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APPLICABILITY OF STRIP THEORY TO VESSELS WITH LOW LENGTH TO BEAM RATIO: A LITERATURE SURVEY

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Approved by T. Garrett Director/Technology Division

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ABSTRACT

This paper surveys the applications of strip theory to low length to beam ratio (L/B) vessels (L/B < 7.0) in an attempt to establish the domain of L/B values and of Froude numbers in which strip theory predictions are reliable. A number of the papers that are included in this review contain direct comparisons between the predictions of strip theory and model test results for low L/B vessels. The vessels considered had L/B values ranging from 2.0 to 7.0. These papers are discussed in detail, and their abstracts are included as an appendix. It appears that strip theory gives fair to good predictions of the pitch and heave amplitudes of vessels with L/B ratio greater than about 4.0, up to Froude numbers less than about 0.4. However, many of these vessels exhibit considerable dynamic swell-up and incident wave distortion, and this often leads to poor relative motion predictions. The vertical acceleration predictions are usually poor, although there are occasionally fair to good predictions in head, bow and beam seas. A second class of papers included in this survey applies strip theory to low L/B vessels without referring to the results of model tests for correlation. The vessels involved had L/B values ranging from 3.9 to 7.0. These papers implicitly assume that the predictions of strip theory for low L/B vessels are still reliable enough to be useful. This second group of papers is not directly relevant to this study, and is included only for completeness.

RESUME

On passe en revue les applications de la théorie du déshabillage aux navires à faible ratio longueur/largeur (L/B < 7,0) pour tenter d'établir le domaine des ratios et des nombres de Froude dans lequels les prévisions de la théorie sont fiables. Un certain nombre de documents étudiés font état de comparaisons directes entre les prévisions de la théorie et les résultats d'essais de modèles pour des navires à faible ratio L/B, se situant entre 2,0 et 7,0. Ces documents sont étudiés en détail et leurs résumés sont donnés en annexe. Il apparaît que le théorie du déshabillage produit des prévisions passables à bonnes de l'amplitude du tangage et du pillonnement des navires dont le ratio L/B est supérieur à 4,0 environ, pour des nombres de Froude inférieurs à 0,4 environ. Cependant, on a constaté une distorsion dynamique à la houle et aux vagues incidentes considérable pour bon nombre de ces navires, ce qui souvent appauvrit les prévisions de leur mouvement relatif. Les prévisions de l'accélération verticale sont habituellement médiocres, bien qu'elles soient parfois passables à bonnes pour des mers avant, de proue et du travers. D'autres documents étudiés appliquent la théorie du déshabillage aux navires à faible ratio L/B sans corrélation avec des résultats d'essais de modèles. Ces navires sont de ratio L/B allant de 3,9 à 7,0. On suppose implicitement dans ces documents que les prévisions de la théorie sont suffisamment fiables pour être utiles dans le cas des navires à faible ratio L/B. Ces documents ne sont pas directement pertinents à notre étude et ne sont donnés qu'à titre de complément.

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NOTATION

B	ship beam
L	ship length between perpendiculars
T	ship draft
ε_z	heave to wave phase angle
ε_θ	pitch to wave phase angle
λ	wavelength

1. INTRODUCTION

The purpose of this paper is to determine whether strip theory can be applied to ships with low length to beam ratio (L/B). The predictions of strip theory have previously been shown to compare reasonably well with the results of both model tests and full-scale trials for conventional hulls with L/B > ~7.0 at low to moderate speed (Fn < ~0.4)[1,2]. Strip theory is derived under the assumption that the ship is slender, i.e. B/L and T/L are both small. The accuracy of the strip theory predictions can be expected to decrease with L/B; however, given the success of strip theory for conventional hulls, there is a natural desire to use the theory outside the range for which it was originally intended. This work surveys the applications of strip theory to low L/B vessels (L/B < 7.0) in the literature, in an attempt to establish the domain of L/B values and of Froude numbers in which strip theory predictions are reliable.

A number of the papers surveyed contain direct comparisons between the predictions of strip theory and the results of model tests for low L/B vessels. These particularly relevant papers are reviewed in detail in the next section, and abstracts of these papers are included as an appendix. The abstracts are taken directly from the original sources, with one noted exception, and contain small editorial changes. The following vessels are considered in this group of papers: five fishing vessels with L/B values ranging from 2.4 to 5.0; a number of relatively conventional warship hulls with L/B > 6.0; four L/B variants of an 0.7 block coefficient, Series 60 hull with L/B > 4.0; seven small recreational boats with L/B values between 2.0 and 4.0; two oceangoing barges with L/B values of 4.0 and 4.6; and, finally, two roll-on/roll-off vessels with L/B values of 6.6 and 6.8.

A second class of papers included in this literature survey applied strip theory to low L/B vessels without referring to the results of model tests for correlation. The vessels included in these works had L/B values ranging from 3.9 to 7.0. These papers implicitly assume that the predictions of strip theory for low L/B vessels are still reliable enough to be useful, and in general, this position is supported by the results found in the papers containing direct comparisons of strip theory predictions and model test results. This second group of papers is included only for completeness; no detailed discussion of these papers will be given.

2. LITERATURE SURVEY

Before beginning the discussion of specific papers, some general remarks about the organization of the survey will be made.

The analytic computations in the papers surveyed were performed by a number of different strip theory programs. It was necessary to establish that the predictions of the various programs were in reasonable agreement with each other; otherwise the discrepancies due to the failings of strip theory could not be separated from the discrepancies due to the shortcomings of individual programs.

A comparison between the predictions of twenty-two strip theory programs for the motions of a containership proceeding at moderate speed was included in the report of the Seakeeping Committee to the Fifteenth International Towing Tank Conference[3]. The papers contained in the present literature survey made use of the following programs: PHHS[4], SCORES[5], SMP[6], HANSEL[7], the Frank Close-Fit Ship-Motion Program[8], two Japanese "Ordinary Strip Method" programs[9], a program based on the strip theory formulation of Gerritsma[10], and a program based on a modified version of the theory of Korvin-Kroukovsky and Jacobs[11,12]. Assuming that the results of the ITTC comparison are indicative of the general case, all of these programs can be expected to give fairly similar predictions except for roll; the peak predicted roll amplitude varied by more than a factor of two in this comparison. It was felt that, for the purposes of the present study, the predictions of the other responses were consistent enough that conclusions about the applicability of strip theory to low L/B forms could be drawn, but that the roll predictions of the different programs varied too much to make any meaningful conclusions. Hence, roll results will be given only minor emphasis in this work.

It should be pointed out that there has recently been progress in the computation of roll damping and that improved roll predictions have resulted[13,14]. Unfortunately, few comparisons between state-of-the-art predictions and measured roll responses have been made for low L/B forms. Once more such comparisons become available, it will be possible to determine the limits of applicability of the method.

The agreement between measured and predicted transfer functions will be quantified by using the "motion indices of correlation" as introduced by Dalzell in Reference 1. These are simply the maximum differences between the experimental and theoretical results, expressed as percentages of the maximum experimental responses. For the present work, agreement will be considered good when the motion index of correlation is fifteen per cent or less, fair when the index is between fifteen and thirty per cent, and poor when the index is thirty per cent or more. At first sight, it may appear to be rather generous to consider a motion index of correlation of fifteen percent to be good agreement; however, it should be pointed out that some of the model test results exhibited scatter of more than ten percent, and the full-scale trials contained random errors that were considerably larger than this. Taking the data as a whole, it was felt that a motion index of correlation of fifteen percent or less was a realistic criterion for good agreement.

In Reference 1 it was found that for ships with normal L/B, the motion indices of correlation increased with increasing Froude number. This trend is typical of strip theory predictions. At Froude numbers up to 0.3, the pitch and heave indices of correlation varied between 5 and 30 at all headings. The index for the relative bow motion in head seas also varied between 5 and 30 in the same speed range, while the index for roll in oblique seas varied between 10 and 100. No data were available for the other responses. Hence, by the criteria of the present work, the strip theory predictions for pitch, heave, and relative bow motion are not always good, even for relatively slender ships; however, they are usually at least fair. The roll predictions are often poor, but as mentioned above, the state-of-the-art for roll has recently been improved.

