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Experimental Investigation into the Effects of Wave Direction on Seakeeping Performances of Ship

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ABSTRACT

In early design stage of ship form design, there are some aspects need to be considered for estimation and evaluation of seakeeping of the ship. This study describes the influence of wave directions on ship motions and the effect of speed on the characteristics of ship seakeeping. In response to this study, various tests of seakeeping in irregular waves are performed in wave basin. The seakeeping tests comprise motions and accelerations tests. Experimental results are presented in tables and graphical form and the ship performances are discussed and compared with recently published data. Results presented in this paper offer practical data and may prove useful for designers at conceptual or preliminary design stages.

KEY WORDS: *Seakeeping; Wave Direction; Model Test.*

1. INTRODUCTION

1.1 Background

The seakeeping of ship are important from a safety point of view. As ships have to be operated under various climatic and sea conditions, a ship's sea-keeping quality constitutes an important factor from the standpoints of safety and economy. Thus, when ship is built, its seakeeping qualities are thoroughly checked at the basic design phase.

It is very complicated or even impossible to give a general definition of an optimal behavior of a ship in seaway. This optimum can be related to various phenomena, like motions, accelerations, workability at certain locations etc. Sometimes, contradictory effects will be found [Journée et al, 2002]. Attempts to define general criteria for these phenomena can be found in the literature.

This experimental study intends to investigate the influences of wave directions on ship motions.

In order to study the influences on these characteristics, a series of measurements was conducted with free running model in wave basin. The seakeeping tests are carried out with various wave directions of irregular waves. The model was installed instruments to record the wave elevations, motions (roll, pitch and heave) and accelerations (vertical and transverse directions).

1.2. Model Description

The ship model of tanker is based on froude's law of similitude and manufactured of wood to a linear ratio of 1:45. The body plan of ship is shown in Figure 1. While iinstrumentation was set-up and its configuration on the ship model is shown in Figure 2:

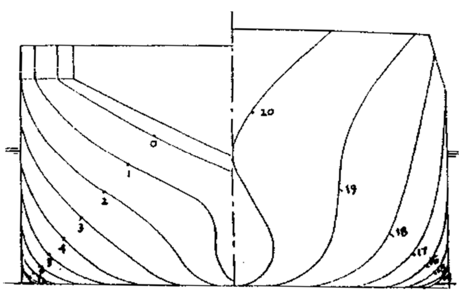

Figure.1: Body plan of ship

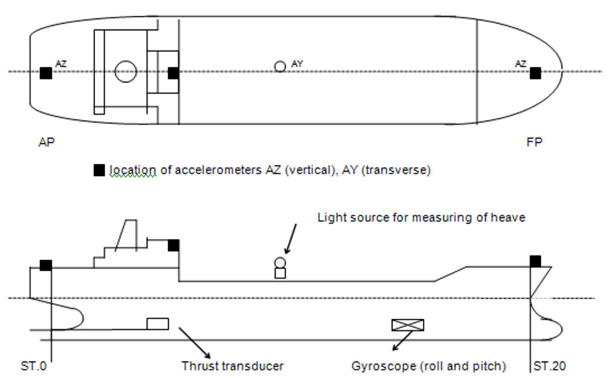

Figure.2: Instrumentations on ship model

Table.1: Main particulars of ship

Designation	Symbol	Unit	Values
Length between perpend.	LPP	m	167.00
Breadth	B	m	28.00
Draft fore	Tf	m	10.30
Draft aft	Ta	m	10.30
Depth	D	m	15.00
Displacement weight	Δ	tf	39.632
Centre of gravity	KG	m	8.25
Centre of buoyancy Metacentric	LCB	m	4.19
height	GM	m	3.50
Long.rad. of gyration	kyy	m	41.75
Transverse.radius of gyration	kxx	m	11.20
Natural roll period	Tϕ	s	12.00
Natural pitch period	Tθ	s	7.51

Prior to being tested, the ship model was checked dimensionally and balanced dynamically following the specified data as listed in table 1.

The transverse weight distribution was adjusted in such a way that the natural period of roll coincides with theoretical value given by [Bertram, 2000].

$$T_\phi = \frac{2\pi . k_{xx}}{\sqrt{g.GM}} \qquad (1)$$

In which:

$T\phi$ = natural period of roll.
K_{xx} = radius gyration for roll.
g = acceleration due to gravity.
GM = transverse metacentric height.

