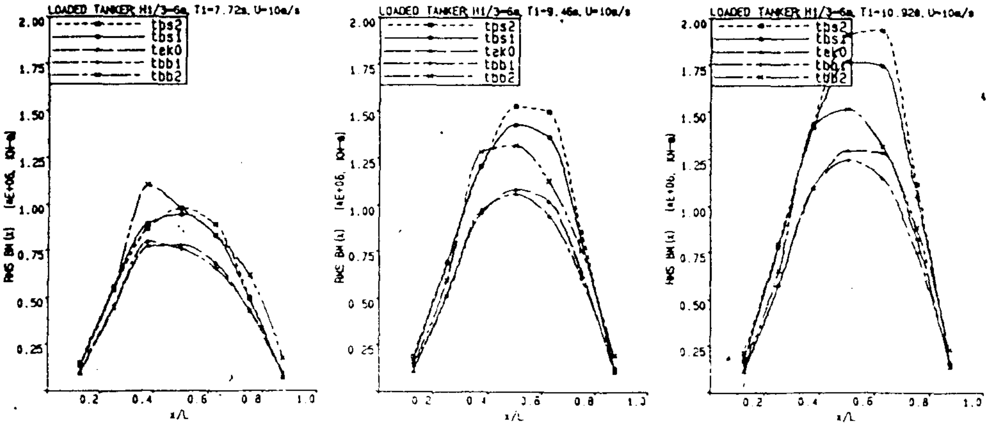

Fig. 10 Comparison of RMS BM(x) between trim conditions, U=10m/s

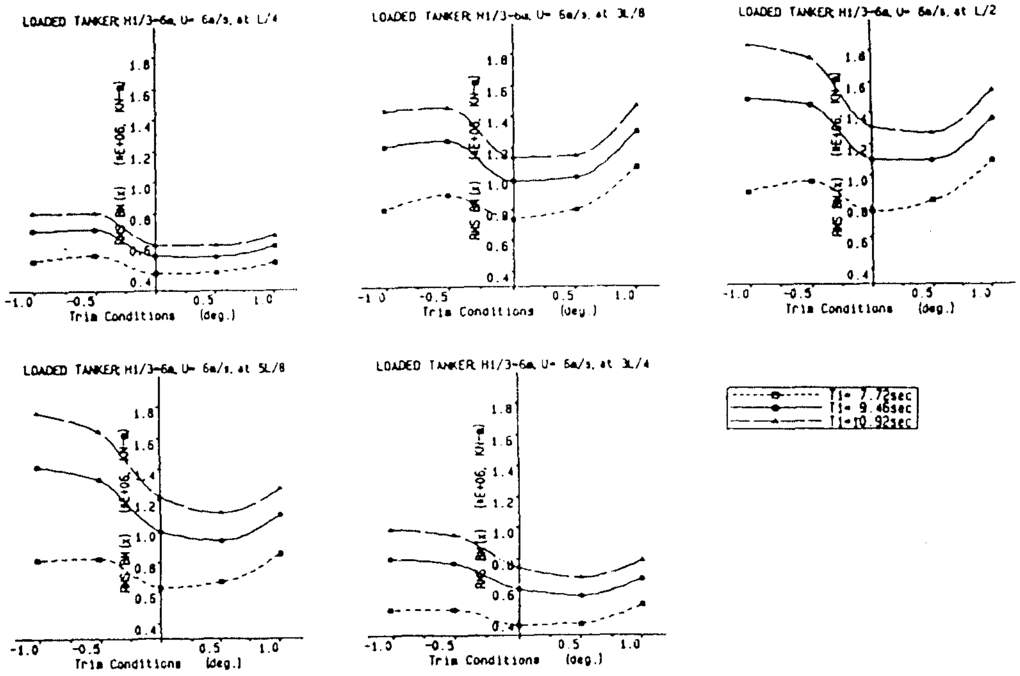

Fig. 11 RMS BM-Trim condition(T_1), U=6m/s

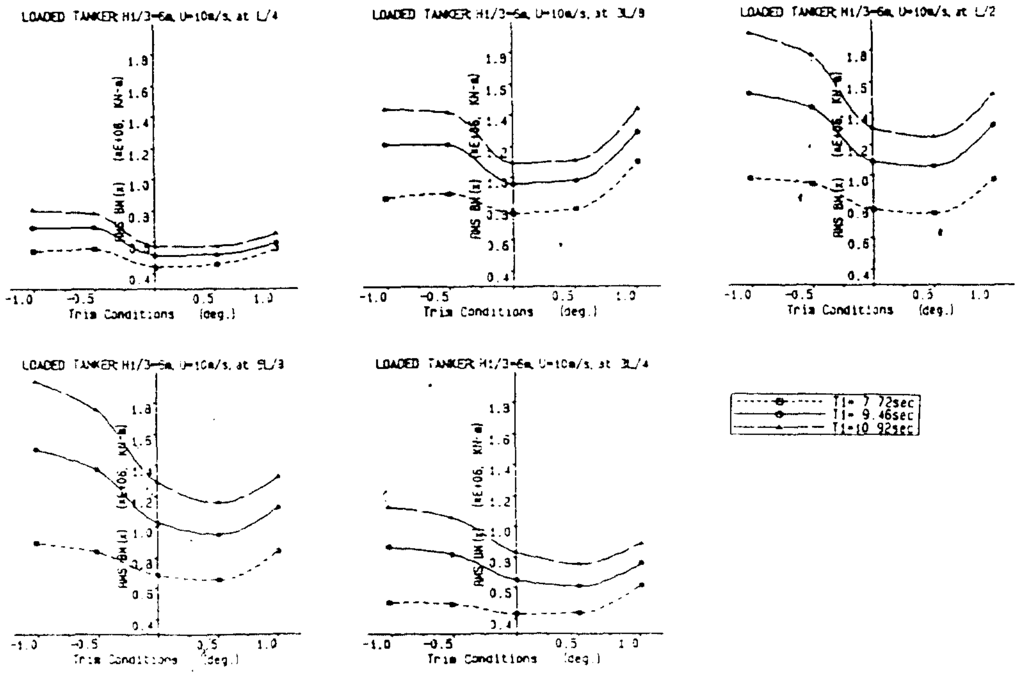

Fig. 12 RMS BM-Trim condition(T_1), U=10m/s

low frequency range trim by the bow results in much highter amplitudes, in both heave and pitch, than trim by the stern. This result confirms one of the conclusions appeared in ref.(1), which, further, stresses that it *possibly* leads to capsize, The effect of ship's speed does not change this trend, except in the pitch mode, where at higher speeds the difference in the ship-wave matching frequency becomes more obvious while the magnitudes are, practically, the same, These results will affect the severity and intensity of slamming.

SWBM and RMS Bending Moments

In the study on the effect of mass distribution variations in an even keel condition, it has been found that there are certain correlations in the changes taking place in the SWBM and (RMS) WBM[16]. It would also be interesting to examine whether this is applicable when trim varies. To begin with, however, it should be pointer out that the amount and direction of trim is very influential on the values of ship responses to waves. For instance, the WBM refults of light trim by the bow (i.e. tbb1) do not show, in general, many differences with those of the even keel condition. On the other hand, light trim by the stern(tbs1) produces, in general, WBM values even higher than those of the heavier trim by the bow (tbb2). In this context, one may note that the effects on the SWBM are rather straightforward(Sec.5.2).

Nevertheless, both maximum (and significant magnitudes of)SWBM and WBM occur in the region aft of amidships when trimmed by the bow and forward of amidships when trimmed by the stem. Consequently and importantly, for instance, in the vicinity of 3L/8, maximum trim by the bow considered(i.3. tbb2) results in the largest WBM in the area and this must be considered together with the fact that the corresponding SWBM in the vicinity is also the largest one of all. On the other hand, trim by the stem results in significant WBM magnitudes in the area amidships to 5L/8 where the SWBM values are also considerable. One of the features revealed in ref.