One other point about the motion indices of correlation is worth making. The indices are based on the maximum difference between measured and predicted response curves; hence, they provide an upper bound on the percent difference between measured and predicted RMS responses for any sea spectrum. However, they may greatly overestimate this difference for a particular spectrum. This would be the case, for example, if the measured and predicted response curves differed only at high frequency, and the sea spectrum of interest had most of its energy in the low frequency regime. Hence, if a ship is being designed with specific operating conditions in mind, the percent difference between measured and predicted RMS values for a representative sea spectrum from the geographic area in question will provide a more realistic estimate of the reliability of the theoretical predictions.

2.1 Comparisons Between Measured and Predicted Transfer Functions

This section begins the discussion of specific papers which contain comparisons between measured and predicted responses of low L/B vessels.

Reference 15, in Japanese, reports on a comparison between the results of model tests and the predictions of strip theory for three fishing vessels. The strip theory predictions were made using an "ordinary strip method" program[9]. The three vessels, designated A, B, and C for discussion purposes, had lengths of 18.5, 28.3, and 39.2 metres, and L/B values of 4.3, 4.6, and 5.0, respectively. The boats were tested in regular head waves at speeds ranging from Fn = 0.0 to 0.3. The responses considered were pitch, heave, relative bow motion, and vertical acceleration at stations 0 and 1. (Throughout this paper, a twenty station ship with station 0 at the forward perpendicular will be assumed.)

The motion indices of correlation for the fishing vessels are shown in Tables 1 to 3. The agreement between measured and predicted pitch and heave results is usually typical of that found for normal L/B ships (i.e. fair to good), except for several poor heave predictions at low Froude number. The dimensions of the tank used for the model tests were not apparent in Reference 15; however, from the photographs included in the paper, it appears likely that the experimental results at low speed were affected by tank-wall interference. Hence, the poor indices of correlation at low Froude number may have been due to experimental rather than theoretical shortcomings.

TABLE 1 - MOTION INDICES OF CORRELATION FOR FISHING VESSEL A OF REFERENCE 15 IN HEAD SEAS

Fn	HEAVE	PITCH	RELATIVE BOW MOTION	STATION 1 ACCELERATION
0.0	39	19	37	74
0.1	38	18	124	61
0.2	15	9	19	15
0.3	11	16	11	13

TABLE 2 - MOTION INDICES OF CORRELATION FOR FISHING VESSEL B OF REFERENCE 15 IN HEAD SEAS

Fn	HEAVE	PITCH	RELATIVE BOW MOTION	BOW ACCELERATION
0.0	52	18	37	76
0.15	14	15	23	8
0.3	13	18	16	18

TABLE 3 - MOTION INDICES OF CORRELATION FOR FISHING VESSEL C OF REFERENCE 15 IN HEAD SEAS

Fn	HEAVE	PITCH	BOW ACCELERATION
0.0	24	14	47
0.3	16	9	24

The relative bow motion and bow acceleration predictions were also fair to good at the higher Froude numbers considered, but in this case, the predictions at low Froude number were so poor as to be of no use.

It should be pointed out that the experimental data exhibited significant scatter - up to 27 per cent in some cases. Despite this scatter and the several cases of high indices of correlation, the authors felt that the agreement found between theory and experiment was good.

Reference 16 describes the results of a comparison of model test results, strip theory predictions, and the predictions of a three-dimensional linear sink-source method for a wide beam, short fishing vessel. The strip theory predictions were made using two different strip theory programs, namely HANSEL[7] and a revised version of HANSEL designated SMP[6].

The hull form was chosen specifically to test the limits of applicability of the strip theory method and had an L/B of only 2.4. The hull of the vessel had two hard chines and a wide transom stern. The vessel also had a large skeg.

Program HANSEL offers the user the option of including in the calculations several speed dependent end terms associated with the added mass, damping, and diffraction force at the aftermost section of the ship. These end terms appear in the strip theory of Salvesen, Tuck and Faltinsen[17]. Reference 16 computes the motions of the fishing vessel both with and without the end terms. These terms are not included in the revised version of the program, or in many other strip theory programs - SHIPMO[18] for example. Hence, the computations which included the end terms will not be discussed here, except to note that while the end terms did produce a noticeable effect on the predictions, agreement was usually degraded.

The model was tested in regular head and beam waves. The head sea tests were conducted at Froude numbers of 0.19 and 0.38, while the beam sea tests were conducted at zero speed. The vessel was tested at ballast and design drafts in head seas. In beam seas, the model was tested at three different loading conditions; the two drafts tested in head seas, plus a second ballast condition at the deeper draft with a lower metacentric height.

The motion indices of correlation from the two strip theory programs are shown in Tables 4 and 5. The comparison between the three dimensional method and the results of model tests has been omitted, since it is not relevant for the present study; however, it is worth noting that the strip theory predictions were at least as good as those of the three dimensional method, and occasionally considerably better.

TABLE 4 - MOTION INDICES OF CORRELATION FOR THE FISHING VESSEL OF REFERENCE 16 IN HEAD SEAS

	Fn	HEAVE	PITCH
DEEP DRAFT			
HANSEL	0.19	12	9
SMP	0.19	13	22
HANSEL	0.38	15	26
SMP	0.38	13	30
SHALLOW DRAFT			
HANSEL	0.19	10	22
SMP	0.19	14	23
HANSEL	0.38	14	43
SMP	0.38	11	41

TABLE 5 - MOTION INDICES OF CORRELATION FOR THE FISHINC VESSEL OF REFERENCE 16 IN BEAM SEAS AT ZERO SPEED

	SWAY	HEAVE	ROLL
DEEP DRAFT, LARGE GM			
HANSEL	50	24	50
SMP	50	26	9
DEEP DRAFT, SMALL GM			
HANSEL	50	-	50
SMP	50	-	20
SHALLOW DRAFT			
HANSEL	15	21	60
SMP	30	25	7

The heave amplitudes for both head and beam seas were as well predicted for this ship as for more slender hull forms, even at the relatively high Froude number 0.38. The pitch amplitudes were less well predicted, particularly in the shallow draft case at the higher speed. The pitch predictions at the lower speed were fair; they were perhaps slightly worse than those usually found for slender ships in head seas at this speed, but they were nevertheless good enough to be useful.

The heave and pitch phase angles were generally predicted quite well by the strip method. The largest discrepancy occurs in the short wavelength regime, at the higher of the two speeds considered.

The SMP roll predictions at zero speed were fair to good. The HANSEL roll predictions were poor. The sway predictions of both strip theory programs were poor to fair.

Reference 19 describes a comparison of measured responses and strip theory predictions for a deep draft, L/B = 3.3 fishing vessel. The tests were conducted in regular head waves, at Froude numbers of 0.16, 0.32, and 0.48. Responses considered in the study were heave and pitch (amplitude and phase), and relative motion at stations 0.0, 2.0, 5.0, and 10.4. The strip theory computations were performed using the Frank Close-Fit computer program[8].

The motion indices of correlation from this comparison are shown in Table 6.

TABLE 6 - MOTION INDICES OF CORRELATION FOR THE FISHING VESSEL OF REFERENCE 19 IN HEAD SEAS

Fn	HEAVE	PITCH	STATION 0 REL. MOTION	STATION 2 REL. MOTION	STATION 5 REL. MOTION	STATION 10.4 REL. MOTION
0.16	16	19	29	28	40	38
0.32	39	32	33	31	38	40
0.48	72	89	58	80	107	63

The pitch and heave predictions were fair at the lowest Froude number considered, Fn = 0.16, but were poor at Fn = 0.32, and became completely unrealistic at Fn = 0.48. There were, however, some factors about the model tests at the two higher speeds which may have influenced this comparison. This point will be discussed below.

