MODELING OF CLIMATE CHANGE IMPACTS ON COASTAL STRUCTURES - CONTRIBUTION TO THEIR RE-DESIGN

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ABSTRACT

Climate change is expressed on the open sea and the coastal zone through a number of impacts, such as: sea level rise, increase of the frequency of extreme wind events, change of the annual winds frequency, more frequent storm surge events, higher waves, changes of the dominant wave direction, stronger currents on the coastal zone etc. The above impacts, mainly due to a new sea level design and higher waves attack, induce morphodynamic responses such as beach and dune erosion, inundation on low-lying areas leading to increased flooding risk of the coastal zone, increase of wave penetration into harbours, failure of the existing coastal protection structures to protect sandy beaches from erosion.

In the present work, a numerical model, for the re-design of the existing coastal structures, is presented. The model is based on the higher order Boussinesq equations and describes non linear wave transformation in the nearshore zone as well as wave structure interaction.

By introducing a moving boundary scheme, the nonlinear wave propagation model is adapted to simulate wave run up on beaches and breakwaters, as well as overtopping and propagation behind the coastal structures. Using the proposed numerical model the Coastal Engineer can re-design coastal structures aiming to reduce the overtopping, by increasing crest level or/and offshore slope or by constructing a berm/submerged breakwater offshore the coastal structure. In addition since the model describe wave penetration into harbours, it can be used for the re-design of ports and harbours under the future climate change conditions.

The model is also able to describe breaking wave-induced current (simply after time integration of the wave horizontal velocities). After the coastal current simulation and together with the wave hydrodynamics prediction, sediment transport formulae are easily incorporated. Therefore, the model can be applied to simulate beach cross-shore morphology evolution and consequently can be used to estimate coastal erosion caused by extreme marine events.

The wave-structure interaction simulation together with the sediment transport simulation, lead to the description of the two-dimensional erosion-accretion processes and the simulation of the effects of coastal protection structures on coastal morphology. Thus, the model, can be used for the re-design of coastal protection structures under the future conditions (higher waves, changes of the dominant wave direction, sea level rise, etc).
Concluding, the model provides a useful tool to Coastal Engineers for the redesign of the existing coastal structures (higher waves, changes of the dominant wave direction, sea level rise, etc).

Keywords: Wave modelling, climate change, coastal structures, coastal erosion

1. Introduction

Climate change is expressed on the open sea and the coastal zone through a number of impacts, such as: rise of the mean sea level due to global warming, increased storm surge events (Isobe, 2013), changes of the frequency and the direction of extreme wind and wave events, stronger currents on the coastal zone etc. The above impacts, could lead to the increase of extreme wave run-up and overtopping of coastal structures (Chini and Stansby,

2012) and increase of wave penetration into harbours. Moreover, more intense morphodynamic responses can be induced such as beach and dune erosion, inundation on low-lying areas leading to increased flooding risk of the coastal zone and failure of the existing coastal protection structures to protect sandy beaches from erosion. In addition the impacts distract the operational aims of ports and coastal defence structures.

In the present paper advanced numerical models will be presented for the modeling of climate change impacts on coastal flooding/erosion, ports and coastal defence structures**,** aiming to contribute to the advancement of knowledge regarding the criteria, the methods and the goals of the design and upgrading of coastal structures against coastal flooding and erosion under the prospect of climate change.

2. Nearshore wave propagation and flooding model

Nearshore wave propagation is simulated by a Boussinesq nonlinear wave model. The following higher order Boussinesq-type equations for breaking and nonbreaking waves are used (Karambas and Koutitas, 2002, Karambas and Karathanassi, 2004). In the swash zone, the moving boundary scheme proposed by Cho and Kim (2009) is used to simulate runup and overtopping.

In order to examine the model's capability in wave breaking, bore propagation, overtopping and coastal flooding, we reproduced the Roeber *et al*. (2010) experiments on solitary wave transformation over an idealized fringing reef. The experimental flume is 48.8 m long, 2.16 m wide, and 2.1 m high. Figure 1 presents the comparison of the measured and computed wave profiles as the solitary wave propagates across the flume.

