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Extreme wave generation using self correcting method — Revisited

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ABSTRACT

A proper design of offshore and coastal structures requires further knowledge about extreme wave events. Such waves are highly nonlinear and may occur unexpectedly due to diverse reasons. One of these reasons is wave–wave interaction and the wave focusing technique represents one option to generate extreme wave events in the laboratory. The underlying mechanism is the superimposition and phasing of wave components at a predefined location. To date, most of the existing methods to propagate target wave profile backwards to the position of the wave generator apply linear wave theory. The problem is that the generated waves with different frequencies generate new components which do not satisfy the linear dispersion relation. As a result, small changes in the wave board control signal generally induce large and random shifts in the resulting focused wave. This means that iterations are necessary to get the required wave profile at the correct position in the flume. In this study, a Self Correcting Method (SCM) is applied to optimize the control signal of the wave maker in a Numerical Wave Tank (NWT). The nonlinearities are included in the control signal and accurate wave focusing is obtained irrespective of the prevailing seabed topography (horizontal or sloping) and type of structure (reflective or absorbing). The performance of the proposed SCM is numerically investigated for a wide variety of scenarios and validated by scale model tests in the Large Wave Flume (*Großer Wellen Kanal, GWK*), Hannover, Germany. Moreover, the application of the proposed SCM in the Numerical Wave Tank to generate a tsunami at a predefined position and the comparison of the results with the time series recorded in the Pago Pago harbour (Samoa) is very encouraging. The strengths and limitations of the proposed SCM are discussed, including the potential for further developments.

1. Introduction

In harsh weather, extreme events will lead to damages to ships, offshore and coastal structures. The design of reliable and economic coastal and offshore structures requires further knowledge of such episodic waves. These are unpredictable waves that are out of the statistical logic Osborne et al. (2000). Extreme waves are considered like a strange phenomenon because they are highly asymmetric and nonlinear waves (high ratio between wave crest and wave trough) that can occur in a relative calm sea state. This is not only occurring in deep water, but more recently in shallow water depth, for instance the extreme wave recorded near the Cape Olga, Kamchatka (Russia), in Fig. 1. Extreme wave events may occur due to four main processes: wave–current interactions, wave–bottom interactions, wave–wave interaction and wind–wave interactions. The generation of extreme wave events in laboratory flumes by means of nonlinear superposition and phasing of wave components (known as wave focusing) is particularly considered in this work. Several different approaches to generate such episodic waves were suggested in the past, but they are based on linear theory to transform the target wave from the focal point backwards to the position of the wave maker (Clauss, 2002; Clauss and Klein, 2011; Hofland et al., 2010; Rapp and Melville, 1990). A methodology to create 3D wave packets in an irregular wave field was elaborated by Ducrozet et al. (2012), but linear dispersion relation is used to calculate the wave component celerity. Shemer et al. (2007) developed a computational model based on the unidirectional spatial Zakharov equation to describe the evolution of steep wave groups over constant water depth and they validated the theoretical model at the *GWK*, Hannover, Germany. The NewWave theory was used by Westphalen et al. (2012) and Ma et al. (2010) to produce extreme wave events from a measured or theoretical spectrum. Also Borthwick et al. (2006) generated normal and oblique focused wave groups at the toe of a plane beach by using the New Wave Theory. Liu et al. (2011) employed a method based on Longuet-Higgins theory to simulate extreme waves at a certain location preserving the statistical properties of a realistic sea state. On the other hand, Funke and Mansard (1988) developed a method of reversible dispersive

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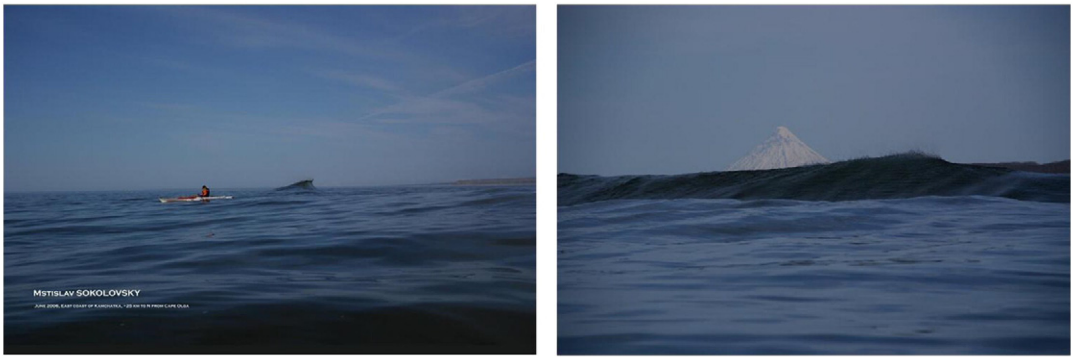

Fig. 1. Extreme wave close to the Kamtchatka coast (Russia), 11th June 2006 (the authorship of the picture belongs to Mstislav Sokolovsky) (Didenkulova and Pelinovsky, 2011).

technique to generate extreme waves (or episodic), that can also deal with variable water depth. However, they used linear theory during the process of wave assemblage. Thus, one needs to conduct trial and error to obtain the profile at the required position in the flume. Baldock and Swan (1996) presented a series of experimental tests in which they generated focused wave groups over shallow and intermediate water depths. To avoid the shifts at the focal point, x_p, they empirically determined the value of x_p in order to generate the focused wave at the desired position.