The pitch and heave phase angles were predicted reasonably accurately at all three speeds considered. Representative results are shown in Figure 1.

The agreement between measured and computed relative motions was fair to poor at Fn = 0.16, and poor at the higher speeds.

The computed relative motions were obtained by taking the vector sum of the predicted pitch and heave responses, and subtracting from this the incident wave profile. The authors found that by replacing the predicted pitch and heave responses with the measured responses in these computations, the measured relative motions could be reproduced reasonably well. It was concluded that strip theory was failing to predict the pitch and heave responses sufficiently accurately to be of use in making relative motion predictions.

At speed, the model experienced sinkage and a trim by the stern. In addition, the vessel generated a large bow wave. It was felt that the use of the measured high speed waterline (instead of the customary calm water waterline) would improve the strip theory predictions. This is the subject of Reference 20. Unfortunately, the hoped for improvement did not materialize, and it was concluded that the discrepancies resulted from the vessel's violations of the basic strip theory assumptions.

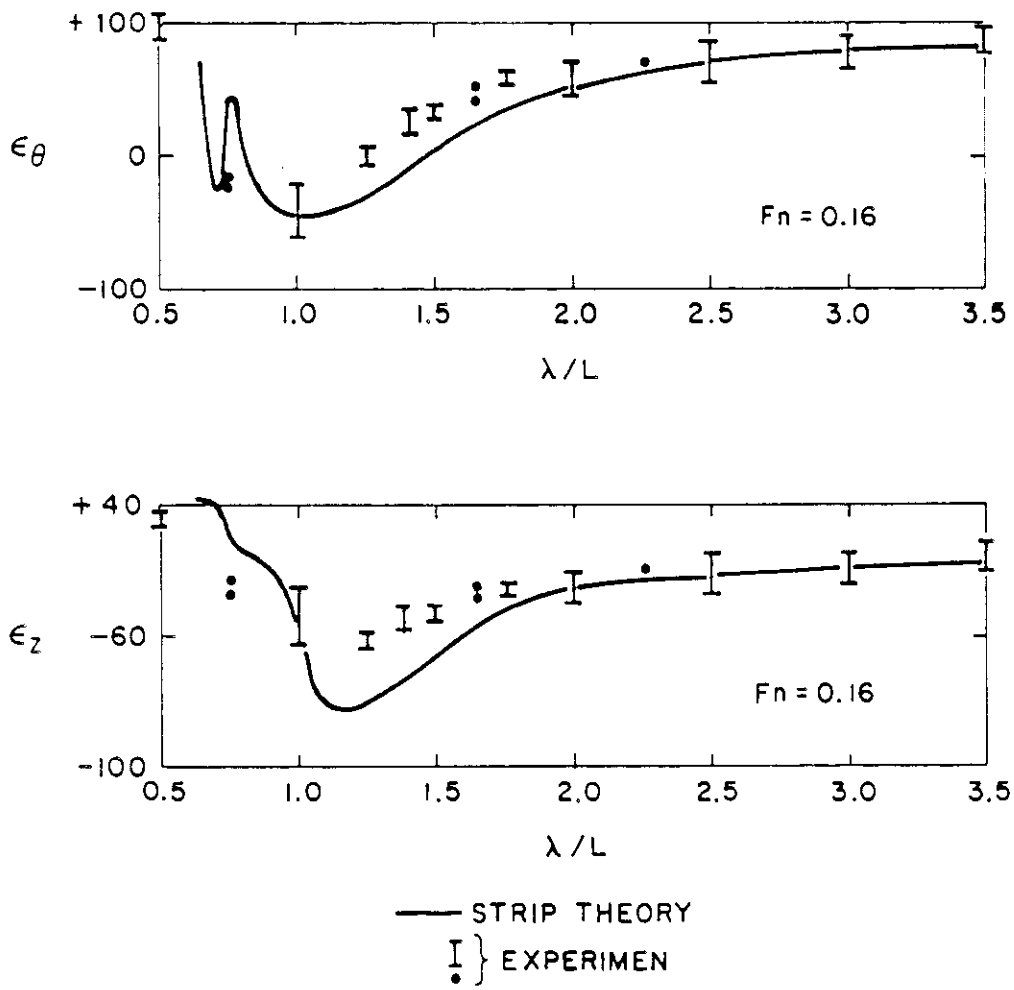

Figure 1 - Measured and Predicted Pitch and Heave Phase Angles for the Fishing Vessel of Reference 19

While pitch was also overpredicted at Fn = 0.38 for the L/B = 2.4 fishing vessel considered in Reference 16 (Table 4), the degree of discrepancy reported in Reference 14 between the measured and predicted pitch and heave results must be viewed as surprising. Some unusual features about the tests of this model will now be described.

The fishing vessel was designed with freeing ports to allow the decks to clear of water. The vessel was ballasted to a minimum freeboard condition, and at the two higher speeds, the sinkage and trim were sufficient to permit water to be shipped through the freeing ports, even in calm water. In waves, water was shipped through the freeing ports at all speeds. While deck wetness was minimal at Fn = 0.16, the main deck was usually awash at Fn = 0.32 and there was some splashing on the poop deck. At Fn = 0.48 the main deck wetness was less extensive than at Fn = 0.32, but there was a heavy propeller wash which threw water onto the poop deck.

The following quote gives an indication of the severity of the deck wetness at Fn = 0.48: "Finally, it must be noted that, at least in the context of experiments with more conventional hulls, the 15 knot (Fn = 0.48) condition appeared to be unrealistic because of deck wetness and inadequate propulsive capacity. As implied by the preceeding discussion, the general impression given by the model at a prototype equivalent speed of 15 knots was that it was running with its after quarter submerged."

The possibility that this quantity of water on the deck could influence the damping characteristics of the ship cannot be discounted. Hence, the large discrepancies found between the predicted and measured responses at the two higher speeds may have been due, at least in part, to the model test conditions. Strip theory may still give reliable pitch and heave predictions for fishing vessels. However, given the poor to fair predictions of relative motions found even at the lowest speed, where deck wetness was not significant, the ability of strip theory to predict relative motions is in question.

Reference 21 discusses the seakeeping performance of the USCG WMEC and consists of two parts. Part 1 describes a comparison of responses derived from full scale trials with those computed by strip theory using the Frank Close-fit ship motion program[8]. Based on the reasonably good agreement found in Part 1, Part 2 derives the slamming and deck wetness characteristics of the class from strip theory predictions. For the purposes of this literature survey, the comparison conducted in Part 1 is especially relevant.

The WMEC is 77.7 metres long between perpendiculars, and has an L/B of 6.71. The full scale trials were conducted in head seas, in sea states 3 and 5, and at Froude numbers of 0.11, 0.19, and 0.28. The study compared both the RMS responses and transfer functions. The responses considered were those of pitch, heave, relative motion at station zero, and vertical acceleration at station fourteen. Comparisons of the measured and predicted phase angles for pitch and heave were also included.

Table 7 shows the motion indices of correlation for the WMEC cutter. The experimental response curves derived from the full scale data in sea states 3 and 5 differ significantly from one another in some cases. For this reason, Table 7 contains motion indices of correlation for both sea states.

TABLE 7 - MOTION INDICES OF CORRELATION FOR THE WMEC CUTTER OF REFERENCE 21 IN HEAD SEAS

Fn	SEA STATE	HEAVE	PITCH	STATION 0 RELATIVE MOTION	STATION 14 VERTICAL ACCELERATION
0.11	3	44	22	15	65
	5	18	19	20	74
0.19	3	53	23	33	34
	5	15	13	37	32
0.28	3	17	32	29	> 100
	5	23	23	19	> 100

The experimental results exhibited considerable scatter, which is typical of transfer functions derived from full scale trials. Note that the motion indices of correlation for the two different sea states should be equal, since the trials conditions were not sufficiently severe to violate linearity. It is therefore reasonable to identify the differences between the indices in the two sea states as experimental error. In particular, the anomalously high heave indices should be ignored.