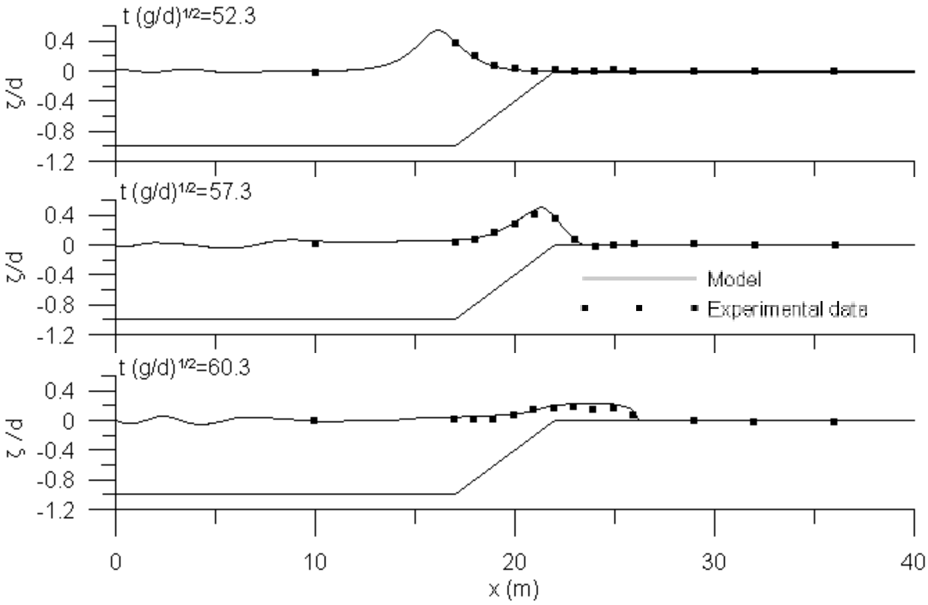

Figure 1: Simulation of coastal flooding due to wave runup and overtopping.

The test involves a steep solitary wave of height A=0.5 m and a water depth of d=1.0 m resulting in A/d=0.5. The wave propagates over the steep 1:5 slope and over a dry reef flat. The initial water depth can be taken from a storm surge model, and consequently using the present wave model the total sea level rise, due to synergy of waves and storm surge, can be obtained.

3. Wave - coastal structure interaction model

The above nonlinear wave propagation model is able to simulate wave overtopping over coastal structures. An overtopping example is presented in Figure 2. Using the proposed numerical model the Coastal Engineers can re-design coastal structures aiming to reduce the overtopping, by increasing crest level or/and offshore slope (Figure 3a) or by constructing a berm/submerged breakwater offshore the coastal structure (Figure 3b).

The nearshore wave propagation model, after the incorporation of appropriate conditions for wave – structure interactions, can be used for the re-design of ports and harbours under the future conditions (higher waves, changes of the dominant wave direction, etc). The model is adapted to incorporate wave – breakwater interactions (Fuhrman *et al.*, 2005 and thus becomes able to estimate wave penetration into a harbour and can be used for the re-design of harbour layout.

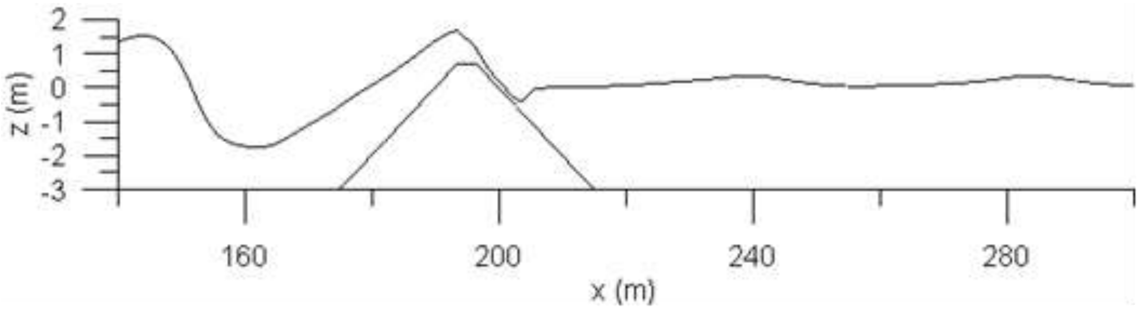

Figure 2: Simulation of wave run up and overtopping.