(16) is that the shape of SWBM curve is similar to that of WBM with relatively small T_1. In this context, the WBM around 3L/4 when trimmed by the bow (tbb2), when T_1 is small, is, in addition, worth noting since the corresponding (hogging) SWBM in the area is also considerable. Unlike the observations appeared in ref.(16), the WBM at the fore of midship does not increase dramatically with increasing T_1 when trimmed by the bow, because the contribution of mass effect in the area is trivial ; however, there is a considerable increase when trimmed by the stern.

6. Conclusive Remarks

From the investigation on the effect of trim on loads, it is found that, although the degree of trim is within practical bounds, significant changes in bending moments may occur. This is due to not only the magnitudes concerned but also concurrence of significant SWBM and WBM as they vary along the hull. It is also anticipated that when changes in mass distribution cause a ship to trim, they provide the most significant effect on responses. In this context, the effect of hydrodynamic properties may well be surmised to be rather smaller-and rather insignificant if the amount of trim is small. Note, however, that this view should not he extended to the subject of stability. The conclusions can be summarized as follows :

(1) The same amount of trim by the stem and by the bow give rise to different results and consequencies : trim by the stern causes WBM to increase much more than corresponding trim by the bow. As the degree of trim becomes greater such a trend becomes the other way round.

(2) Trim by the bow incurs larger motions,

both in pitch and heave, than trim by the stern. This should be considered with the corresponding result found from the view point of stability.

(3) While trim by the bow produces larger SWBM, trim by the stem results in larger WBM in general.

(4) The point of importance is distributions of SWBM and WBM along the hull as trim varies, and certain correlations between them are found to exist even in trim conditions.

(5) From the conclusions (3) and (4), it confirms that operation a ship in level trim condition is most preferable.

Finally, it is believed that the informations of practical mariners on this topic would be of great help to enhance the safety of ships in which trim is a critical factor.

Acknowledgment

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