Experimental campaign on a moored FPSO in complex bi-directional sea states

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Introduction

Experimental campaigns in model basins are usually undertaken for industry purposes when there is the necessity of design verification. Since these tests are rather expensive a few conditions of interest are normally tested. There are rare cases of systematic campaigns such as the series 60 or the international collaboration on the more modern geometry of the DTMB5415 [1]. The data acquired proved to be an invaluable tool for comparisons and verifications.

The needs of offshore industry are nowadays focusing on several different moored structures. One of these is the Floating Production Storage Offloading (FPSO), that is permanently moored in a specific location, usually in the vicinity of an extraction platform. Therefore it needs to be able to face a whole range of different conditions on the place without loosing its operability.

This abstract reports on the experimental campaign of a moored model in bi-dimensional sea-states obtained by systematically combining two different wave systems from varying relative directions.

The Complex Sea-States Concept

The sea-state that may occur in a generic location in the ocean can be thought of as the result of the superposition of different wave systems. These sea-states can originate as described in the following.

Between the waves generated during a storm those with higher values of the group velocity C_g are able to outrun the storm and appear ahead of it as *swell* [2]. If the storm has happened far enough from the investigation point we can hypothesize that only few long, fast travelling wave components will reach the location of the ship.

Apart from these long swell waves there can be another wave system with a higher peak frequency, generated by wind that is blowing close to the location of interest. This wave system would travel a shorter distance before reaching the ship's location. In this case the dispersion property of the waves would not have enough time to select the long regular components and the wave spectrum would be more complex. This last wave system we will refer to as *wind-sea*.

From this description it appears clear that there is no correlation between the two wave systems that can co-exist independently and virtually have any relative direction of propagation [2]. Thus with the combination of two sea-states it is possible to adequately model a real situation.

The capacity of the ocean basin of the Institute of Ocean Technology, National Research Council of Canada, with its array of 164 wave panels on two sides of the rectangular basin (see sketch on top of fig.1), was exploited for generating different wave systems that combine at the center of the basin as if they were coming from different directions. Thus one part of the sea-state generated in the facility was a long reg-

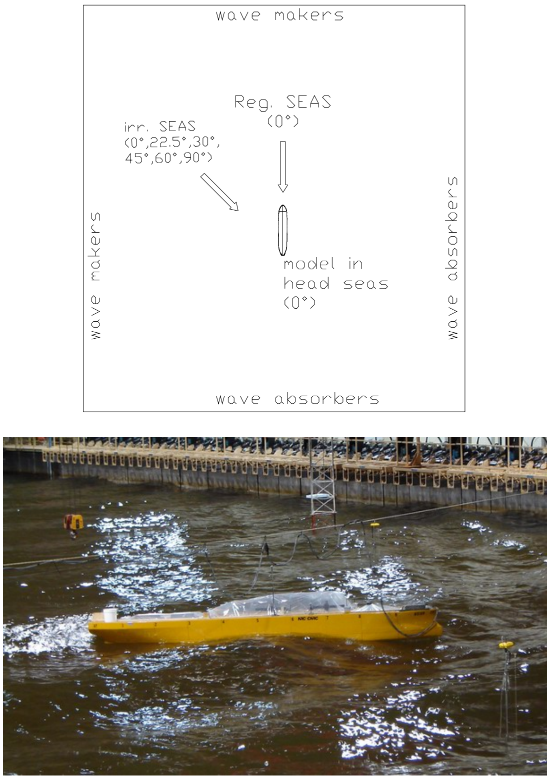

Figure 1: (up) reference plan of the basin and of the position of the model, (bottom) picture of the model in bi-directional sea-states, its bow is rotated towards positive yaw angle.

ular wave system, that acted for our purposes as swell. The wind-sea was modelled by a JONSWAP spectrum following the standard ITTC formulation [3]:

$$S(f) = \alpha \frac{g^2}{2\pi f^5} e^{\left[-\frac{5}{4}\left(\frac{f}{f_p}\right)^{-4}\right]} \gamma^{\alpha}, \qquad (1)$$

where all the parameters are defined as functions of the significant wave height and spectral peak frequency.

