EXPERIMENTAL ANALYSIS ON PARAMETRIC RESONANCE FOR TWO FISHING VESSELS IN HEAD SEAS

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SUMMARY

This paper reports on a series of experiments conducted with two typical fishing vessels in order to investigate the response of the hulls to parametric excitation in head seas. The two vessels have very similar characteristics but their sterns are different. One is a round stern vessel, the other one has a transom stern. For each hull, two metacentric heights were tested. Additionally, different speeds and wave amplitudes were considered. The study focuses on analyzing the influence of speed on the roll motion amplification at the first region of the Mathieu stability diagram. Some conditions show intense amplification. The influence of hull stern shape is discussed. Its influence on the dynamics of roll parametric resonance appears to be relevant for low metacentric conditions.

1. INTRODUCTION

Parametric resonance of the roll motion for the first Mathieu frequency, discussed by Kerwin (1955), Paulling and Rosenberg (1959), Blocki (1980), may strongly influence the dynamic behavior and stability in waves of seagoing vessels, see Oakley, Paulling and Wood (1974), De Kat and Paulling (1989), Munif and Umeda (2000). Fishing vessels, in particular, are frequently reported to develop strong rolling motions associated with the characteristic low cycle resonance. The authors' view is that for this type of vessel, with intrinsic design characteristics and operational requirements, parametric resonance is a most relevant source of dangerous situations. This view is complemented by the understanding that pure loss of stability and broaching are also important (in the sense of endangering the ship) modes to be analyzed by the designer for this category of ships; however, these modes, to become sources of concern, would require quite high speeds in following seas. Very few fishing vessels (some Japanese, certainly) can attain such required high speeds. On the other hand, parametric resonance may be important for typical fishing vessels even in head seas.

Previous investigations conducted by the authors, Pérez and Sanguinetti (1995), Neves, Pérez and Valerio (1999), indicated that in longitudinal regular waves, at zero speed of advance, resonant parametric amplification may result in large and dangerous rolling motions, particularly for fishing vessels with a transom stern in low metacentric height loading conditions. In the present paper, experimental results for different Froude numbers in head seas are discussed. This is a condition often encountered by fishing vessels, as while trying to maintain position in rough weather.

For the present study, comprehensive testing of two typical fishing vessels has been carried out, aiming at investigating the relevance of parametric resonance of the roll motion for the two ships in head seas under distinct speeds. In the experiments, the first region of resonance was investigated. This is defined as the condition corresponding to the encounter frequency coinciding with twice the roll natural frequency.

The two tested hulls have very similar main characteristics, but a different stern shape. One is a typical round stern vessel; the other one is a transom stern fishing vessel. The transom stern configuration had proved to be responsible for large roll amplifications in the zero speed of advance previously tested case. One relevant question that the present paper intends to answer is whether a transom stern arrangement does continue to define strong parametric resonance when different speeds in head seas are considered.

For each hull two loading conditions were defined in order to assess the influence of metacentric height, Froude number was varied in order to verify how the phenomenon of parametric resonance would be affected by the modified hydrodynamic flow due to speed of advance, and finally, distinct wave amplitudes were also considered in the experimental program grid.

The results discussed in the paper may be relevant for the practical problem of designing and operating safer fishing vessels. Strong resonances are found, with large roll angles taking place in few cycles. The introduction of speed as one additional parameter renders complexity to the overall dynamic analysis. For some tuning conditions the transom stern hull may display at high speeds stronger roll amplifications than those registered in the low speed range. Results are interpreted having into account the main terms affecting the energy balance of coupled modes.

2. EXPERIMENTAL ARRANGEMENTS

Tests were conducted at the Ship Model Basin of the Austral University, Valdivia, Chile. The tank main dimensions are:

Total length	45.0 m
Breadth	3.0 m
Depth	1.8 m

A flap-type wave generator positioned at one extreme of the tank generates regular waves.

