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Extreme Wave Events in a Hydrodynamic Laboratory

Natanael Karjanto, E. van Groesen

Applied Analysis and Mathematical Physics Group, University of Twente, The Netherlands

Abstract: We adopt the spatial 'nonlinear Schrödinger' (NLS) equation as a simple mathematical model for nonlinear surface wave evolution in a wave tank of a hydrodynamic laboratory. This equation has many exact solutions, of which we only study a family of solutions which describes extreme wave events in the laboratory. This solution is known as the 'Soliton on Finite Background' (SFB) and it describes the 'modulation instability' (Akhmediev and Ankiewicz, 1997). In the context of water waves, this instability is known as the 'Benjamin-Feir instability' since Benjamin and Feir (1967) investigated the stability of a modulated wave train both theoretically and experimentally. In this presentation, we focus on the physical properties of the SFB and the comparison with experiments in a wave tank of the Maritime Research Institute Netherlands (MARIN).

The SFB in the far field is a 'continuous wave' with a constant amplitude $2r_0$ and a wave frequency ω_0, modulated with a modulation frequency ν. While running downstream, this signal becomes an extreme wave event; reaches a large amplitude at a certain position while preserving the modulation period. After passing the extreme position, it continues to evolve downstream to a situation similar to the initial signal. At the position where the SFB is an extreme wave event, there are times at which the real-valued amplitude vanishes and the phase becomes undefined, resulting in a 'phase singularity' phenomenon. In one modulation period, there is a pair of these singularities. Due to this phenomenon, the physical wave field shows a 'wavefront dislocation', when merging waves or splitting waves are observed.

The experimental setup is a wave tank of 200 m long, with 3.55 m water depth, a wavemaker on one side, and an absorbing beach on the other side. Wave gauges are installed at several positions to capture signals of the generated wave. Applying the inverse problem and using the 'maximum temporal amplitude' (Andonowati and van Groesen, 2003), we designed the initial signal of the SFB such that extreme wave events should occur at a specified position, namely at 150 m from the wavemaker. Due to the discrete positions of the wave gauges, the precise position of the extreme wave cannot be determined very well. However, the experiments showed non-breaking waves with a large amplitude. These waves have an asymmetric structure compared to the ones from the theoretical SFB. Furthermore, the experimental results also show a phase singularity phenomenon. Yet, instead of a pair of singularities as in the SFB, the experiments show only one singularity in one modulation period (van Groesen et al, 2005; Huijsmans et al, 2005). Keywords: freak wave event, Soliton on Finite Background, phase singularity and wavefront dislocation.

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