Usually only a very few conditions are selected as the most probable and tested in a model basin. Thus data for calibration of numerical codes and comparison of the results of simulation is unavailable in the scientific literature. With this matter in mind a systematic experimental campaign on a moored FPSO model was

Sea-state	H_{ship}	T_{ship}	H_{model}	T_{model}
Swell regular sea (sine)	5.300	17.800	0.088	2.298
Wind-sea JONSWAP	3.000	12.000	0.050	1.549

Table 1: the parameters for the first set of tests. The JONSWAP spectra (wind-sea) has been applied also with a spread of 25 and 35 degrees, in these cases the parameter γ was set equal to 3.

undertaken, in order to study the consequences of the superposition of different wave systems propagating at different directions.

Description of the Tests and Observations

All the sea-states were initially run without the model in the basin and measured by an array of capacitive wave probes mounted in place of the model. Another set of wave probes was mounted in the vicinity of the model and was left in place during the entire campaign.

The model, an FPSO hull (bottom picture of figure 1, scale ratio $\lambda = 60$), was moored by means of four mooring lines connected to the bottom of an internal rotating turret located at roughly one third of length from the bow of the model. The mooring lines were equipped with inline load cells for measuring the forces on the lines. A gyroscopic system that measured the linear accelerations and the angular velocities was used in parallel with an optical system for measuring the position of the model in the six degrees of freedom. An accelerometer measured the vertical component of the acceleration in a known location close to the center of gravity. Movies were also taken during all the runs.

In the first series of tests the period and the amplitude of the swell-sea (first line of table 1) were kept constant and its direction of propagation was 0 degrees. The wind-sea direction varied between 0, 22.5, 45, 60 and 90 degrees with reference to the swell direction of propagation. The tests have been performed with initial heading of the model at 0 and at 90 degrees (beam seas with respect to the swell). In this last condition the tests were repeated once with the model being released before the start of the wave-makers and with the model being held for one minute in order to wait for the sea-state to be fully developed.

For further investigating the directional effects, the same conditions have been run with a spreading of 25 and 35 degrees applied on the wind-seas.

Each of the runs lasted for 116 minutes of real scale time. At the end of every run the model was put back in its initial position.

The peak period of the wind-sea waves was chosen close to the natural roll period of the model that was 1.58 s (corresponding to 12.24 s at real scale). The period of the swell was longer, corresponding to 17.80 s at real scale.

In the second set of tests both sea-states had periods close to the natural roll period of the model. In this case the swell characteristics were varied in amplitude and period, as specified in table 2, the direction was always 0 degrees. This time the wind-sea was kept constant in period and amplitude while its direction was varied between the directions of 0, 45, 60 and 90 degrees. The heading of the model was always 0 degrees.

Sea-state	H_{ship}	T_{ship}	H_{model}	T_{model}
Swell regular sea (sine) 1	4.260	11.650	0.071	1.504
Swell regular sea (sine) 2	9.540	12.363	0.159	1.596
Swell regular sea (sine) 3	15.900	12.363	0.265	1.596
Wind-sea JONSWAP	7.980	11.999	0.133	1.549

Table 2: characteristics of the second series of tests. The swell was varied in intensity and period while a constant wind-sea changed direction.

The model, even when starting from different initial orientations, invariably ended in another heading position, sometimes oscillating, other times finding an equilibrium. The factors that determine the final orientation in yaw are yet to be understood, but their comprehension is crucial for assessing the effectiveness of the internal turret as a device for weather vane purposes. Many FPSOs have to use a dynamical positioning system to keep the bow to the waves. The reason of the yaw equilibrium position probably lies in the influence of lower part of the spectrum of the waves. The spectral analysis of the motions and the correlation with the incoming waves will highlight this aspect.

Figure 2 shows an example of part of the recorded plots of the heading, the roll and pitch motions of the model. The top three plots of the figure are relative to a test in which the model was subjected to a sea-state composed composed of a swell and an irregular wave system arriving from 60 degrees direction. The three plots in the middle are relative to a run in which only the swell part of the wave system was generated for the same amount of time. The bottom three plots show the case relative to only the irregular wind-sea coming from a 60 degrees direction.

