Experiments on a segmented ship model in directional irregular waves

JM. Rousset, P. Ferrant, B. Alessandrini
Hydrodynamics and Ocean Engineering Group, Ecole Centrale de Nantes
1 rue de la Noe, 44321 Nantes, France

1 Introduction

Impulsive loads on ship may induce uncomfortable vibrations, may produce local damages and induce significant fatigue on the hull structure. Slamming events usually happen at the bow for severe sea conditions but moderate seas can generate water impacts on flat sterns, especially with present designs associated to pod propulsion systems. Within a French research project some initiatives were established to assess potential new methodologies for ship design in order to take into account the physical phenomena induced by slamming events. Some numerical codes were also developed on the same time and validated firstly on “academic” cases. Forced motion experiments and associated numerical simulations carried out during a first stage were presented during the 20th IWWWFB [1].

The present paper is focusing on experiments performed on a rigid segmented model submitted to irregular, unidirectional and bi-directionnal waves, without forward speed. The study of these different configurations are performed through the comparisons and the analyses of several parameters: occurrence and location of slamming events, ship motions and global loads on parts of the ship model.

2 Experimental setup

The tests are performed in the Centrale Nantes Hydrodynamics and Ocean Engineering Tank (BHGO), a 50 m long and 30 m wide basin fitted with 48 paddles (Fig. 1). Directional waves generation is based on the method of Dalrymple [2] which was firstly implemented and tested on BHGO by Bonnefoy *et al.* [3]. The chosen techniques give us the opportunity to reach good repetitiveness and accuracy of target wave energy, even for cross waves. The wave reflection is assumed to be lower than 10% during the experiments described in this paper.

The experiments are designed to measure the loads exerted by large waves on a rigid segmented ship model. The ship may be considered as an actual large cruise vessel fitted with pods underneath a wide and horizontal stern close to the free surface. The 3m long model has a bare hull, without pods or bilge keels.

The on-board instrumentation is composed of force transducers, accelerometers, wave gauges and pressure cells. A dedicated Aluminium-Carbon backbone with 5-components dynamometers is installed to measure independently the loads on 3 sections of the ship (Fig. 2 and 3). Except the in-line force Fx, two forces and 3 moments are measured on the 3 segments including the twisting moment Rx. A aerial smooth mooring is adapted to the model in order to avoid undesirable effects on pitch and roll. However the set-up is tuned to keep as much as possible the ship heading during the tests. Furthermore an optical tracking system is used to get the 6 degrees of freedom of the ship at a sampling frequency of 60 Hz and synchronously with the others transducers. The precision on the ship attitude (at model scale) is fairly better than ± 1 mm for positions and ± 0.05° for rotations.

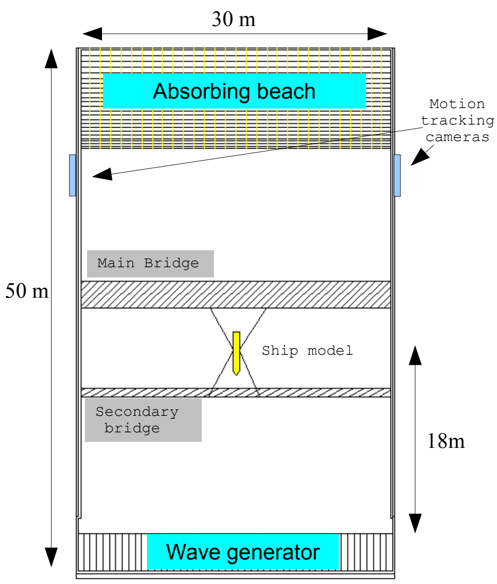

Fig. 1: Sketch of the tank set-up

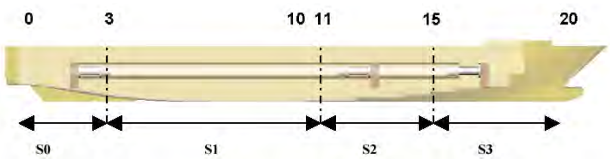

Fig. 2: Sketch of the ship model

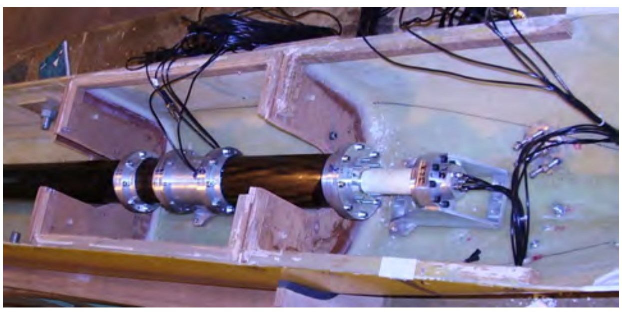

Fig. 3: View of the instrumented backbone during the model preparation.

