High Order Spectral method for wave scenarios with nonlinear and dispersive effects

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Background

Accurate wave modeling is essential for ship and offshore structure designs. Very steep, large unexpected waves exist in the open sea that are extremely dangerous for marine activities, such waves are called rogue waves or also known as freak, monster and abnormal waves. On 1st January 1995, a wave with 25.6 metres height in 12 metres sea-state was recorded at Draupner platform in the North sea. It is the first scientific evidence of rogue wave existence, reported by Haver (2000), see Figure 1. Since then, rogue waves have gained attention in the scientific community and in the shipping and offshore industries.

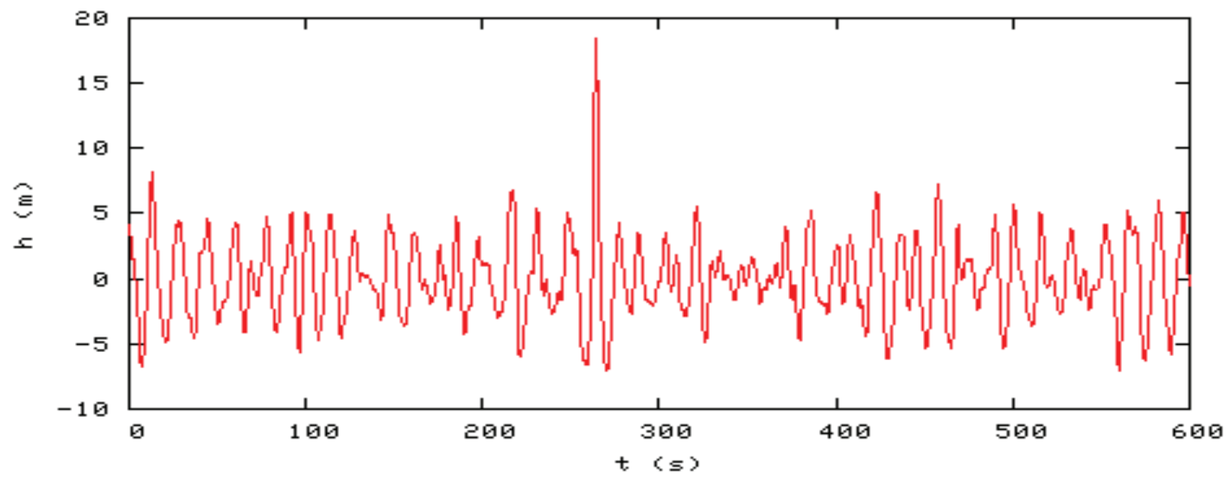

Figure 1. Rogue wave recorded at Draupner platform in the North sea, Haver (2000).

Objectives

1. Develop a High order spectral (HOS) method and assess the quality of reproducing dispersion and nonlinearity effects with experiments and/or other numerical methods related to rogue waves phenomena.
2. Extend the HOS method to handle effects of bottom topography and apply it for 2D cases to assess capability in handling wave steepening during propagation from deep to shallower water regions.

Research Tool

High order spectral (HOS) method is an efficient and accurate numerical method for solving nonlinear water wave equations (see [1] & [2]). However, the original HOS method is only valid for flat bottom and initial value problem with periodic boundary condition. In this study, embedded wave generation is implemented to assess the model with wave tank experiment. Furthermore, HOS method is improved to handle bottom topography and validated with experimental data.

Results

Two selected results are presented to show the capability of HOS method to capture the phenomena that can trigger rogue waves.

Bichromatic Wave Train

Two set of experiments with bichromatic waves were conducted in the 270 m long and 1 m wide wave tank at MARINTEK (now SINTEF Ocean), Norway.

Modulation instability or also known as Benjamin-Feir instability is one of the possible extreme wave generation. This instability was observed in this experiment. After further propagation, ~~sid~~eband frequencies are generated and large individual waves (with breaking) may occur. The HOS third order simulation is able to reconstruct the instability of modulated wave in this experiment.