The period of the two wave systems was similar, while the amplitude of the swell being the double (0.265 m compared with 0.133 m). The influence of the combined wave system is evident. The ship motions are larger than the ones produced by the single contributions alone. The heading oscillates continuously from the initial position to a maximum of -50 degrees not finding a stable orientation. There is a slowly varying yaw motion, with a period of roughly 90 seconds, that makes so that model does not end up in a final position. This instability does not show in the other cases. Also the plots of roll and pitch indicate larger amplitude oscillations compared with the stable oscillation of the swell only case and the less, but still stable oscillation in the wind-sea only case. The larger roll in the combined sea-state is another issue worth investigating and might be related to the slow drift yaw motion. In real life environment a roll of such an amplitude is an impediment for operability.

These observations confirm the importance of considering both contributions together and the need to have an experimental evidence of the effect of the individual components because the single components do not combine their effects in a trivial way. At the largest amplitude of the

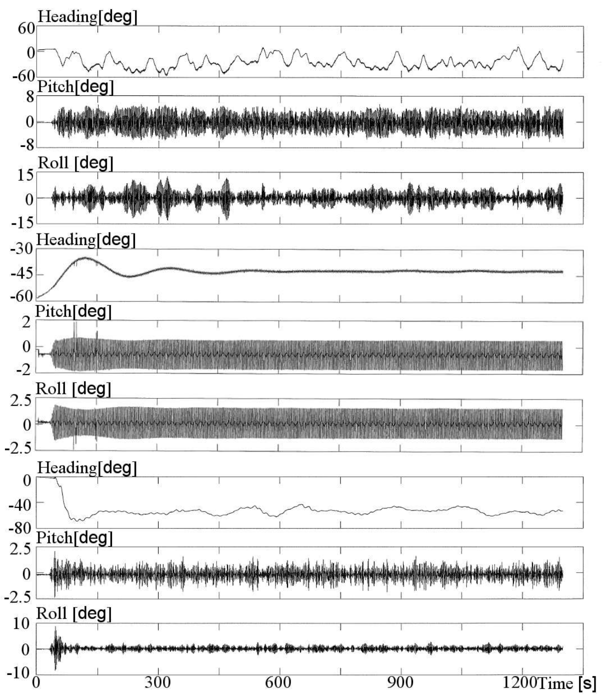

Figure 2: plots relative to heading, pitch and roll. Upper three plots: sea-state combination of swell as in table 2 line 3 and wind-sea as in line 4 from 60 degrees relative direction. Middle three plots: run with the swell only. Bottom: run with the wind-sea from 60 deg. only

wave system the ship was displaying consistent bow splashing. Its behavior was largely non-linear.

The mooring lines stiffness seemed to have been chosen adequately because the model was not showing any fishtail behavior.

Conclusions

To conclude the authors would like to point out that the data available from the wave probes is composed by a double series of measurements for the same sea-states, with and without the model. The data will be used to evaluate the scattering of waves by the model. The sea-states of these tests have been run varying systematically the parameters and directions of two different wave systems combined together. The collected data can be used for comparison with numerical algorithms in very different conditions ranging from one dimensional and linear to complex bi-directional and fully non-linear.

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References

[1] Larsson, L., Stern F. and Bertram V., (2003). *"Benchmarking of Computational Fluid Dynamics for Ship Flows: The Gothenburg 2000 Workshop"*. Journal of Ship Research, vol.47 n°1, pp.63-81 Soc Of Naval Arch & Marine Eng.

[2] Young I.R. (2003) *"A review of the sea state generated by hurricanes"* Marine structures, vol.16 pp.201-218, Elsevier Science Ltd.

[3] *"The Specialist Committee on Waves"* Proc. 23th ITTC, 2002.

[4] O'Donoghue T., Linfoot B.T. (1992) *"An experimental study of turret-moored floating production systems"* Applied Ocean Research, vol. 14, 127-139, Elsevier