The pitch, heave, and relative bow motion predictions were usually fair at all speeds; however, the vertical acceleration predictions were poor. The results of Reference 21 also showed that the phases of the pitch and heave responses were accurately predicted for wavelengths longer than the ship length, but were poorly predicted at shorter wavelengths.

Table 8 compares measured and predicted RMS responses. The RMS pitch, heave, and relative motion predictions are all within 10 percent of the measured values. The acceleration predictions are less reliable, with discrepancies of up to 23 percent.

The authors concluded that the pitch, heave and relative motion predictions were sufficiently accurate to permit the slamming and deck wetness characteristics of the WMEC in head seas to be determined by analytical means. However, they noted that the vertical acceleration at station 14 was usually overpredicted.

TABLE 8 - COMPARISON OF MEASURED AND PREDICTED RMS RESPONSES FOR THE WMEC CUTTER OF REFERENCE 21 IN HEAD SEAS

RESPONSE	SEA STATE	Fn	MEASURED VALUE	PREDICTED VALUE	PERCENTAGE DIFFERENCE
HEAVE (m)	3	0.11	0.34	0.34	0
		0.19	0.40	0.40	0
		0.28	0.46	0.49	7
	5	0.11	1.07	1.04	3
		0.19	1.19	1.16	3
		0.28	1.25	1.28	2
PITCH (degrees)	3	0.11	1.3	1.2	8
		0.19	1.4	1.3	7
		0.28	1.5	1.4	7
	5	0.11	2.7	2.6	4
		0.19	3.1	3.0	3
		0.28	3.2	3.1	3
STATION 0 RELATIVE MOTION (m)	3	0.11	1.46	1.34	8
		0.19	1.55	1.46	6
		0.28	1.77	1.62	8
	5	0.11	2.38	2.13	11
		0.19	2.44	2.65	9
		0.28	2.83	2.83	0
STATION 14 VERTICAL ACCELERATION (m/s^2)	3	0.11	0.30	0.37	23
		0.19	0.37	0.40	8
		0.28	0.55	0.64	16
	5	0.11	0.64	0.67	5
		0.19	0.82	0.82	0
		0.28	1.10	1.22	11

Reference 22 describes the design of the NRC series for fast surface vessels. The series is relevant to the present paper because it provides motion data in head seas for geometrically similar hull forms. The member hulls of the series are derived from parent forms by varying key hull parameters. Although L/B is not one of the basic parameters considered, the series does contain geometrically similar hull forms with L/B values varying from 5.98 to 8.52. It is therefore possible to examine whether there is any trend towards poorer motion predictions at lower values of L/B.

Reference 23 reports on a comparison between strip theory predictions for pitch and heave and the results of model tests for ten members of the NRC series. The strip theory computations were performed using program PHHS[4]. The tests were conducted in head seas at Froude numbers of 0.2, 0.3, 0.4, and 0.5. Results are available at a number of values of L/B for two different parent forms, which are designated Design 18 and Design 24. Design 18 is an extreme U form, while design 24 is a normal hull form.

Tables 9 and 10 contain the motion indices of correlation for heave and pitch, respectively, for the L/B variants of Design 18. Those for Design 24 are contained in Tables 11 and 12.

TABLE 9 - HEAVE MOTION INDICES OF CORRELATION FOR DESIGN 18 OF REFERENCE 23 AND ITS ASSOCIATED L/B VARIANTS IN HEAD SEAS

DESIGN	L/B	Fn = 0.2	Fn = 0.3	Fn = 0.4	Fn = 0.5
14	5.98	16	20	25	31
15	6.74	14	22	37	29
17	7.53	10	24	29	37
18	8.52	12	18	33	44

TABLE 10 - PITCH MOTION INDICES OF CORRELATION FOR DESIGN 18 OF REFERENCE 23 AND ITS ASSOCIATED L/B VARIANTS IN HEAD SEAS

DESIGN	L/B	Fn = 0.2	Fn = 0.3	Fn = 0.4	Fn = 0.5
14	5.98	14	20	35	60
15	6.74	15	22	45	75
17	7.53	5	18	35	50
18	8.52	8	20	35	65

TABLE 11 - HEAVE MOTION INDICES OF CORRELATION FOR DESIGN 24 OF REFERENCE 23 AND ITS ASSOCIATED L/B VARIANTS IN HEAD SEAS

DESIGN	L/B	Fn = 0.2	Fn = 0.3	Fn = 0.4	Fn = 0.5
20	5.98	14	10	11	25
21	6.74	14	10	8	19
23	7.53	10	12	10	19
24	8.52	10	15	10	18

TABLE 12 - PITCH MOTION INDICES OF CORRELATION FOR DESIGN 24 OF REFERENCE 23 AND ITS ASSOCIATED L/B VARIANTS IN HEAD SEAS

DESIGN	L/B	Fn = 0.2	Fn = 0.3	Fn = 0.4	Fn = 0.5
20	5.98	4	8	15	42
21	6.74	4	12	24	50
23	7.53	4	5	15	34
24	8.52	5	7	18	40

There appears to be no trend towards better predictions at higher values of L/B. The predictions for the extreme U form are worse than those for the normal hull form, but this may be partially due to the fact that PHHS uses Lewis forms to represent the ship sections, and may not adequately model the U-shaped sections. At the two lower speeds the predictions are good for the normal hull form, and fair to good for the extreme U form. The pitch predictions are worse than the heave predictions at the two higher Froude numbers. At Fn = 0.4, the pitch predictions are fair for the normal hull and poor for the extreme U form, while at Fn = 0.5 the pitch predictions are poor for both hulls. The heave predictions at Fn = 0.4 are good for the normal hull and poor to fair for the extreme U form. At Fn = 0.5, the heave predictions are fair for the normal form, and poor for the extreme U form.

Reference 23 also compared the measured and predicted phases of the pitch and heave responses. Large discrepancies were sometimes found in short waves, but the responses were small in this regime. Agreement was usually good in longer waves.

There are now plans to extend the NRC series to include some hull forms with lower values of L/B. When this data becomes available, it will be possible to extend the comparison discussed here.

Reference 24 reports on a study to assess the effects of L/B ratio on the hydrodynamic characteristics of a methodical series of ship hulls. The paper considers L/B variants of a Series 60 model with a block coefficient of 0.7. Five hulls are included in the study, with L/B values of 4.0, 5.5, 7.0, 10.0 and 20.0. Measurements of the hydrodynamic coefficients in the pitch and heave equations are reported at Froude numbers 0.2 and 0.3, while sway and yaw hydrodynamic coefficients are reported at Fn = 0.15, 0.2, and 0.3. In addition, pitch and heave amplitudes in regular head waves are reported at the two higher Froude numbers.

The vertical responses were compared with the predictions of two different strip theory formulations, that of Gerritsma[10] and a modified version of the formulation of Korvin-Kroukovski and Jacobs[11,12].

Tables 13 and 14 contain the heave and pitch indices of correlation, respectively, for the L/B variants of the Series 60 hull. The indices from the predictions of the Korvin-Kroukovski and Jacobs theory are shown in brackets. The heave and pitch amplitudes of the L/B = 20.0 model were not measured due to experimental difficulties, and so the motion indices of correlation for this hull could not be obtained.