The transverse metacentric height was adjusted by means of heeling test in calm water.

2. METHODOLOGY

2.1 Experimental Investigation

The seakeeping tests were performed in irregular waves with ship speed of 17.0 knots. The tests are conducted with free running model in the wave basin. Detail test programs for seakeeping tests are presented in Table 2.The ship motions (roll, pitch and heave) and accelerations (vertical and lateral) are measured in a varied wave headings: on head seas 180 deg, bow quartering seas on 135 deg, beam seas on 90 deg, stern quartering seas on 45 deg and following seas 0 deg. All of these wave headings on ship are shown in Figure 3.

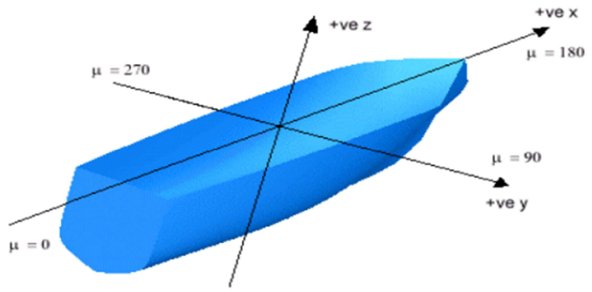

Figure.3: Wave heading on ship

Table.2: Seakeeping test program

Ship speed (knt)	Irregular Seas (P-M Spectrum)		
	Sign. height (m)	Period (sec)	Heading (deg)
17.0	3.0	7.0	180
17.0	3.0	7.0	135
17.0	3.0	7.0	90
17.0	3.0	7.0	45
17.0	3.0	7.0	0

3. RESULT AND DISCUSSIONS

3.1. Test Results and Discussions

The seakeeping aspect of the model tests in irregular waves are discussed on the following sections. In its seakeeping aspects, magnitude of the significant values and some times, the maximum values will be considered. For this investigation, significant double amplitudes (2A1/3) are considered from the results of statistical analysis to determine the effects of wave directions on ship motions and accelerations. For the result from the statistical analysis is shown on Table 3 :

Table 3: Statistical analysis results

Designation	Unit	$A_{1/3}$ +	$A_{1/3}$ -	2$A_{1/3}$
Wave	m	1.50	-1.41	2.79
Head Seas 180 deg				
Roll	deg	0.45	-0.64	0.98
Pitch	deg	0.85	-0.85	1.64
Heave	m	0.25	-0.68	0.89

Designation	Unit	$A_{1/3}$ +	$A_{1/3}$ -	$2A_{1/3}$
Vert.Acc. (fwd)	m/s^2	0.94	-1.00	1.91
Vert.Acc. (aft)	m/s^2	0.75	-0.75	1.47
Tranv.Acc.(wh)	m/s^2	0.15	-0.16	0.30
Bow Quartering Seas 135 deg				
Roll	deg	0.87	-0.90	1.51
Pitch	deg	0.85	-1.39	2.19
Heave	m	0.33	-0.69	1.01
Vert.Acc. (fwd)	m/s^2	1.34	-1.51	2.83
Vert.Acc. (aft)	m/s^2	1.10	-1.08	2.16
Tranv.Acc.(wh)	m/s^2	0.36	-0.31	0.64
Beam Seas 90 deg				
Roll	deg	3.65	-3.68	7.20
Pitch	deg	0.32	-0.63	0.91
Heave	m	1.17	-1.59	2.71
Vert.Acc. (fwd)	m/s^2	0.63	-0.69	1.30
Vert.Acc. (aft)	m/s^2	0.97	-1.10	2.04
Tranv.Acc.(wh)	m/s^2	0.35	-1.29	2.61
Stern Quartering Seas 45 deg				
Roll	deg	1.56	-2.15	3.57
Pitch	deg	0.71	-1.22	1.87
Heave	m	0.10	-0.43	0.47
Vert.Acc. (fwd)	m/s^2	0.67	-0.69	1.32
Vert.Acc. (aft)	m/s^2	0.61	-0.62	1.21
Tranv.Acc.(wh)	m/s^2	0.44	-0.54	0.96
Following Seas 0 deg				
Roll	deg	0.99	-0.85	1.71
Pitch	deg	0.45	-0.57	0.79
Heave	m	0.03	-0.31	0.29
Vert.Acc. (fwd)	m/s^2	0.13	-0.13	0.25
Vert.Acc. (aft)	m/s^2	0.12	-0.14	0.24
Tranv.Acc.(wh)	m/s^2	0.18	-0.21	0.38