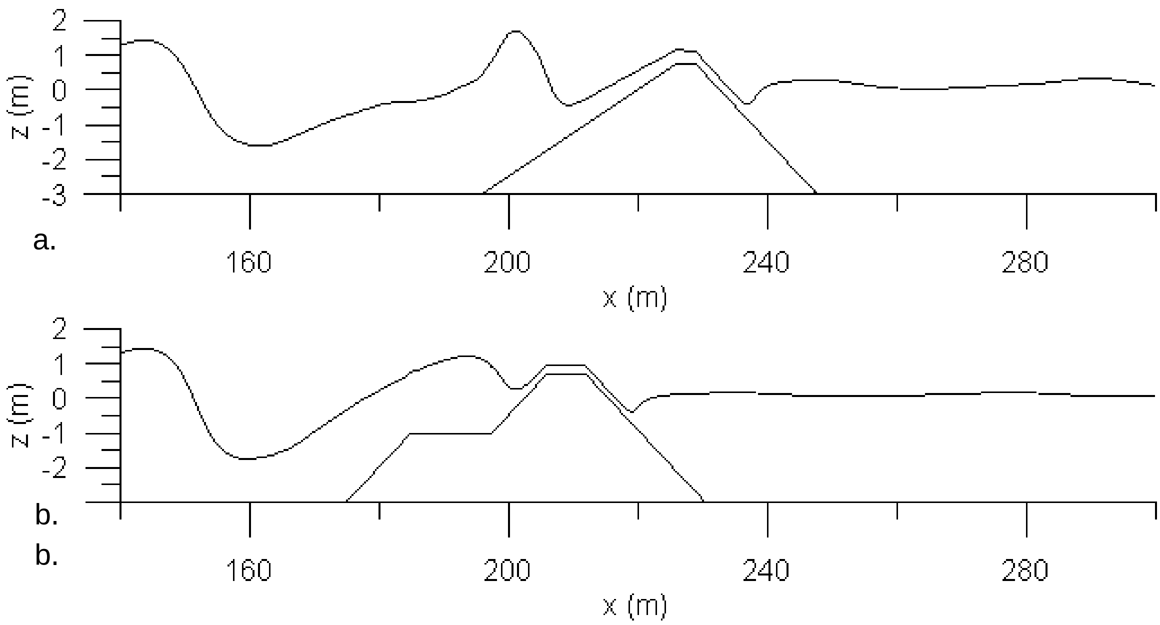

Figure 3: Simulation of wave run up and overtopping on a re-designed breakwater: a. by increasing slope, b. by construction a berm.

4. Coastal morphodynamics model

The wave model describes nonlinear wave transformation in the surf and swash zone. The model is also able to describe breaking wave induced current (simply after time integration of the horizontal velocities). By incorporating sediment transport formulae (Karambas, 2012) the model can be applied to simulate beach morphology evolution and can be used to incorporate the effects of coastal protection structures on bed morphology evolution, aiming to contribute to a proper design of them. Figure 4 shows an application of the model for the design of a detached breakwater for coastal protection (reproduction of Ming and Chiew (2000) experiments, breakwater length 0.9 m, distance from the initial shoreline 1.2m).

In Karambas (2012) the model is used to incorporate the effects of coastal protection structures on bed morphology evolution, aiming to contribute to a proper design of them. In Figure 4 the model is applied to design a detached breakwater for coastal protection (reproduction of Ming and Chiew (2000) experiments, breakwater length 1.2 m, distance from the initial shoreline 1.2m). In Figure 5 the same reproduction of the experiment is conducted, having considered significant sea level rise due to a storm surge event during the wave attack. Under these conditions the breakwater does not behave as an emerged one, but as a low-crested structure. A transmission coefficient equal to 0.3, due to wave overtopping, is considered. In this way the effects of the sea level rise due to storm surge (which increase the wave transmission) on coastal morphology can be evaluated.