3 Results and discussion

The table below summarises the incident irregular waves, the current heading of the model and the wave direction. Letter A is referring to the design sea state associated with the ship ultimate strength limit: H_s =15 m and T_p =14 s. This wave can be unidirectional or a directional spreading function can be applied (function type cos ^{2n}, with n=12). Bidirectional sea state B is built as the linear superposition of two wave spectra (B_0 and B_2) propagating according two directions (the total energy of B is assumed to be analogue to the energy of A):

- B_0 with H_s =12.3 m and T_p =14 s ;
- B_2 with H_s =8.7 m and T_p = 10 s.

Table 1: Waves conditions at full scale

Irregular waves	Model heading [°]	Wave direction [°]	Spreading n (cos ^{2n}) [-]	Hs [m]	Tp [s]
A_0	180	0	0 (Unidir.)	15	14
A_2	158	22	0	15	14
A_4	135	45	0	15	14
A_n	180	0	12 (Spreading)	15	14
B	180	-	0 (Bidir.)	15	-
B_0	180	0	0	12.3	14
B_2	158	22	0	8.7	10

Example of measurements

Each configuration is reproduced several times in order to compare the statistics from the measurements. As seen on Fig. 5, the free surface elevation is correctly replicated during successive tests. Fig. 4 is showing some temporal measurements extracted from one of the tests, focusing on the aft segment (model scale values). Slamming events are detected by the impact pressure on the stern (transducer PR2) and on a panel force transducer mounted on the same section (FR1). When the slamming is strong enough or affecting a large area of the segment, a springing phenomenon can be also view of the global forces signals (Fz for exemple).

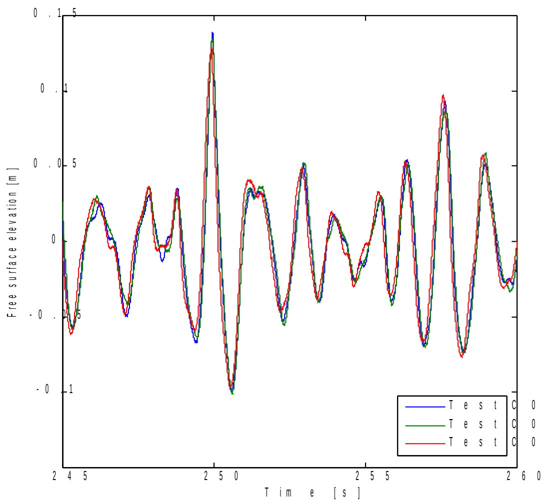

Fig. 5: Comparison of the free surface elevation for 3 identical tests with A_0 wave condition.

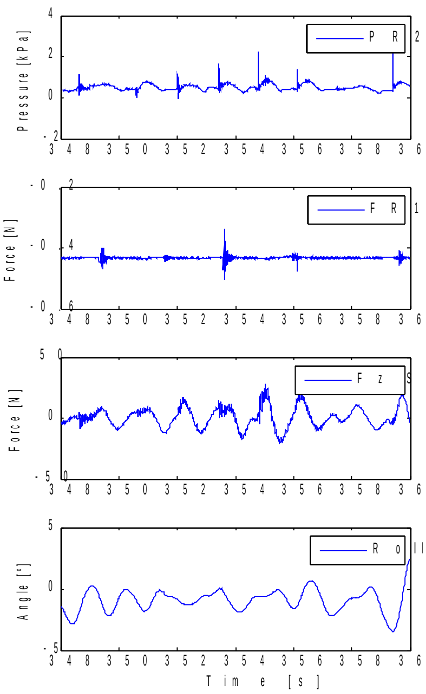

Fig. 4: View of slamming events during a test: local pressure (PR2) and local normal force (FR1) on the aft segment, global vertical force on the segment and roll angle of the ship

Bulb emergence

The following table presents the probability of emerging bulb as this configuration is considered leading to a bow slamming event. The occurrence frequency is evaluated as the ratio of the number of times the bulb is emerging over the total number of waves seen by the ship during the test. More than 400 waves are generated in a test.

Table 2: Probability of bulb emergence in irregular waves

Irregular waves	Model heading	No of waves	Occurrences of bulb emergence	
	[°]	[-]	Average [%]	Std [%]
A_0	180	410	16	2
A_2	158	416	22	3
A_4	135	448	19	1
A_n	180	415	18	1
B	180	412	11	3
B_0	180	404	8	-
B_2	158	446	(0.2)	-

Fig. 6: View of the bulb emerging in bidirectional waves

For the design sea state A, the heading seems to have little effect on the number of bulb emergence events. Angular wave spreading is leading to the same level of probability as unidirectional waves. According to the initial hypothesis, we have about 19-20 % of slamming occurrences in this sea state. The table tends also to demonstrate that the number of bulb emergence is decreasing with the wave height. The comparison between the 14 s period unidirectional waves A (H_s=15m) and B_0 (H_s=12.3m) is showing a half level of slamming probability.

When the small wave B_2 is generated alone, almost no slamming occurs (1 on 446 waves). But once superposed to B_0 wave, it has nevertheless the effect to increase slightly the probability to about 11%. The value in bidirectional sea is then not negligible but still half the slamming probability for unidirectional design waves. In this case, the ship structure fatigue would then be reduced compared to the one expected with unidirectional sea.