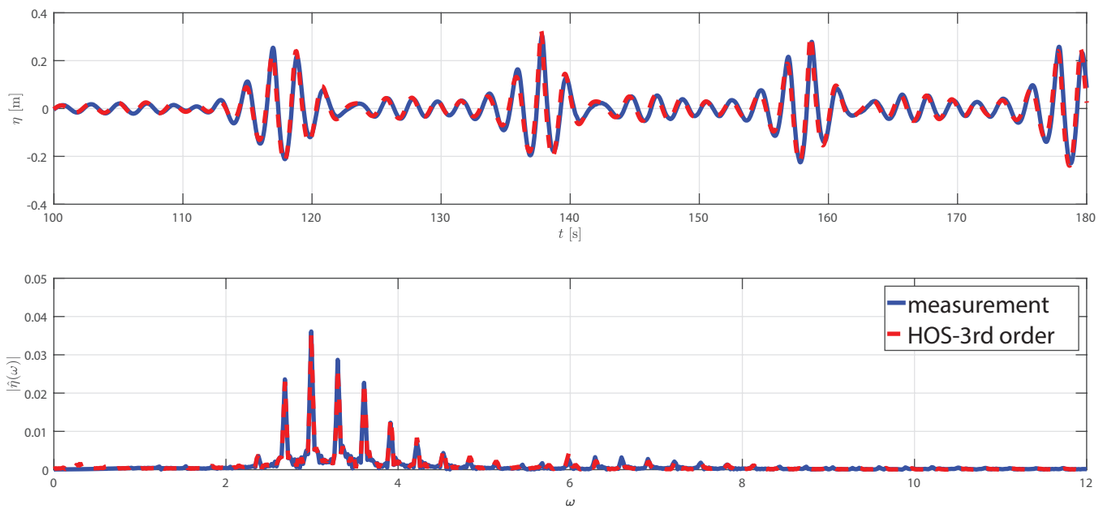

Figure 2. Evolution of wave elevation (upper plot) and amplitude spectrum (lower plot) for bichromatic wave train experiment at position 160 m from wavemaker.

Focusing Wave Group

An experiment was designed to have a focused wave at certain position in 200 m long wave tank at MARIN, Netherlands.

The dispersive focusing is one of the mechanism of extreme wave generation by considering the dispersion effect. However, some breaking waves were observed just downstream of the focusing point which indicates that nonlinearity is also important. From the results, the spectrum deforms with respect to the initial spectrum, especially in the tail due to nonlinear interaction.

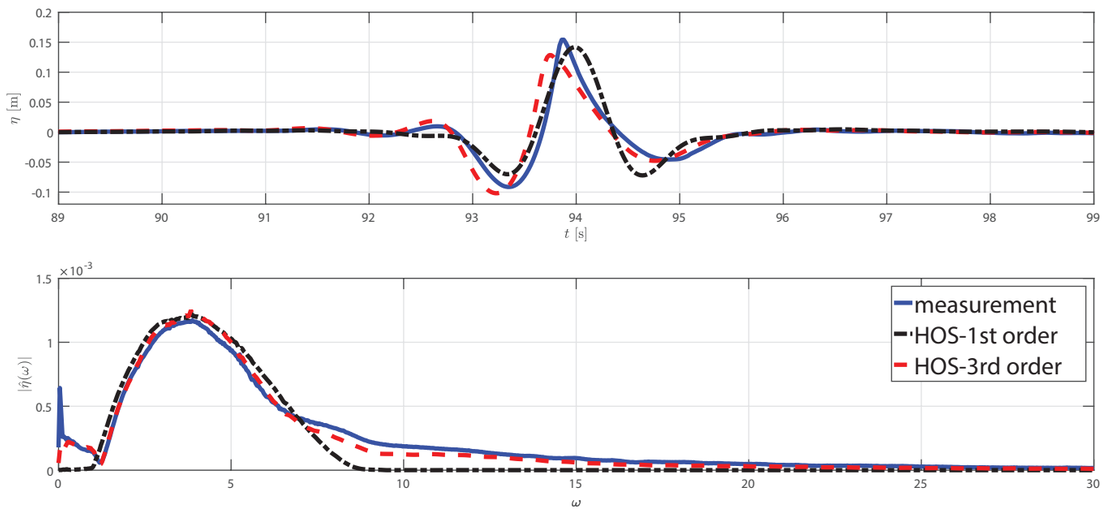

Figure 3. Evolution of wave elevation (upper plot) and amplitude spectrum (lower plot) for focusing wave group experiment at position 50 m from wavemaker.

Preliminary Conclusion and Further Work

The HOS method has been implemented successfully with embedded wave generation and validated extensively against various experimental cases. The bottom variation may enhance the occurence of rogue waves. The effect of bottom slope, and the depth ratios between deep and shallow region have been studied in the thesis but the results are not discussed here because of space limitation.

Due to the capability and efficiency of HOS method to reproduce the mechanism of rogue wave occurence in 2D case, it is recommended to investigate the rogue wave in short-crested waves above varying bottom.

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References

[1] Haver, S., 2000. Evidences of the existence of freak waves. Proc. Rogue Waves, 2000. Ifremer, 129-140.

[2] West, B.J., Brueckner, K.A., Janda, R.S.,Milder, D.M., Milton, R.L., 1987. A new numerical method for surface hydrodynamics. J. Geophys. Res., 92,11803–11824.

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