TABLE 13 - HEAVE INDICES OF CORRELATION FOR THE SERIES 60 MODEL OF REFERENCE 24 AND ITS ASSOCIATED L/B VARIANTS IN HEAD SEAS

L/B	Fn = 0.2	Fn = 0.3
4.0	20 (20)	17 (17)
5.5	13 (6)	16 (5)
7.0	16 (10)	24 (10)
10.0	28 (17)	14 (14)

TABLE 14 - PITCH INDICES OF CORRELATION FOR THE SERIES 60 MODEL OF REFERENCE 24 AND ITS ASSOCIATED L/B VARIANTS IN HEAD SEAS

L/B	Fn = 0.2	Fn = 0.3
4.0	7 (11)	14 (14)
5.5	13 (16)	13 (16)
7.0	12 (18)	16 (21)
10.0	12 (12)	15 (17)

The pitch predictions of the Gerritsma theory at Fn = 0.2 are good; all other predictions are fair to good. There is no trend towards better correlation at higher values of L/B. The heave predictions of the Korvin-Kroukovski and Jacobs theory are better than those of the Gerritsma formulation, but in the case of pitch predictions the situation is reversed.

Readers interested in the comparisons between measured and predicted hydrodynamic coefficients should consult Reference 24.

Reference 25, in Japanese, reports on a study of the seakeeping qualities of roll-on/roll-off ships. Two different five metre models, designated A and B, were tested at Fn = 0.25 and Fn = 0.26, respectively. The tests were carried out in regular and irregular waves at a number of different headings. The responses considered were pitch, roll, yaw, and vertical and lateral acceleration at the centre of gravity. The regular wave results were compared with the predictions of an "ordinary strip method" program[9].

Roll-on/roll-off vessels are characterized by wide beams and shallow drafts. Those considered in the study had L/B values of 6.6 and 6.8.

The motion indices of correlation for the vessels considered in this report are given in Tables 15 and 16. In these tables, and elsewhere in this paper, a heading of 180 degrees indicates head seas.

TABLE 15 - MOTION INDICES OF CORRELATION FOR ROLL-ON/ROLL-OFF VESSEL A OF REFERENCE 25 AT FROUDE NUMBER 0.25

	180 DEGREE HEADING	135 DEGREE HEADING	90 DEGREE HEADING	60 DEGREE HEADING	30 DEGREE HEADING
PITCH	20	24	-	10	18
VERTICAL ACCEL.	23	13	17	58	42
ROLL	-	39	17	42	67
YAW	-	57	-	36	32
LATERAL ACCEL.	-	17	19	26	38

TABLE 16 - MOTION INDICES OF CORRELATION FOR ROLL-ON/ROLL-OFF VESSEL B OF REFERENCE 25 AT FROUDE NUMBER 0.26

	180 DEGREE HEADING	135 DEGREE HEADING	90 DEGREE HEADING	60 DEGREE HEADING	30 DEGREE HEADING
PITCH	2	7	-	17	25
VERTICAL ACCEL.	12	21	14	25	40
ROLL	-	50	18	69	35
YAW	-	20	-	33	28
LATERAL ACCEL.	-	13	11	52	44

The pitch predictions for both vessels were fair to good at all headings. The vertical acceleration predictions were fair to good in head, bow, and beam seas. The predictions were usually poor in quartering seas; however, the vertical accelerations were small in this regime.

The predictions of the lateral motions were less accurate, especially the roll predictions which were usually poor. However, as noted above, this also tends to be the case for finer forms as well.

The authors concluded that the strip method remains useful for vessels of this class.

Reference 26 includes a comparison between model test results and strip theory predictions for an offshore supply vessel in long-crested following waves. The strip theory computations were performed using program HANSEL[7]. The tests were conducted at Froude numbers of 0.11 and 0.28, and the responses considered were heave, pitch, and relative motion. Relative motion was measured at the forward and after quarter points, at the location of the longitudinal centre of buoyancy, and at the after perpendicular. The vessel had an L/B of 4.4, two hard chines and a prototype length of 52 metres.

The motion indices of correlation for this supply vessel are contained in Table 17.

TABLE 17 - MOTION INDICES OF CORRELATION FOR THE OFFSHORE SUPPLY VESSEL OF REFERENCE 26 IN FOLLOWING WAVES

Fn	HEAVE	PITCH	RELATIVE MOTION AT STATION 5	RELATIVE MOTION AT THE LCB	RELATIVE MOTION AT STATION 15	RELATIVE MOTION AT THE AP
0.11	12	24	53	55	39	49
0.28	18	29	88	69	79	56

The heave amplitudes predictions were fair to good, while the pitch amplitude predictions were only fair. The results also showed that the pitch and heave phase angles were reliably predicted except at short wavelengths where the responses were small. The relative motion predictions were poor in all cases: although there was occasionally good agreement at long wavelengths, the peak responses were considerably overpredicted.

The overprediction of the relative motion responses led to conservative analytic predictions for the probability of deck wetness; however, it was found that correcting the actual geometric freeboard for the effects of trim and sinkage and wave profile led to predictions that were in close agreement with the experimentally determined probability of deck wetness. It was concluded that the conservative predictions for the probability of deck wetness were due primarily to the effects of dynamic swell-up and incident wave distortion.

Reference 27 contains a comparison between strip theory predictions and model test results for seven small recreational boats. The boats included in the study consisted of two jonboats, a dinghy, a runabout, a skiff, a dory, and a half-scale model of one of the jonboats. The half-scale model was included to study the effect of size variations, in case nonlinear effects turned out to be important.

The vessels considered in this reference were tested under a number of different loading conditions, and the L/B ratio varied with loading. For this reason, the L/B values given below are the length overall divided by beam overall.

The two jonboats were 4.11 and 4.27 metres in length, and had L/B values of 3.6 and 3.0 respectively. Jonboats have flat bottoms and flat ends, and rectangular sections with one hard chine. The dinghy was 2.44 metres long and had an L/B value of 1.98. Its hull form was similar to that of the jonboats. The runabout was a 4.66 metre long, tri-hull design with an L/B value of 2.72. The skiff was 3.69 metres long and had an L/B value of 2.84. This boat had a full pointed bow, and a rectangular transom stern with two hard chines. The dory was 4.82 metres long and had an L/B value of 3.96. This boat had a flat bottom, long pointed overhangs and high flares. The last boat was a half-scale model of the 4.11 metre jonboat.

The strip theory computations were performed by program HANSEL[7], modified slightly to be able to handle sections with hard chines.

The first part of the model test program consisted of testing these boats in waves of two different heights to see if the motions were linear or not. It was found that the transfer functions at the two wave heights varied by a small amount - usually on the order of ten percent, and occasionally by up to thirty percent. It was estimated, however, that the experimental scatter was equally large, and occasionally even larger. The authors view twenty percent differences in motion estimates to be quite acceptable, and therefore consider cases in which the nonlinearity is less than twenty percent to be linear. (Note that a twenty percent difference in motion estimates would be considered fair agreement in the present work.) There were only four cases which were nonlinear, and these will not be discussed here.

The purpose of Reference 27 was to investigate the swamping tendencies of recreational boats. For this reason, the tests were performed at zero speed and included a number of loading conditions in which the boats were heavily loaded at one end. These boats all had shallow drafts, and the more severe of these loading conditions resulted in one end of the boat being out of the water. This resulted in a waterplane which varied dramatically with draft. Program HANSEL assumes that vessels are wall-sided near the waterline. Since this assumption is badly violated under these loading conditions, poor predictions might be expected even for slender vessels. For this reason, only the less extreme loading conditions are included in this discussion. Even with this restriction, the wall-sided assumption is poorly met by these boats.

Table 18 contains the motion indices of correlation for the recreational vessels. The heave predictions were poor, the pitch predictions were poor to fair, and the relative transom motion predictions were completely unrealistic.

