WAVE IMPACTS DUE TO STEEP FRONTED WAVES

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INTRODUCTION

It is the question whether 'Rogue waves' can only be identified and characterized by their extreme heights. The results presented in this abstract and related papers [1,2,4,5,6] show for instance that an extreme wave front steepness can induce large impact pressures on the hull of a moored ship-type offshore structure. As part of the 'SAFE-FLOW' Joint Industry Project these loads were investigated with a dedicated series of model tests.

PROBLEM

Wave impact damage has been experienced by both the Foinaven and Schiehallion FPSOs. During the night of the 9th November 1998, in a sea state estimated as $H_s = 14$ m, $T_p = 15\text{-}16$ seconds, an area of forecastle plating on Schiehallion above the main deck, between 15 and 20 m above notional mean water level was pushed in by 0.25 m.

Figure 1: Damage to the Schiehallion bow

There was some associated minor plating deformation inside the fore peak (see Figure 1), below the main deck but there was no damage to the flare supports (which are mounted on top of the forecastle) or any process equipment. The damage occurred at the time in the storm at which the measured wind gust speeds were strongest but at the time the wind sensors on the vessel recorded a 10-minute gust speed of 59 knots compared with a one-year-return-period design value of 69 knots. By contrast, the most severe vessel motion, due to heave and pitch, occurred between 2 and 6 hours later. Wave records from a vessel some 12 km distant from Schiehallion showed a rapid increase in wave height in the period leading up to the damage event. A mean zero crossing period of 11 s, coupled with a significant wave height of 14 m indicates a severe sea state steepness estimated as 1/13, but there are no corresponding records of individual waves.

EXPERIMENTS

As part of the SAFE-FLOW project MARIN performed 2 series of model tests at scale 1:60 in deep water. First tests were carried out on a free floating Schiehallion FPSO model (Figure 2).

Figure 2: Bow impact event on free floating model

In these tests in irregular seas the incident wave data, vessel motions and resulting relative motions, bow pressures and structural response were measured. The tests showed that more detailed load measurements were necessary and that an investigation was needed into the relation between the incoming waves and these loads. This resulted in the second model test series on a highly instrumented fixed simplified bow, see Figure 3. The simplified bow was instrumented with a large array of pressure transducers and 3 force panels. The test program, also making use of extensive video recordings, was designed such that it was possible to determine the correlation between undisturbed wave shape and the impact pressure time traces. From these tests irregular sea incident wave data and bow pressure results are available on a fixed schematic bow structure with varying rake and plan angles.

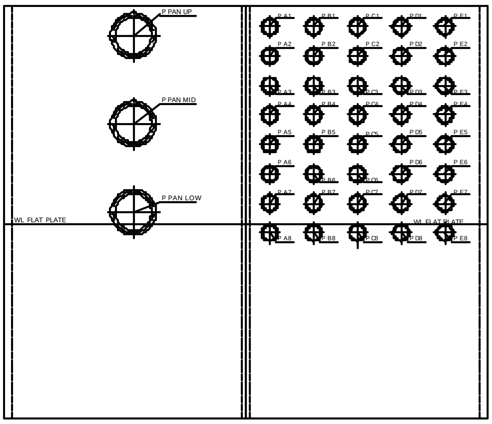

Figure 3: Instrumented plate-like fixed bow with force panels (left) and pressure cells (right)

OBSERVATIONS

It was found that the magnitude of the wave impacts at the front of the bow is dominated by the wave characteristics (namely the local wave steepness), rather than by the motions of the ship relative to the waves (relative wave motions). Further the maximum pressures are measured close to the crest of the incoming waves. An example of a steep wave front reaching the bow structure is shown in Figure 4.