3.2. Rolling

Rolling is one of the most important ship motions because it can produce large dynamic angle when the wave period coincides with natural period of ship. The results in Figure 4 shows the ship does not develop a significant rolling response in head seas 180 deg and following seas 0 deg. In beam seas 90 deg, roll is a very important factor in judging the seakeeping qualities of the ship in which the maximum roll angle occurred

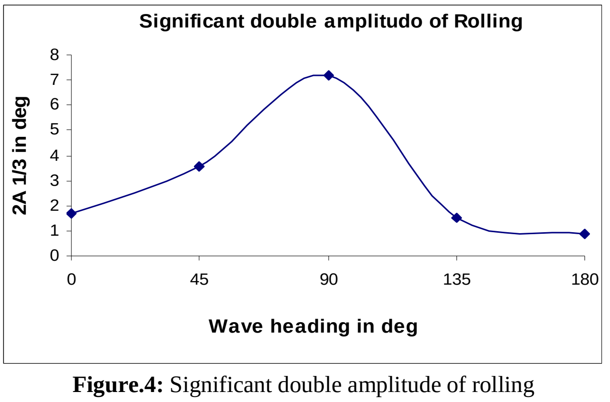

Figure.4: Significant double amplitude of rolling

The experiments show that, in beam seas, large amplitude roll motion occurs not only in the frequency region of the roll resonance but also on the wide frequency region higher than the resonant frequency, and that kind of jump phenomena of roll motion appears [Kuroda et al, 2003]. It is confirmed that the cause of these phenomena is that drift motion induced by high waves changes encounter frequency and shifts roll resonance to higher frequency.

3.3. Pitching

For a ship, pitching is a very dominant motion that depends on the state of the sea, the ship speed and the direction in which the ship sails with respect to the waves.

From the results as shown in Figure 5, the maximum significant double amplitude occurs in bow quartering seas 135 deg and stern quartering seas 45 deg. Pitching amplitudes are largest when the wave length is approximately 1.5 times the ship length. Furthermore, in head, beam and following seas are in general not considered significant values

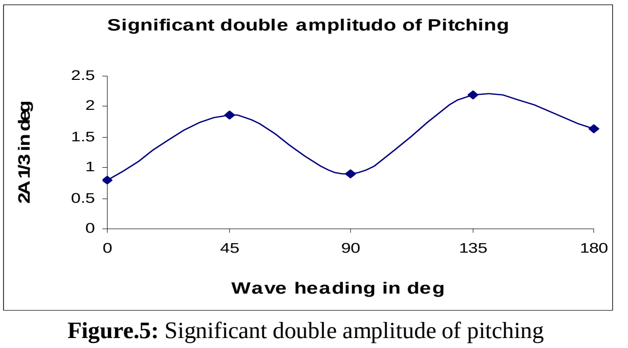

Figure.5: Significant double amplitude of pitching

In quartering seas, the pitch motion shows a significant value. This motion is usually associated with roll and yaw motions. When a high wave reaches the stern of the ship, the stern is lifted. Because the sterns of these ships are usually broad and flat, the ship is simultaneously heeled to starboard (if the waves come from other side).

Through this combined pitch and roll motion the bow is now more deeply submerged. This deeper submergence of the bow in combination with the roll angle introduces an asymmetry, both in longitudinal and athwart direction, and so a considerable yawing moment is generated on the ship. This yaw moment is quite big that it is pushing the bow of the boat to port side. In the worst case however the yaw motion gets out of control and the ship usually ends up in beam seas and possibly at excessive heel. In extreme cases this may even lead to a capsize [Quadvlieg et al, 2009].

3.4. Heaving

There is a difference on the magnitude of heave response in every wave heading conditions. The maximum heave motions of ship occurs in beam seas because of the large wave length/ship length ratio, see Figure 6.

In beam seas, it have double significant heave motion approximately equals the double significant wave height. For other wave headings are considered to be a small response.