Whenever a ship model is to be towed in waves, a major difficulty has to be overcome: to perform the towing of the model without undesirable interference of the towing arrangement with the wave excited bodily motions of the model. This is particularly complicated when large perturbations are associated with the translational average motion of the hull. The satisfactory solution to the problem that was implemented in the present series of tests is illustrated in Fig. 1. Two auxiliary lines were respectively fixed to the bow and stern of the model at calm water level, with these two lines tied to the towing wire. The resulting elasticity of the set was found in all cases to be appropriate in order to secure free evolution of the different (symmetric and anti-symmetric) modes of motion at a controlled speed. In particular, large yaw motions could develop without noticeable interference in practically all runnings.

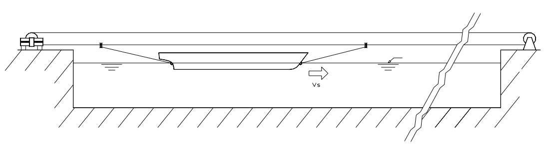

Figure 1: Towing arrangement adopted in the experiments.

Table I

PRINCIPAL PARTICULARS OF SHIPS		
Denomination	**RS**	**TS**
Length (m)	24.36	25.91
Length between perpendiculars (m)	21.44	22.09
Beam (m)	6.71	6.86
Depth (m)	3.35	3.35
Draught (m)	2.49	2.48
Displacement (tons)	162.60	170.30
Waterplane area (m^2)	102.50	121.00
Trans. radius of gyration (m)	2.62	2.68
Long. radius of gyration (m)	5.35	5.52

3. PARTICULARS OF SHIPS

The main characteristics of the ships used in this paper are listed in Table I. Figures 2 and 3 show their lines plans.

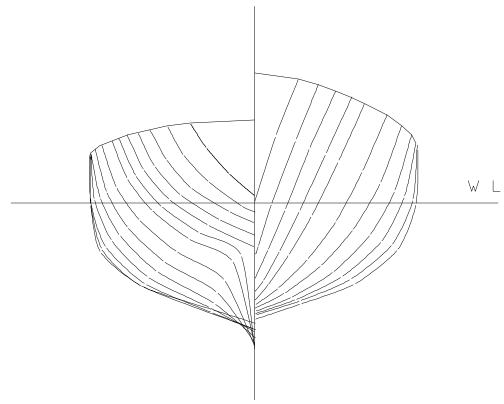

Figure 2: Body plan of tested vessel RS

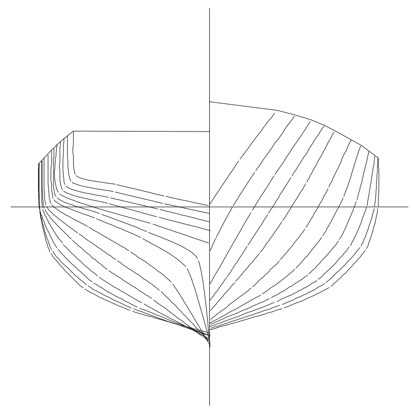

Figure 3: Body plan of tested vessel TS

From Table I and Figs. 2 and 3 it may be observed that the two hulls have very similar dimensions and characteristics but different stern arrangements. The first one will be called RS. It is a quite typical fishing vessel hull form with conventional round stern. The second hull, which will be called TS, corresponds to a typical transom stern fishing vessel. The tested models were built to a scale 1:30. As mentioned previously, the two hulls had already been tested under parametric resonance in the case of zero speed of advance, see Neves, Pérez and Valerio (1999).

4. TESTED CONDITIONS

In the present series of tests the conditions were defined associated with one single encounter frequency ω_e for each loading condition. This is defined as:

$$\omega_e = \omega - kU \cos \chi$$

Table II: Tested Conditions for RS

GM *(m)*	*Fn*	*a* *(m)*	*Wave steepness* h_w / λ	$\overline{\phi}$ *(deg.)*
0.34	0.10	0.59	1/33	7
		0.69	1/28	14
		0.84	1/23	30
	0.14	0.51	1/42	3
		0.80	1/27	20
		0.84	1/26	24
	0.20	0.75	1/33	5
		0.87	1/28	7
		0.96	1/26	17
	0.34	0.90	1/35	0
		1.02	1/31	5
0.48	0.10	0.48	1/30	10
		0.66	1/22	20
		0.90	1/16	32
	0.14	0.54	1/30	9
		0.66	1/25	18
		0.90	1/18	30
	0.20	0.48	1/39	5
		0.66	1/28	16
		0.90	1/21	20
		1.02	1/18	21
	0.34	1.02	1/23	0