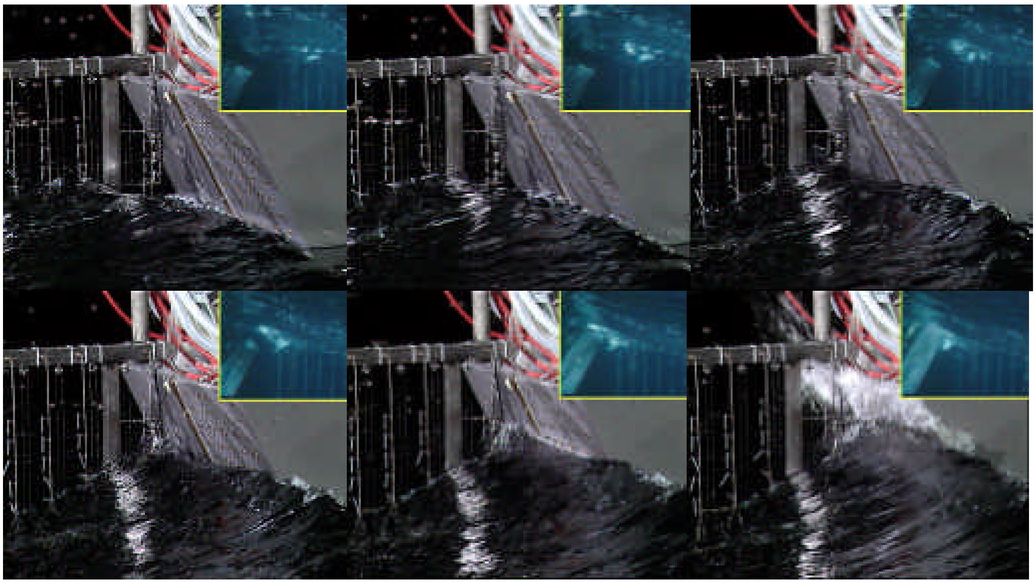

Figure 4: Typical stages during a bow impact

The local wave steepness (d?/dx) could be determined from measurements of the wave elevations in an array of probes. An example is shown in Figure 5, which shows the spatial wave profile for successive steps in time. The time step between the different lines is 0.31 seconds and the distance between the probes 6 meter allowing for an accurate derivation of the local wave steepness.

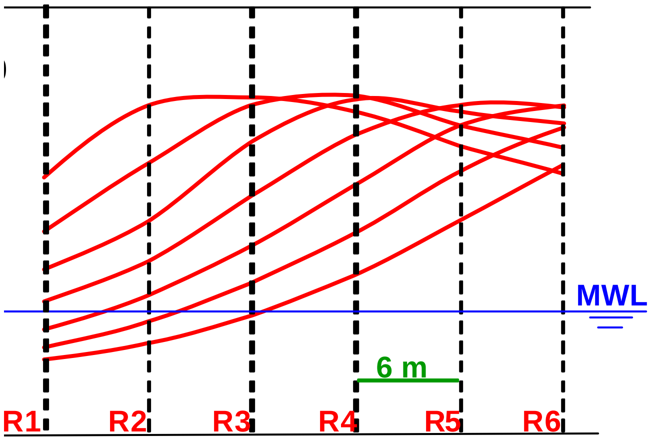

Figure 5: Visualisation of the local wave steepness (d?/dx) based on the measurements of the wave elevations in an array of probes

It was found that wave impacts on the bow could always be related to an exceedance of a certain wave front steepness. Typically wave front steepnesses above 30 degrees (with the horizontal) resulted in wave impacts, see Figure 6.

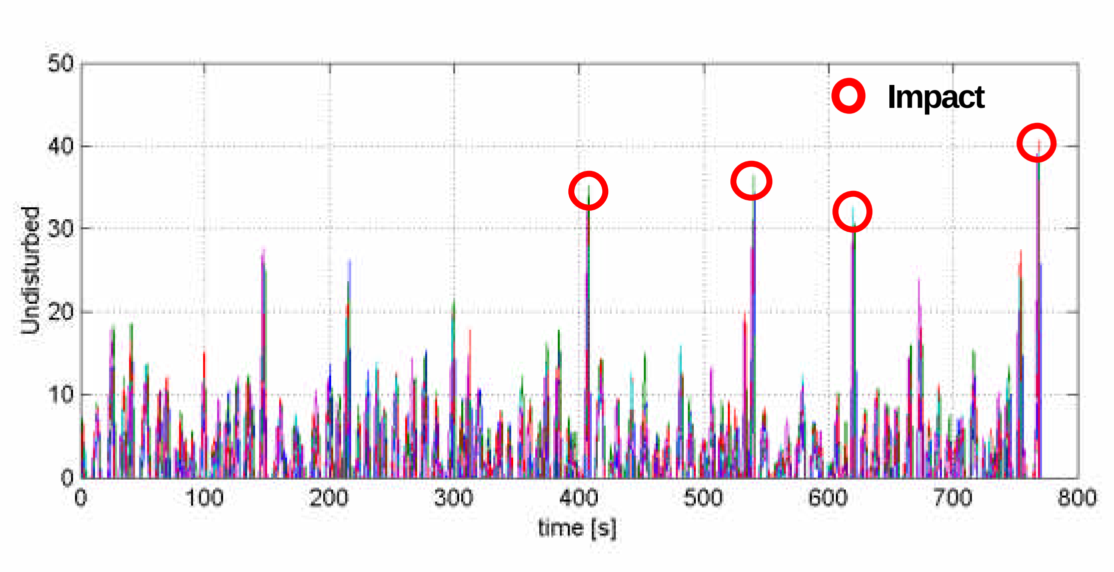

Figure 6: Relation between the local wave steepness (d?/dx in degrees) and occurrences of wave impacts on the fixed bow

The combined spatial and temporal information of the sea state needed to derive the local wave steepness is not generally available (in full scale data and model tests). Therefore the vertical free surface velocity (d?/dt) is preferred as input to a prediction model.