TABLE 18 - MOTION INDICES OF CORRELATION FOR THE RECREATIONAL BOATS OF REFERENCE 27, AT ZERO SPEED

VESSEL	L/B	HEAVE	PITCH	RELATIVE TRANSOM MOTION
JONBOAT(4.11 m)	3.60	18	14	55
JONBOAT(4.27 m)	3.00	30	22	47
DINGHY	1.98	28	34	37
RUNABOUT	2.72	50	15	86
SKIFF	2.84	32	35	54
DORY	3.96	34	20	55

The agreement found between the measured and predicted relative motion was particularly poor. In the strip theory calculations of relative motion, it is assumed that the diffracted wave height is negligible compared to the incident wave height. It was found, however, that for the large transom boats considered in this paper, the diffracted wave can be of equal height to the incident wave. The authors felt that the large diffracted waves were a significant source of error in the relative motion results.

It is clear that strip theory is unsuitable for application to small recreational vessels; however, it is difficult to attribute the large discrepancies found in this paper to a single source. Not only did the vessels considered have very low values of L/B, they also had flat bottoms, shallow drafts and waterplanes that varied considerably in the vicinity of the waterline. In addition, the diffracted wave was neglected in the relative motion computations.

Reference 28 describes a new strip method for predicting the motions and loads of a ship advancing in regular oblique waves. The new theory turns out to be quite similar to that described in Reference 17, although the derivation is different. The paper contains an extensive comparison of model test results and the predictions of the new theory. Included in the correlation study were two oceangoing barges, labelled A and B, with L/B values of 4.0 and 4.6, respectively. The barges were tested at zero speed only, in head, beam, and oblique seas. (The exact heading to waves was not specified.) The responses considered were heave, pitch, and roll.

The motion indices of correlation for these barges are shown in Table 19. The motion predictions are all fair to good. It is likely that the agreement found here would not persist at higher speeds. However, since oceangoing barges operate at low Froude number, it appears that strip theory may be adequate for these forms.

TABLE 19 - MOTION INDICES OF CORRELATION FOR THE OCEANGOING BARGES OF REFERENCE 28, AT ZERO SPEED

VESSEL AND RESPONSE	HEAD SEAS	OBLIQUE SEAS	BEAM SEAS
A - HEAVE	14	16	16
A - PITCH	6	15	-
A - ROLL	-	25	18
B - HEAVE	-	-	14
B - ROLL	-	-	19

2.2 Comparisons Between Measured and Predicted RMS Responses

Reference 29 describes the results of open-water tests of radio-controlled models of four different patrol craft. The vessels tested were a 225 tonnes fast patrol boat with L/B = 5.38 (HMS TENACITY), a 460 tonnes coastal mine countermeasures vessel with L/B = 4.85 (CMS, formerly Ton Class Minesweeper), a 200 tonnes patrol boat with L/B = 4.70 (Bird Class), and a 1210 tonnes patrol boat with L/B = 4.73 (Island Class). Each model was tested in at least two different sea states, in head, bow, beam, quartering, and following seas. The TENACITY was tested at Froude speeds of 0.39 and 0.78; the CMS was tested at Fn = 0.38; the Bird was tested at Fn = 0.42 and 0.57; and the Island was tested at Fn = 0.34. The models were instrumented to record pitch angle, roll angle, vertical and lateral accelerations forward and aft, yaw angle, yaw rate, and rudder angle. Sea state data was recorded with a unidirectional wave buoy.

In this paper, the RMS values for pitch, and vertical accelerations forward and aft in head seas were presented, as well as the RMS values for the roll and lateral accelerations in beam seas. The measured values were compared with predictions made by the computer program SCORES[5].

In general, the agreement found in this paper between theory and experiment was rather poor; however, experimental trends were usually predicted by the computed results. Many of the RMS pitch and vertical acceleration predictions differed from the experimental results by about thirty percent. The motion predictions in the lateral plane were off by even more, with some roll predictions off by well over fifty percent.

The differences between the measured and computed results are attributed to three sources by the authors.

First, the sea spectral data was recorded by a unidirectional wave buoy. A cosine-squared spreading function was used in the computed results to take account of the directionality of the spectra, but this procedure is only approximate. Some of the recorded spectra were multi-peaked, indicating the presence of more than one wave system, so that there may have been more than one principal direction associated with the spectra. Under these conditions, the approximation provided by a cosine-squared spreading function would not be good.

Second, there were probably differences in coursekeeping between that realized in the model tests, and that assumed in the calculations. The models were not equipped with autopilots, but were steered by remote control. This meant that any deviations from the intended course were not detected until a fairly large angle of yaw was built up, requiring a large rudder deflection to bring the model back on course. The result was that the model tended to zig-zag instead of steering a straight course. A small uncertainty in the model heading to waves can result in a sizeable uncertainty in the predicted motions, especially under resonant conditions.

Third, there were shortcomings in the mathematical model in the computer program. This last category includes, in particular, the degree of applicability of the strip theory to low L/B forms, and the limitations of strip theory at high speed.

Unfortunately, it is impossible to quantify the degree to which each of these three sources of error contributes to the discrepancies found between measured and predicted results. Hence, no conclusions on the applicability of strip theory to low L/B forms will be drawn from this work.

Reference 30 discusses the seakeeping characteristics of the U.S. Coast Guard WTGB class, and includes a comparison between RMS vertical accelerations measured in full-scale trials and those predicted by strip theory. The strip theory computations were carried out using program SMP[6].

These vessels are 39.6 metres long between perpendiculars, and have an L/B ratio of 3.85. The vertical acceleration was measured at the pilot house, which is located a distance of 0.23 metres from the centreline of the ship, at station 14.7.

The full-scale trials were conducted in three different sea states, at Froude numbers of 0.13, 0.26, and 0.39, and at a number of different headings to waves. A sample comparison between measured and predicted results is shown in Table 20 for Fn = 0.39.

TABLE 20 - COMPARISON BETWEEN MEASURED AND PREDICTED RMS VERTICAL ACCELERATION FOR THE CUTTER OF REFERENCE 30 AT Fn = 0.39

HEADING	MEASURED VERTICAL ACCELERATION (g)	PREDICTED VERTICAL ACCELERATION (g)	PERCENT DIFFERENCE
0	0.0159	0.0034	79
45	0.0306	0.0080	74
90	0.0902	0.0386	57
135	0.1704	0.1309	23
180	0.1705	0.1570	8
225	0.1328	0.1313	1
270	0.0757	0.0397	48
315	-	0.0081	-

The agreement between theory and experiment is fair in head and bow seas, and poor in beam, quartering, and following seas, but the discrepancies are largest in the regime where the responses are smallest.

The centreline vertical accelerations in port and starboard bow seas should be comparable; however, the accelerations at headings of 135 and 225 degrees given in Table 20 differ by about 25 percent. This is an indication that considerable uncertainty is present in the full-scale results.

The strip theory predictions were made for long-crested seas, using an analytic spectral formulation. Real ocean spectra, on the other hand, always exhibit some spreading about the mean direction of the seaway, and are often fairly irregular. This introduces another factor which may have influenced the comparison shown in Table 20. Under these circumstances, the agreement found between theory and experiment in head and bow seas is as good as can be expected.

2.3 Other Applications of Strip Theory Programs to Low L/B Vessels

This section lists papers which apply strip theory to low L/B vessels without referring to the results of model tests for correlation. These papers implicitly assume that the predictions of strip theory for low L/B vessels are still reliable enough to be useful. These papers are of limited interest for this survey, and are included only for completeness. No detailed discussion of these papers will be given.

Reference 31 compares the seakeeping predictions of two U.S. Coast Guard patrol boats using regular wave responses derived from strip theory. The vessels considered were a 28.9 metre WPB class boat with an L/B value of 4.89, and a 42.7 metre WAGB class boat with an L/B ratio of 3.86.

Reference 32 predicts the RMS responses in irregular seas of four U.S. Coast Guard Cutters using response functions derived by strip theory. Three of these vessels had low L/B values. The cutters involved in the study were a WMEC cutter, with an L/B value of 6.71, the USCGC RESOLUTE, with an L/B value of 6.06, the USCGC POLAR STAR, with an L/B value of 4.51, and the USCGC HAMILTON, which has an L/B value of 8.30. The reader is reminded that a comparison between measured and predicted response functions for the WMEC cutter in head seas was included in Reference 21.