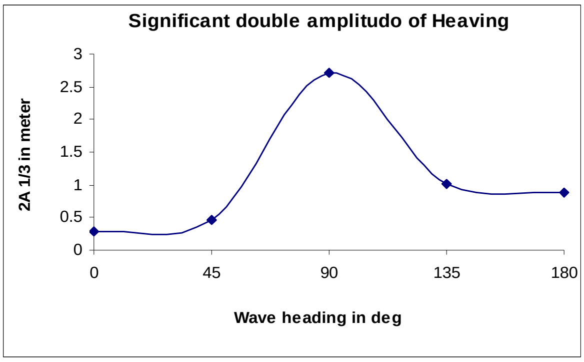

Figure.6: Significant double amplitude of heaving

The heave and roll motion in beam seas show the same magnitude due to the roll natural period of the model ship used in the experiments are close to heave natural period.

3.5. Vertical Accelerations

All values of the vertical acceleration were recorded by using accelerometer which was located at fore and aft of the ship model. The vertical accelerations, which are in fact the second derivatives of the vertical motion are not only sensitive to the motion amplitudes but also to the frequency of encountered squared. Therefore trends observed for heave and pitch motion can be recognized. The contribution of the heave and pitch motions to the vertical acceleration is dependent on the phase relationship between the two motions and the location on the ship. At the fore peak contribution due to pitch in the local vertical motion is considerable and therefore the vertical accelerations at the fore peak are high compared to after peak.

It is clear as shown in Figure 7 that the maximum vertical accelerations (at fore and aft of ship model) occur in stern quartering seas 135 deg. The pitch motion values (significant double amplitude) will affect the vertical acceleration values.

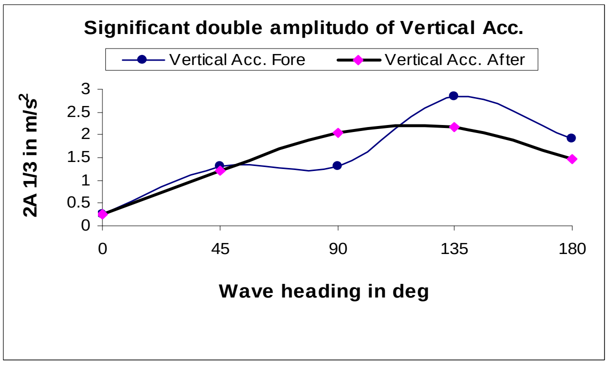

Figure.7:.Sign.double amplitude of vertical acceleration

Peaks of the vertical acceleration are the key factors to judge if seakeeping behavior is acceptable or not, not only from a comfort point of view, but especially from a safety point of view

3.6. Transverse Accelerations

The transverse acceleration was recorded using accelerometer which was located at the wheel house of the aft-ship model. The values of transverse acceleration in beam seas 90 deg are significantly higher than other wave headings, as shown in Figure 8.

It can be explained that in beam seas condition the transverse accelerations are influenced by sway motion, encountering frequency, roll angle (which in Figure 3 shows that in beam seas the values is quite high) and the gravity acceleration which takes more proportion.

The transverse and vertical accelerations are strongly related to human effectiveness and comfort, in particular considering seasickness [O'Hanlon et al, 1974; McCauley et al, 1976].

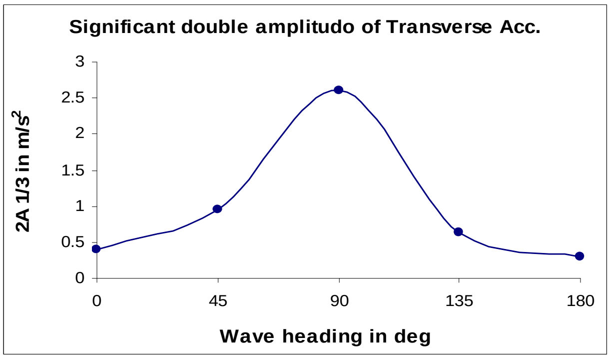

Figure.8: Sign double amplitude of transverse acceleration

4. CONCLUSION

The experimental investigation were used to study the effects of wave directions on seakeeping performance of tanker in irregular waves with free running model.

The results of model tests show that the wave directions are very significant influences on ship motions and accelerations. In beam seas, the maximum heave and roll motions as well as transverse acceleration occurred, while the maximum pitch and vertical accelerations occur in stern quartering seas

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