The local free surface steepness is linearly related to the free surface vertical velocity (d?/dt) through the wave celerity. Though this is strictly true only for linear waves and on a wave to wave basis, given free surface continuity and according to Cauchy's intermediate value theorem, there are values of and such that the relationship is verified for a wave that results from a sum of elementary components.

The relationship between the maxima in the vertical free surface velocity (d?/dt) and the impacts is shown in Figure 7. It shows the traced impacts (circles) versus the time traces of the vertical surface velocity. The impacts occur at the same moment as the maxima in the vertical free surface velocity.

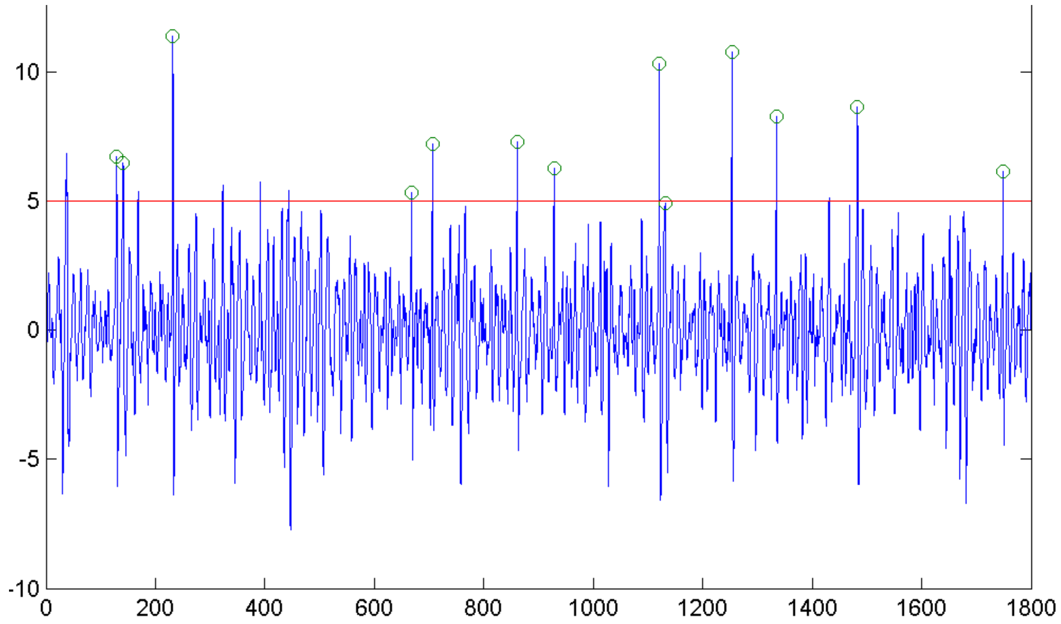

Figure 7: The traced impacts (circles) versus the time traces of the vertical free surface velocity

In steep waves that cause the bow impact, linear theory clearly under predicts the wave steepness. The most suitable method of simulating the water surface to give a reasonable probability of vertical free surface velocity was found to be second order wave theory, as described by Sharma and Dean (1981) for instance. Applying second order wave theory results in an improved prediction of d?/dt, as shown in Figures 8 and 9 for the basin waves applied.