Reference 33 uses strip theory to derive the regular wave responses of three parent offshore supply vessel forms. The vessels considered had L/B values of 5.14, 4.50, and 4.00. The response functions obtained were used to compare the seakeeping performance of the three vessels.

Reference 34 compares the seakeeping characteristics of two ferry candidates. One of the proposed vessels was a small-waterplane twin hull (SWATH) ship, while the other was a conventional displacement hull with an L/B value of 6.17. The seakeeping characteristics of the conventional ship were predicted using regular wave responses derived from strip theory.

3. CONCLUDING REMARKS

This paper has surveyed the applications of strip theory to low L/B vessels (L/B < 7.0) in an attempt to establish the domain of L/B values and of Froude numbers in which strip theory predictions are reliable. A number of the papers reviewed contained direct comparisons between the predictions of strip theory and model test results for low L/B vessels. The vessels considered had L/B values ranging from 2.0 to 7.0. These papers have been discussed in detail, and their abstracts have been included as an appendix. Several types of vessels were included in this discussion, and the findings for these different classes will be summarized separately.

Strip theory predictions for five fishing vessels with L/B values ranging from 2.4 to 5.0 were compared with the results of model tests. The pitch and heave predictions at Froude numbers up to 0.3 were usually almost as good for these vessels as for more slender forms ($L/B \geq 7.0$). Very little data were available at higher speeds, but the pitch predictions near Fn = 0.4 seemed worse than those for finer vessels. There were a number of instances of poor relative motion predictions for fishing vessels. The effects of dynamic swell-up and incident wave distortion appear to be at least partially responsible for this failing. The vertical acceleration was poorly predicted near zero speed, but the predictions were fair to good at Fn = 0.3. This is the opposite of the usual trend for normal L/B vessels of worse predictions at higher speeds.

A number of relatively conventional warship hulls were included in the study, with $L/B > 6.0$. Included in this group were two series of L/B variants of geometrically similar hulls. It was found that the pitch and heave amplitude predictions for these hulls were as good as those for finer forms. Moreover, there was no trend towards worse predictions at lower values of L/B. The pitch and heave phases were sometimes poorly predicted at short wavelengths, but the responses were small in this regime. The phase agreement was usually good in longer waves. There was only one vessel in this class for which comparisons of measured and predicted relative motions and vertical accelerations were available. The relative motion predictions were usually fair, but the vertical acceleration predictions were poor.

The heave and pitch amplitude predictions for four L/B variants of an 0.7 block coefficient, Series 60 hull were found to be fair to good. The models in question had L/B values ranging from 4.0 to 10.0. Once again, there was no trend towards worse predictions at lower values of L/B.

The strip theory predictions of the vertical plane responses of small recreational boats at zero speed were usually poor. The vessels considered had L/B values ranging from 2.0 to 4.0 and were characterized by small drafts and flat bottoms. It is concluded that strip theory is not applicable to this class of vessel.

Strip theory was found to give fair to good predictions for the motions of two oceangoing barges at zero speed. The barges had L/B values of 4.0 and 4.6. Since these vessels operate at low Froude number, it appears that strip theory may be adequate for these forms.

Fair agreement was found between the measured and predicted pitch and heave responses of an L/B = 4.4 offshore supply vessel. The tests were conducted in following waves at Froude numbers 0.11 and 0.28. However, the relative motion predictions were poor due to the significant dynamic swell-up and incident wave distortion.

Strip theory predictions for two roll-on/roll-off vessels were compared with the results of model tests. The vessels had L/B values of 6.6 and 6.8, and were tested at Froude numbers of 0.25 and 0.26. The pitch predictions were fair to good at all headings. The vertical acceleration predictions were fair to good in head, bow, and beam seas. The vertical acceleration was poorly predicted in quartering and following seas; however, the acceleration was small in this regime.

Three of the papers reviewed contained comparison of RMS motions predicted and measured in the open sea, but the results were inclusive. Irregular seas comparisons seem to be of little use in establishing the limits of applicability of strip theory to low L/B vessels, because of the large uncertainties usually found in the experimental results.

From the comparisons described above, it appears that strip theory gives fair to good predictions of the pitch and heave amplitudes of vessels with L/B ratio greater than about 4.0, up to Froude numbers less than about 0.4. However, many of these vessels exhibited considerable dynamic swell-up and incident wave distortion, and this often led to poor relative motion predictions. The vertical acceleration predictions were usually poor, although there were occasionally fair to good predictions in head, bow and beam seas.

A second class of papers that were considered in this survey applied strip theory to low L/B vessels without referring to the results of model tests for correlation. The vessels involved had L/B values ranging from 3.9 to 7.0. These papers implicitly assumed that the predictions of strip theory for low L/B vessels are reliable enough to be useful. This second group of papers was not directly relevant to this study, and was included only for completeness.

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APPENDIX: Abstracts From Selected Referenced Papers

15. "The Seakeeping Quality of Fishing Boats in Waves (Part I): The Analysis of the Ship Motions of Fishing Boats by the Strip Method in Longitudinal Regular Waves" by Y. Yamakoshi, M. Areji, and S. Suzuki

Recently, many reports have been published concerning ship motions in waves. Good agreement has been found between results calculated by the strip method and measured results for many vessels including high-speed containerships, oil tankers, etc.

The authors try to clarify in this report whether the strip method can be used to estimate the motions of fishing boats in longitudinal regular waves. The calculated values from strip theory are shown to be in good agreement with experimental results for fishing boats.

16. "Comparison of Theoretical Seakeeping Predictions with Model Test Results for a Wide Beam Fishing Vessel" by T.O. Karppinen

Motion transfer functions and phase lags computed by linear strip theory for a very wide and short fishing vessel are compared with model test data and theoretical results determined by the three-dimensional, linear sink-source method. Results are presented for beam waves at zero speed and for head seas at the trawling speed and at top speed. Heave in head seas is predicted by the strip theory equally well for this wide beam vessel as for more slender, ordinary hulls. Problems arise in pitch prediction, particularly at the higher speed. Roll computed by a new strip theory computer program is in close agreement with experimental roll data. The strip theory gives either a much better than or at least an equally good fit to the model test data as the three-dimensional method.

19. "Validity of a Strip Theory - Linear Superposition Approach to Predicting Probabilities of Deck Wetness for a Fishing Vessel" by N.K. Bales, L.E. Motter, and R.M. Watkins

The motions and ship-to-wave relative motions of a fishing vessel in head, regular waves are determined from a model experiment and from strip theory computations. The experimental results indicate that linear superposition is not universally applicable to the fishing vessel investigated. Correlation between the experimental and strip theory results is never excellent, and becomes extremely poor at the higher speed considered. The invalidity of linear superposition and strip theory found for the fishing vessel is shown to produce gross errors in predicted deck wetness probabilities.

20. "Dynamic Waterline Seakeeping Predictions For a Fishing Vessel" by R.M. Watkins and N.K. Bales

This report examines the use of a dynamic waterline for strip theory motion computations for a full-hull fishing vessel. This vessel exhibited considerable trim, sinkage, and bow wave at high speed. Because of this, it was thought that the use of an experimentally determined high speed waterline could improve prediction accuracy. It is shown, however, that no improvement was obtained. It was concluded that computational errors introduced by the dynamic waterline were negligible compared to errors introduced by the full-hulled vessel's violation of strip theory assumptions.

21. "Slamming and Deck Wetness Characteristics of a United States Coast Guard Medium Endurance Cutter (WMEC) in Long-Crested, Head Seas" by N.K. Bales

The use of analytical results to characterize the bottom slamming and deck wetness of a United States Coast Guard Medium Endurance Cutter (WMEC) in head seas is justified on the basis of correlation with a prior experiment and of a hypothesis to the effect that dynamic swell-up and incident wave distortion can be neglected for purposes of computing slamming probabilities. Slamming and deck wetness are then analysed in the context of the wave environment for two WMEC operational regions. This analysis indicates that the WMEC will be limited by slamming in wave conditions which are expected to occur at least one percent of the time in both regions considered. It also shows that the operation of the ship may be limited by deck wetness at low speeds in rarely-occurring long waves.