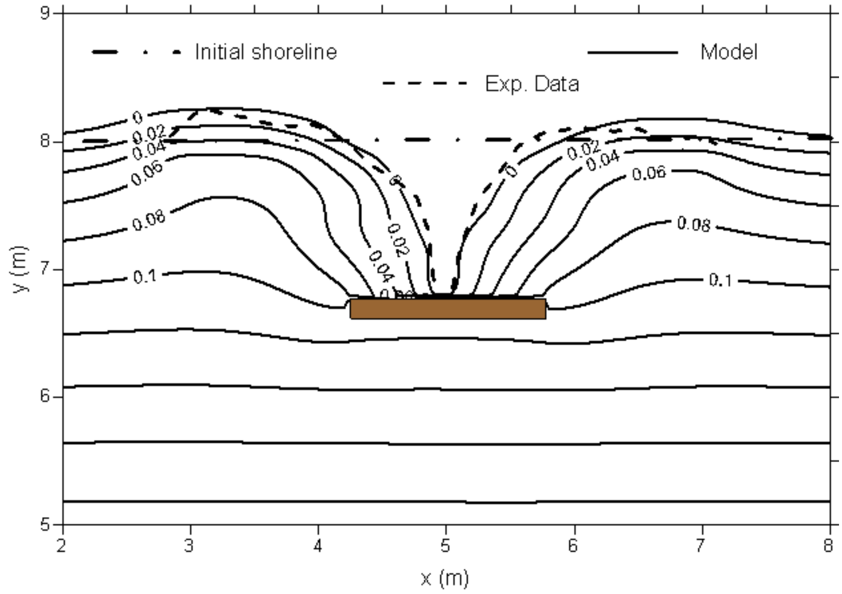

Figure 4: Tombolo formation behind a detached breakwater for coastal protection.

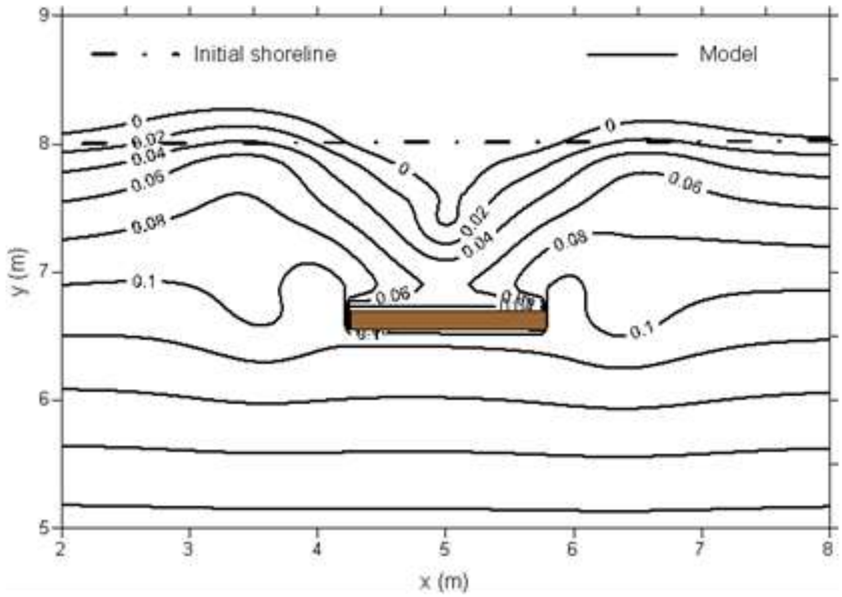

Figure 5: Salient formation behind a low-crested detached breakwater (with transmission coefficient equal to 0.3).

5. Conclusions

Numerical models for nearshore wave propagation can be adapted to simulate climate change impacts on coastal flooding/erosion, ports and coastal defence structures. The models, through the simulation of wave overtopping over the breakwaters crests, wave entering the harbour basin through diffraction, coastal erosion and storm surge/wave flooding, provide to Coastal Engineers a useful tool for the redesign of the existing coastal structures.

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