Table III: Tested Conditions for TS

GM *(m)*	*Fn*	*a* *(m)*	*Wave steepness* h_w / λ	$\overline{\phi}$ *(deg.)*
0.37	0.11	0.30	1/53	15
		0.66	1/24	27
	0.15	0.45	1/39	18
		1.02	1/17	28
	0.20	0.45	1/44	4
		0.60	1/33	19
	0.30	0.60	1/40	5
		0.78	1/31	38
0.50	0.11	0.39	1/31	19
		0.63	1/19	22
		1.02	1/12	27
	0.15	0.39	1/35	2
		0.60	1/23	13
		1.08	1/13	16.5
	0.20	1.02	1/15	0
	0.30	1.02	1/19	0

In the above definition, ω is wave frequency, U is ship speed, k is wave number and χ is the angle of wave incidence with respect to ship. For head seas, $\chi = 180^0$. The tested conditions were those defined in Tables II and III. In these tables, a is wave amplitude, h_w is the wave height and λ is wavelength.

The last columns of Tables II and III present, for each speed and wave amplitude, for the tested conditions corresponding to $\omega_e = 2\omega_n$ (where ω_n is the natural frequency in the roll mode) the registered values of $\overline{\phi}$ (in degrees), the final (steady) roll amplitude observed in each test after all transients had died out. Clearly, for constant encounter frequency, this final roll amplitude is a measure of the level of parametric amplification in each tested condition.

In summary, the experimental test programme involved two hulls with distinct stern arrangements to be compared, each vessel with two metacentric heights, varying speeds and wave amplitudes.

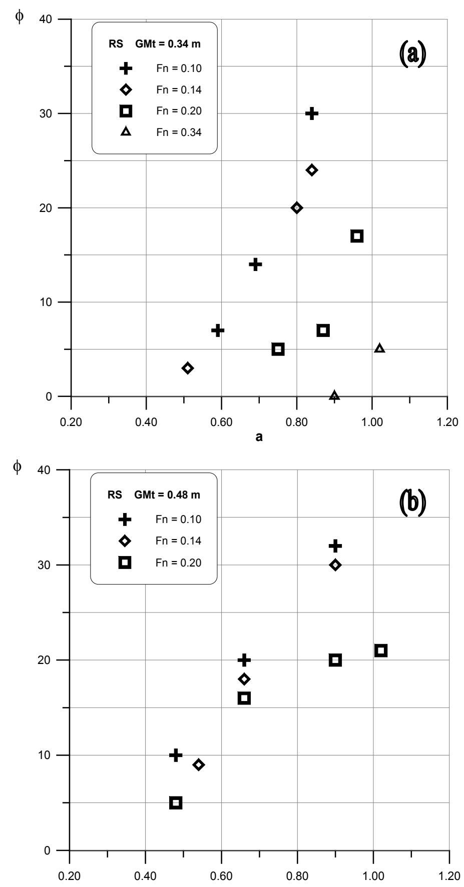

Figure 4: Variation of roll amplitude with wave amplitude for different *Fn*. RS hull, (a) $GM = 0.34m$; (b) $GM = 0.48m$.

5. ANALYSIS OF EXPERIMENTAL RESULTS

5.1 RS HULL

In graphical form, Table II may be summarized as in Fig. 4(a, b) for RS hull. The graphs show roll amplitude against wave amplitude at the tested Froude numbers and display all tested conditions.