The problem is that when a wave packet containing different wave frequencies is generated, the waves interact and new components that are not satisfying the linear dispersion relation are created (due to wave–wave interaction). This means that small changes in the associated wave maker control signal can lead to large and unpredictable changes in the generated focused wave, resulting in premature wave focusing. Additionally, as linear dispersion relation is used to back scatter the target wave elevation to the position of the wave maker, when a wave packet is generated, the wave is travelling faster as compared to the celerity calculated by means of linear wave theory, therefore focusing occurs after the theoretical focal point. Other reason for premature wave focusing is due to the presence of spurious components generated by the wave paddle Sriram et al. (2013). Furthermore, most of these methodologies cannot deal with varying topography and cannot account for wave reflection (when testing a fully reflective wall for instance).

As most of the extreme wave tests with offshore or coastal structures are conducted with an uneven bottom and with reflective structures like vertical breakwaters or seawalls, the nonlinear effects due to the presence of an uneven bottom or wave reflection increase. This means that larger shifts at the focal point location occur. Hence, the effects of the complex bathymetry and wave reflection have to be included in the wave board control signal in order to ensure the generation of an accurate focused wave at the desired location in the flume.

In this work, a Self Correcting Method (SCM) is proposed. The pioneering work on the SCM was performed in the '80s at the University of Hannover, for the generation of irregular (Daemrich et al., 1980) and higher order regular waves (Daemrich and Gotschenberg, 1988) by establishing amplitude and phase transfer functions. It was found out that this method may not always work due to the generated spurious, free sub or super harmonics components when using linear paddle displacements (Prof. Daemrich personal communication). For this reason automation of the method was not implemented. Later, Chaplin (1996) used a similar approach for focused wave generation employing phase corrections alone and reported good results. An iterative approach was also used by Do et al. (2004) for Gaussian wave packet simulation. Schmittner et al. (2009) developed both amplitude correction and phase correction, and showed excellent results for improving deterministic wave trains. Recently, this method was also employed for tsunami wave simulation in a small wave flume Buldakov (2013). However, the potential and disadvantages of this method were not reported previously. In our previous investigations (Fernandez et al., 2013) the performance of the SCM was demonstrated to be dependent on the correction scheme (phase only or phase and amplitude correction steps) and the type of wave profile used for the development of the correction steps (first or second order). In this paper, the SCM is further tested in a Numerical Wave Tank (NWT), the objective is its implementation at the *GWK* for the generation of accurate focused waves at the predefined location irrespective of the bathymetry and the kind of structure.

The goals of this paper are: (i) to analyse the performance of the SCM by means of using different correction schemes, (ii) to demonstrate the capability of the SCM to reproduce accurate wave focusing in presence of wave reflection and sloping bottom, (iii) to verify the methodology for generating non breaking and breaking focused waves, (iv) and to apply the SCM for the generation of tsunami series recorded in the field at a predefined location in a laboratory flume.

The paper is arranged as follows. First, an overview of the SCM and the NWT is provided. At the second part the results of the numerical simulations and laboratory tests are discussed. Finally, the application of the SCM to reproduce tsunami time series is addressed followed by the concluding remarks and outlook.

2. The self correcting method (SCM)

The SCM is a proper way to improve the quality of the control signal by means of taking into account the inherent nonlinear interactions in the resulting wave train. The efficiency of the wave focusing is iteratively improved after some correction steps. If one knows the experimental set up (focal point, bathymetry, etc.) to be employed at the physical tests, the SCM can be applied by following these steps:

1. The target wave profile to be generated at the predefined location is back transformed to the position of the wave maker by means of linear theory without considering any nonlinear interactions.
2. Using (1) as a initial control signal the simulation is being carried out. Later, the control signal is corrected in frequency domain (in terms of wave phases and amplitudes) by means of the differences between the target and the recorded wave profile.
3. After applying 2 or 3 correction steps, the control signal is improved by the SCM and a required target wave is generated at the predefined location irrespective of the water depth present in between the wave maker and the focal point. Thus, the missing nonlinear interaction that was not taken into consideration will be taken cared of automatically.

The physical testing is expensive and time consuming, so the above steps can be carried out in a Numerical Wave Tank (NWT) and the final control signal will be used in the experimental wave paddle. In our previous investigations (Fernandez et al., 2013 the performance of the SCM was demonstrated to be dependent on the correction scheme (phase or phase and amplitude correction steps) and the type of wave