23. "Hull Form Series for Fast Surface Ships, Part 9: Comparison Between Results of Seakeeping Tests and Theoretical Predictions" by D.C. Murdey*

This report contains comparisons between ship motions measured on ten models from a series representing fast surface ships and corresponding predictions based on strip theory. The experimental data used in this report are the response curves of pitch and heave (amplitudes and phases) obtained from tests in regular waves. The theoretical calculations were performed by the Defence Research Establishment Atlantic using program PHHS. The results indicate that there is a problem with strip theory for speeds corresponding to Froude number 0.3 and above. In almost all cases the theoretical result overestimates that from strip theory. The degree of agreement is little affected by changes in beam/draft ratio or length/displacement ratio, but the section shape does have an effect. Very large differences between measured and predicted phases were found in very short waves; however, the motions are small in this regime so this discrepancy is unlikely to be of importance. In longer waves, the phases are generally in better agreement than the amplitudes of the motions.

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*This abstract has been excerpted from the main body of the text of Reference 20.

24. "The Effects of Beam on the Hydrodynamic Characteristics of Ship Hulls", by J. Gerritsma, W. Beukelman, and C.C. Glansdorp

Forced oscillation experiments have been carried out with a systematic ship model family in which the length-beam ratio ranged from 4 to 20. The experiments also included a thin plate to simulate the case of an infinite length-beam ratio. Vertical and horizontal harmonic motions in calm water have been considered and the corresponding hydrodynamic coefficients have been determined. Moreover, the vertical motions and added resistance in waves have been measured. The results are presented in graphical form and are compared with some existing calculation methods.

25. "A Study on Motion Characteristics of Roll-On/Roll-Off Vessels (The First Report: Seakeeping Quality)" by M. Hirano, J. Takashina, and T. Nakajima

The authors recently carried out extensive investigations on the motion characteristics of roll-on/roll-off vessels using both model experiments and theoretical calculations. This paper deals with the results obtained in the field of seakeeping quality.

Using two kinds of 5.0 metre, self-propelled roll-on/roll-off vessel models, the following experiments for seakeeping quality were conducted in the 80(m) x 80(m) basin of the Ship Research Institute.

1. Free and forced rolling tests in running condition.

2. Motion and acceleration measurements in regular and irregular waves.

3. Tests to control rolling motion by fin stabilizer in regular and irregular waves.

4. Tests to control rolling motion by rudder in regular and irregular waves.

Theoretical approaches based upon the strip method were also made. A method to calculate the the effects of fin stabilizer or rudder on roll reduction was developed by adding fin stabilizer or rudder forces to the strip theory roll equation.

The conclusions obtained in this study are summarized as follows.

1. The computed strip method results are in good agreement with the experimental results for motion and acceleration in regular waves. Strip theory is useful for wide beam, shallow draft vessels such as the roll-on/roll-off vessels considered here.

2. The rolling characteristics of the roll-on/roll-off vessels in this study is excellent.

3. The effect of fin stabilizer on roll reduction is assured to be remarkably large in both regular and irregular waves.

4. For a fin stabilizer control system, both proportional and rate control are very effective; however, rate control is normally the best choice since proportional control shortens the natural rolling period, which is undesirable.

5. For roll reduction by fin stabilizer or rudder, the results computed by the method proposed here agree well with experimental results.

6. The rudder is also effective in reducing roll, but at the same time large yawing motions are induced in the models. It seems that there exist problems to be solved in roll reduction by the rudder.

26. "Validity of Analytical Predictions of Deck Wetness for an Offshore Supply Vessel in Following Waves" by N.K. Bales and R.M. Watkins

The deck wetness characteristics of an offshore supply vessel in following waves are predicted analytically and compared with experimentally derived results. It is found that the analytical predictions are conservative given specified conditions. The conservatism of the analytical results is attributed primarily to the influence of dynamic swell-up and incident wave distortion on ship-to-wave relative motion.

27. "Prediction of Swamping Tendencies of Recreational Boats" by B.W. Oppenheim and F.J. Nickels

Seven small recreational boats were tested to obtain heave, pitch and relative transom motion RAO curves in regular longitudinal waves. This data was needed to determine the feasibility of making mathematical simulations of swamping tendencies using linear strip theory, and, in a few cases, a 3-D motion theory. The probability of swamping of the boats was calculated for seven sample severe wave conditions. The boats included two jonboats, a dinghy, a runabout, a skiff, a dory, and a half-scale model of a jonboat, all in a number of asymmetric loading conditions. The motions were found to be linear. The strip theory was found to be unsuitable for the boats. The probability of swamping was found to be high indeed. The 3-D theory yielded promising results, but more research is needed to establish its suitability for the boats.

28. "Motions and Hydrodynamic Loads of a Ship Advancing in Oblique Waves" by C.H. Kim, F.S. Chou, and D. Tien

An analytic technique developed to estimate the response motions and loads of a vessel is presented and the results are correlated with those of model tests and other methods. The stripwise computation technique is applied to the following hydrodynamic problems: wave-excited and motion-induced forces and moments, wave loads on cross sections, and hydrodynamic pressure and relative motion. Extensive correlation analyses between theory and experiment, including full-scale comparisons, have been carried out for basic motions and loads and a number of derived responses in the cases of barges, in deep and shallow sea environments. The study shows that the predictive capability of the technique presented here covers a variety of responses of diverse configurations of ships and ocean platforms, as well as estimation of shallow-water bottom effect. The predictions, however, are less accurate in the region of shorter waves and higher ship speeds.

29. "The Solent Seakeeping Experiments: Some Results and their Comparison with Computer Predictions" by A.P.A. Hawes and M.J. Stevens

The paper is concerned with experiments carried out on a series of models of patrol craft to investigate their seakeeping under free-running conditions in realistic wind-generated waves at sea. The reasoning behind the experiments and the objectives are outlined, and the models, equipment and test techniques employed are described.

In view of the very large quantity of data obtained, the paper describes only a relatively limited selection of results obtained from the first four vessels of the test series. Computer predictions for the same vessels in the same sea states are also presented and comparisons are made between the relative performance of the various vessels and between the results obtained from the experiments and calculations respectively.

It is concluded that, as might be anticipated, the computer predictions did not accurately predict the absolute values obtained in the model experiments but nevertheless the trends and general orders of magnitude give some confidence in the continued use of the program.

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13. ABSTRACT

This paper surveys the applications of strip theory to low length to beam ratio (L/B) vessels (L/B < 7.0) in an attempt to establish the domain of L/B values and of Froude numbers in which strip theory predictions are reliable. A number of the papers that are included in this review contain direct comparisons between the predictions of strip theory and model test results for low L/B vessels. The vessels considered had L/B values ranging from 2.0 to 7.0. These papers are discussed in detail, and their abstracts are included as an appendix. It appears that strip theory gives fair to good predictions of the pitch and heave amplitudes of vessels with L/B ratio greater than about 4.0, up to Froude numbers less than about 0.4. However, many of these vessels exhibit considerable dynamic swell-up and incident wave distortion, and this often leads to poor relative motion predictions. The vertical acceleration predictions are usually poor, although there are occasionally fair to good predictions in head, bow and beam seas. A second class of papers included in this survey applies strip theory to low L/B vessels without referring to the results of model tests for correlation. The vessels involved had L/B values ranging from 3.9 to 7.0. These papers implicitly assume that the predictions of strip theory for low L/B vessels are still reliable enough to be useful. This second group of papers is not directly relevant to this study, and is included only for completeness.

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KEY WORDS

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Regular Wave Responses
Correlation Study
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