In Fig. 4(a,b) it is observed that for both values of GM and for each Fn there is a linear tendency in the growth of the roll amplitude for larger wave amplitudes. Additionally, this tendency is kept almost the same as larger speeds are considered. There is a clear tendency, when the same wave amplitude is considered, for roll amplitudes to become smaller at higher speeds. Figure 5 illustrates this tendency. The figure displays time series of roll motion obtained for RS, $GM = 0.48m$ for three Froude numbers and $a=0.90m$. Clearly, there is a marked reduction in roll amplification as speed increases. It is noted that for this value of metacentric height no roll amplification was observed for $Fn = 0.34$.

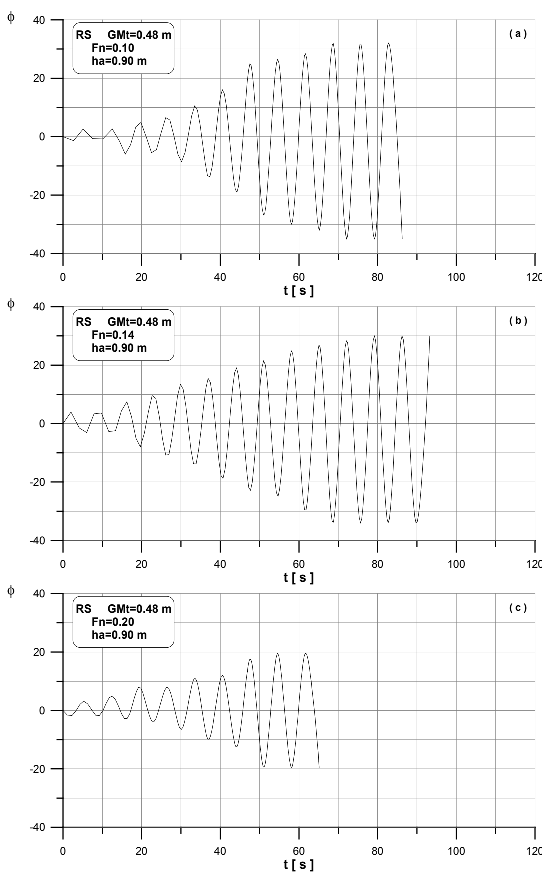

Figure 5 Time series of roll motion for RS hull, $GM = 0.48m$, $a = 0.90m$, (a) *Fn = 0.10*; (b) *Fn = 0.14* and (c) *Fn = 0.20*, respectively.

The implication here is that with increased speed of advance, more damping (mainly lift damping) now acts against a higher level of vertical motions, resulting in less roll parametric amplification. This was discussed in detail by Neves, Pérez, Lorca and Valerio (2001). Another way of viewing this roll reduction with speed is seen in Fig. 6(a,b). In this figure, final (steady) roll amplitudes are plotted against Froude number for a particular wave amplitude. For the lower metacentric height condition, Fig. 6(a), the tested wave amplitudes are not exactly the same for all speeds, thus linear interpolation has been applied. But the important aspect to be observed from the two graphs is the common tendency for roll motion amplification to attenuate in face of higher speeds, irrespective of the tuning.