Ship motion according the wave configurations

Some basic statistics of the pitch motion are summarised on Table 3 for uni-modal extremes seas. The higher values are reached for oblique waves and not for head seas. On the other hand, unidirectional and spread waves are giving almost the same pitch motion. This remark is in agreement with the previous table as the probability of bow slamming is also higher for quartering seas than head seas.

The roll motion statistics are presented in Table 4. The values are focused on bi-directionnal waves. Except for the maximum values, the roll angle are obviously symmetrical in a head sea (B_0). On a first approach, the resulting roll angle of the ship in cross waves can be assumed to be the sum of the angles obtained with each of the waves.

Table 3: Pitch motion of the model

Irreg. Waves	Positive values [°]			Negative values [°]		
	Max.	$P_{0.90\,\%}$	Mean	Max.	$P_{0.90\,\%}$	Mean
A_0	5.21	3.82	1.89	-6.08	-4.5	-2.14
A_2	6.34	4.61	2.1	-7.83	-5.31	-2.42
A_4	9.86	6.85	2.85	-10.45	-7.5	-3.39
A_n	5.18	3.72	1.9	-6.33	-4.31	-2.07

Table 4: Roll motion of the model

Irreg. Waves	Positive values [°]			Negative values [°]		
	Max.	$P_{0.90\,\%}$	Mean	Max.	$P_{0.90\,\%}$	Mean
B	3.91	2.84	1.31	-4.41	-3.12	-1.45
B_0	2.04	1.19	0.54	-1.56	-1.19	-0.56
B_2	2.22	1.51	0.72	-3.49	-2.25	-0.99

Time-domain analysis of slamming events

As the signal recorded during the experiments are not linear neither stationary, some slamming events are analysed with a still unusual data-analysis method: the empirical mode decomposition (EMD) coupled to Hilbert spectral analysis (has) known as the Hilbert-Huang Transform (HHT, [4]).

As seen of Fig. 7 below, the HHT method gives the opportunity to empirically decompose the force component (here the moment My on the upper graph) into a mode varying with the waves (lower graph) which can be assumed to be easily modelled with CFD and an other mode mainly containing the slamming events (middle graph). The study of the magnitude and the spectral components of this latter mode can then be performed without drawbacks of Fourier analysis (spurious harmonics etc.).

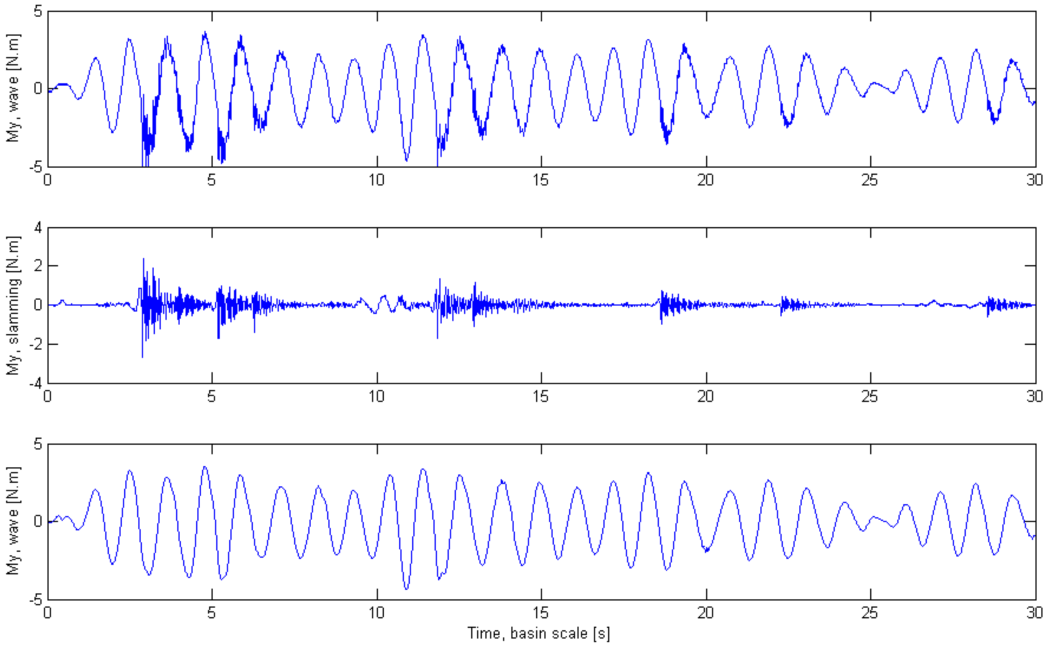

Fig. 7: Time-domain decomposition of My for a configuration inducing bow slamming.

References

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[4] Huang N.E., Shen S.P.S. (2005). “The Hilbert-Huang transform and its applications”, Interdisciplinary Mathematical Sciences, vol. 5, World Scientific Pub., 310 p.