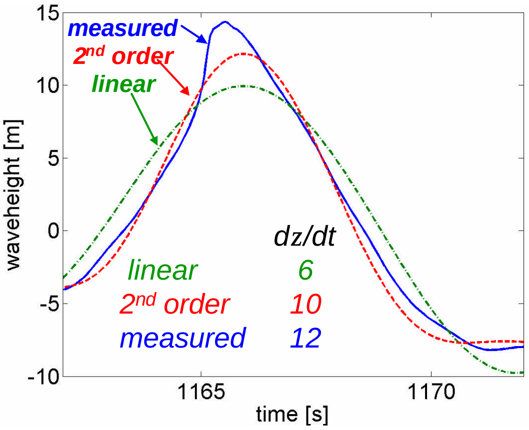

Figure 8: Measured, first order and second order wave time trace

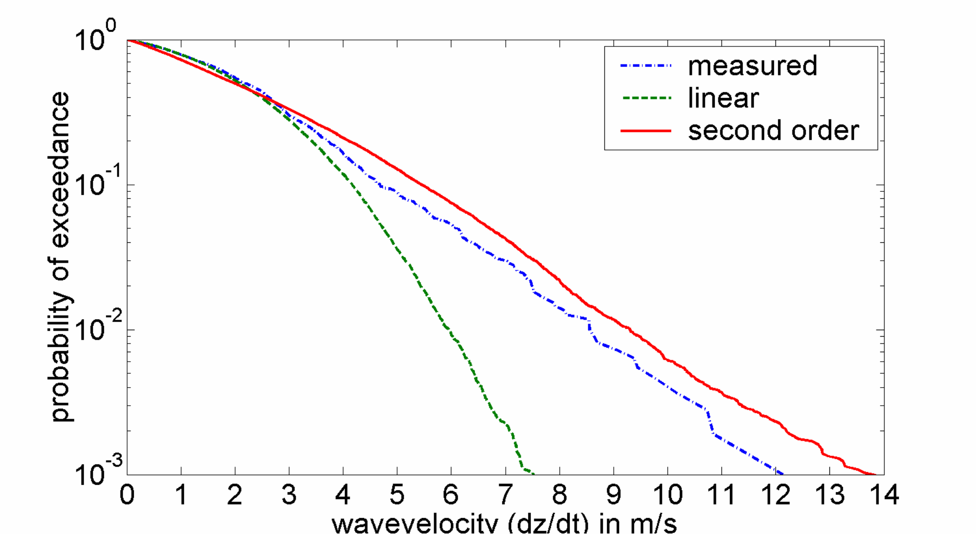

Figure 9: Probability of exceedance of a vertical free surface velocity (measured, linear and second order)

It is clear that the second order theory is not capable to describe the asymmetry in the measured non-linear wave. However, within the accuracy of the present design methodology this is not considered a critical aspect and the distribution of the vertical free surface velocities do match the measured non-linear distribution reasonably well.

Beside the slam probability, the slam magnitude is of vital importance. After analysis of all data, it was decided to relate the slam impulse (I), the area under the load time trace, to vertical free surface velocity (d?/dt).

Figure 10 shows the measured impulses versus the corresponding vertical free surface velocities. For different velocity bins the mean and standard deviation of the occurring impulses is added to the figure, resulting in straight lines.

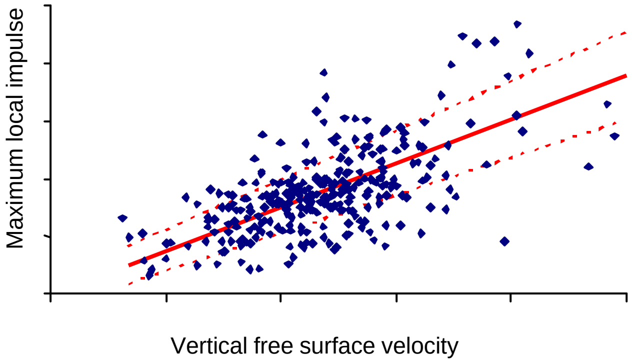

Figure 10: The measured impulses versus the corresponding vertical free surface velocities

The relation is independent of the sea state and holds for a schematic flat plate bow. Within the design method the mean fit is used as a maximum that can occur. For more realistic curved bow shapes the loads are reduced. The spreading around this mean can be used as input to the derivation of the load factors in a first principles reliability approach.

Other wave impact characteristics, such as rise time, decay time, spatial extent and the effect of the bow shape are later applied to this local impulse on a flat plate to determine the resulting structural response. More details can be found in [1,2,4,5,6].

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REFERENCES

1. Buchner, B., Hodgson T., Voogt, A.J. (editors), Ballard, E., Barltrop, N., Falkenberg, E., Fyfe, S., Guedes Soares, C., Iwanowski, B., Kleefsman, T., 2004, "Summary report on design guidance and assessment methodologies for wave slam and green water impact loading", MARIN Report No. 15874-1-OE, Wageningen, The Netherlands.
2. Guedes Soares, C., Pascoal, R., Antão, E.M, Voogt, A.J. and Buchner B. 2004, "An approach to calculate the probability of wave impact on an FPSO bow", Proceedings of the 23st OMAE Conference, ASME, New York, paper OMAE2004-51575.
3. Sharma, J. N. and Dean, R. G., 1981, "Second-Order Directional Seas and Associated Wave Forces", J. Soc. Petroleum Engineering, 4, pp 129-140.
4. Voogt, A.J., 2001, "Discussion Problem Identification, SAFE-FLOW project", MARIN Report No. 15874-1-OB, Wageningen, The Netherlands.
5. Voogt, A.J. and B.Buchner, 2004, "Prediction of Wave Impact Loads on Ship-type Offshore Structures in Steep Fronted Waves", Proceedings of the ISOPE2004, paper no. 2004-JSC-343
6. Voogt, A.J. and B.Buchner, 2004, "Wave Impacts Excitation On Ship-Type Offshore Structures In Steep Fronted Waves", Proceedings of the OMAE Speciality Symposium on FPSO Integrity, Houston, 2004