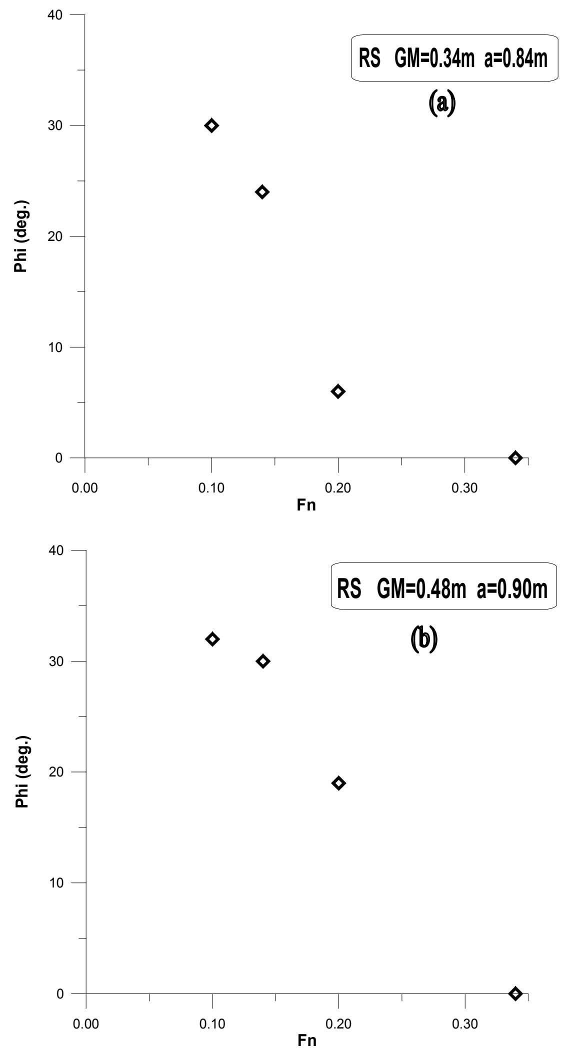

Figure 6: Roll amplitudes against *Fn* for RS hull:
(a) $GM = 0.34m$, $a = 0.84m$, $\omega_e = 1.49rad/s$
(b) $GM = 0.48m$, $a = 0.90m$, $\omega_e = 1.78rad/s$

5.2 TS HULL

Consider now the results for TS hull given in Table III, presented in graphical form in Fig. 7(a,b). It may be observed from Fig. 7(a) that for the lower GM and small Froude numbers there is a tendency for roll angles to change in a similar way as discussed previously to the RS hull. Yet, for higher speeds, the tendency is reversed, and it is observed that very large roll angles are obtained for *Fn=0.30*.

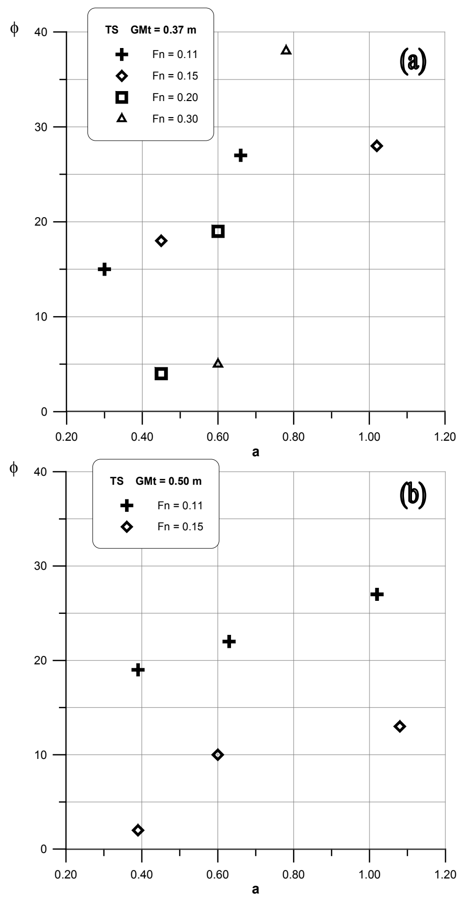

Figure 7: Variation of roll amplitude with wave amplitude for different *Fn*. TS hull, (a) $GM = 0.37m$; (b) $GM = 0.50m$

In fact, considering the complete test program, the largest roll response was obtained for this condition, corresponding to angles of the order of 38 degrees being reached in few cycles, wave amplitude being *a=0.78m*. The time series corresponding to this impressive parametric roll amplification in head seas is given in Fig. 8. This intense resonance for *Fn=0.30* is larger than the roll amplitudes registered for zero speed, as reported by Pérez and Sanguinetti (1995) and Neves, Pérez and Valerio (1999). For zero speed, *GM=0.35m* and *a=0.90m*, roll angles of 34 degrees were obtained. Still considering this low *GM* for TS testing, it is observed that at *Fn=0.20* there are intense responses, though not as intense as in the *Fn = 0.30* case. For the higher metacentric height, *GM=0.50m*, a tendency similar to what was observed for the RS hull is back: higher speeds now imply lower amplifications. It may be noticed that for TS hull at this high GM condition, for *Fn>0.15* practically no amplification was observed.

It may be observed that the situation for TS hull at the low *GM* condition is completely different from the RS hull responses in the high speed range. From Fig. 7(a) for *a=0.78m* (applying linear interpolation for the lower Froude numbers) one gets Fig. 9(a). When the same procedure is applied in Fig. 7(b) for *a=1.02m,* one gets Fig. 9(b).

It is seen in Fig. 9(a) that for TS hull in the range of low speeds corresponding to $0.11 \leq Fn \leq 0.15$, roll amplitudes decay, as was the case with RS hull. But for higher speeds, instead of progressively lower responses, there is now an increase in roll response. In fact, responses are all high, but what is striking is the difference in trend. Now, it is seen that for the higher metacentric height *GM=0.50m*, Fig. 9(b), there is the continuous trend for roll amplitudes to decay with increased speeds. In fact, for *Fn=0.20* and above this value, no amplification was observed for this condition.

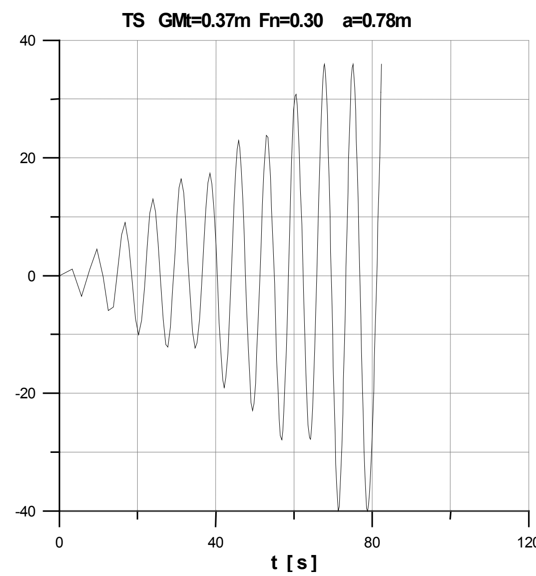

Figure 8: Roll angle time series for TS hull at *Fn=0.30*, low GM, *a=0.78m*.

One notices at first that the TS hull form is in general a more damped hull form than the RS hull, as reported by Neves, Pérez and Valerio (1999). Secondly, it is noticed that reports in general point to less parametric amplification in head seas with speed, see France et al. (2001). This is the observed trend in the present investigation for the RS hull in the two tested loading conditions. It is also the situation with the TS hull at the high metacentric height condition, *GM=0.50m*. What would be the explanation for the distinct trend for TS hull for the low GM condition?

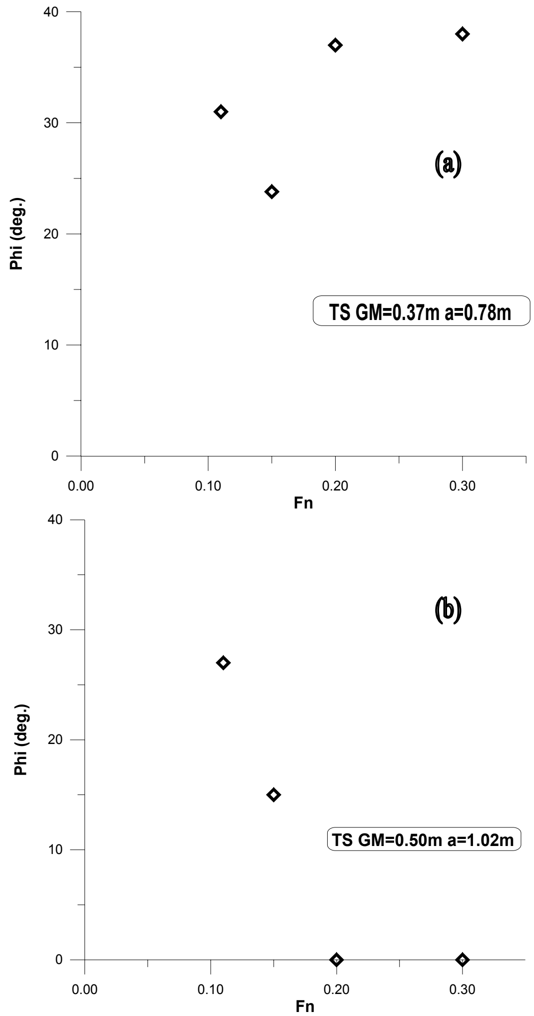

Figure 9: Roll amplitudes against *Fn* for TS hull:
(a) $GM = 0.37m$, $a = 0.78m$, $\omega_e = 1.72 rad / s$
(b) $GM = 0.50m$, $a = 1.02m$, $\omega_e = 2.00 rad / s$

From the mathematical model discussed in Neves, Pérez and Lorca (2002) it may be concluded that the internal transfer of energy from the vertical modes to the roll motion is regulated essentially by hull form parameters such as the longitudinal distribution of local breadth $b(x)$ and flare at waterline $\left.\frac{dy}{dz}\right|_0 (x)$. It is shown in Fig. 10 that TS hull, due to its transom stern configuration displays much larger longitudinal asymmetry in flare distribution than the RS hull. Thus it is clearly a more efficient converter of energy from vertical modes to roll motion. In this context, it may be argued that for such critical dynamic characteristic to take place, metacentric height must be low. If this is not the case, then increased damping at high speeds will prevail against the unstabilizing effect of parametric excitation.

In summary, low GM (*GM=0.37m*) for transom stern TS hull produces intense parametric resonances at all speeds at wave amplitudes of the order of *a=0.78m*. The other hull, even at a slightly lower metacentric height, *GM=0.34m*, and larger wave amplitude, *a=0.90m*, tends to respond less and less for higher speeds. The same TS hull for a high GM condition (*GM=0.50m*) does not amplify parametric excitation at high speeds, indicating that a transom stern shape together with a low GM has a relevant effect on parametric amplification.

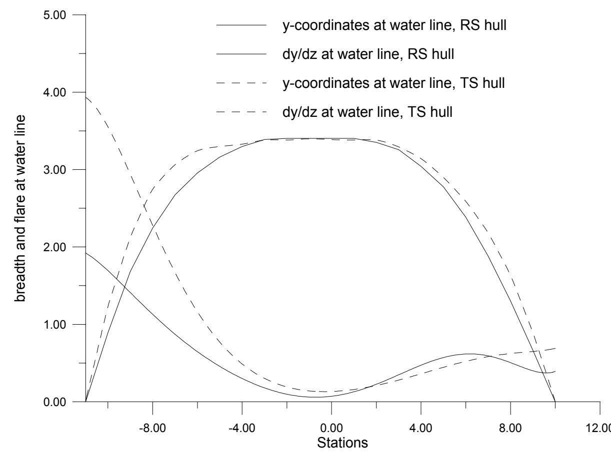

Figure 10: Longitudinal distribution of breadth and flare at waterline for the two hulls.

6. CONCLUSIONS

Results of a series of experiments on parametric rolling undertaken for two fishing vessels in head seas have been presented. The first region of Mathieu instability was investigated. The parameters varied in the test programme were: wave amplitudes, metacentric heights, and speeds.

Similar hulls tested in similar conditions displayed very distinct responses at specific testing conditions. The experiments demonstrate that in some cases strong parametric resonances in head seas can take place in quite few cycles. Angles of the order of 38 degrees have been reached for wave conditions often met by fishing vessels at sea. This is indicative that for this type of vessel, head seas conditions may be a source of real risk of ship capsize.

Effect of speed on parametric resonance is strongly dependent on stern shape. A transom stern, incorporating longitudinal asymmetry in flare, may exert a significant influence in establishing the tendency of a fishing vessel hull to display strong parametric amplification in head seas, particularly in a condition of low metacentric height. These conclusions are relevant in practice for hull design and operational considerations in rough seas.

7. ACKNOWLEDGEMENTS

This work was partially supported by CNPq and FAPERJ of Brazil and CONICYT of Chile. The authors express their thanks for this essential financial support.

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