Coastal Engineering 109 (2016) 63–75

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

Groin impacts on updrift morphology: Physical and numerical study

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ARTICLE INFO

Article history:
Received 13 April 2015
Received in revised form 1 December 2015
Accepted 8 December 2015
Available online 6 January 2016

Keywords:
3D movable bed model
LTC numerical model
Pelnard-Considère formulation
Shoreline
Cross-shore profile

ABSTRACT

Groins interfere with coastal dynamics and sediment transport, leading to sediments accumulation at the updrift side, while at downdrift, the erosive process is anticipated due to the lack of sediments. To improve numerical modeling capacity to simulate the groins impacts, it is necessary to totally understand the shoreline evolution along time and its relationship with the cross-shore profiles shape. The main goal of this work was to analyze and compare the performance of physical and numerical studies on evaluating the evolution of updrift cross-shore profiles geometry and shoreline position after the construction of a groin.

This study analyzed a coastal stretch updrift of the groin, at a prototype and model scales, considering the analytical formulation of Pelnard-Considère, the numerical model LTC (Long-term Configuration) and the laboratory tests. The laboratory tested scenario was designed with the aim to gather results, which could be analyzed and compared with numerical simulations from LTC (Coelho, 2005), allowing its improvement, and with the Pelnard-Considère (1956) analytical formulation, both at model scale.

The developed study shows an important difference between LTC and Pelnard-Considère (1956) approaches because the analytical solution for the shoreline in equilibrium does not include the wave refraction effects over the updated bathymetry. LTC observed trend of the equilibrium shoreline is not parallel to the initial shoreline, and this behavior was confirmed in the laboratory tests. It was also observed that the sediment transport capacity has very small impact on the LTC shoreline configuration, despite the refraction effects over the updated bathymetries along time. The profile shape obtained in laboratory includes bed forms difficult to reproduce in long-term numerical modeling evaluation of cross-shore profiles because LTC transversal behavior is only based on geometrical considerations and does not represent cross-shore sediment transport and its impact on profile geometry.

1. Introduction

Groins are often used as a coastal defense intervention, promoting sand accumulation at the updrift side. However, groins have been misused, due to the inherent knowledge limitations on the complex dynamic behavior interaction, between the wave climate, the sediments dynamics, and the beach evolution. The comprehension of the hydrodynamic phenomena in the structure surroundings, the interference of the groins with the wave propagation and its influence on sediment transport volumes, and cross-shore profile evolution, downdrift and updrift of the structure is difficult to perform (Silva, 2010).

To improve numerical modeling capacity to represent the groins impacts (updrift sediment accumulation and downdrift erosion anticipation), it is necessary to totally understand the shoreline evolution along time and its relationship with the cross-shore profiles shape, dependent on the side of the groin and distance to it (Coelho, 2005). The main goal of this work was to evaluate the updrift shoreline evolution and final (equilibrium) position, and the cross-shore profiles final geometry after the construction of a groin. To complete the objectives, it was necessary to determine the beach equilibrium updrift of the groin, considering the shoreline and the profile width evolution along time.

A study case was defined recreating a scenario for evaluation of the morphological impact of a groin, in a coastal stretch located updrift of the structure. It was intended to study the groin impact (at prototype and model scales) by applying and comparing the results of the Pelnard-Considère (1956) formulation, LTC numerical model (Coelho, 2005 and Coelho et al., 2013), and by building a physical model at a reduced scale, at a laboratory wave tank, considering movable beds (Silva, 2010). The prototype scale results were analyzed according to the Pelnard-Considère (1956) formulation and the LTC numerical model, looking at the shoreline position and the cross-shore profiles' width. At the model scale, in addition to the previously approaches, the laboratory results were also considered to evaluate the cross-shore profile shape.

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http://dx.doi.org/10.1016/j.coastaleng.2015.12.003

2. Study case

The considered study case was defined based on the prototype and the model adopted by Silva (2010). Prototype and model scale characteristics are presented below.

2.1. Prototype scale definition

The prototype study case reproduces a beach stretch (500 m length) located in the central region of the Portuguese Northwest coast, south from Vagueira beach, which is undergoing an erosion situation and is influenced by the presence of a transversal defense structure, a groin with 145 m of extension. The Northwest Portuguese coast is a highly energetic coastal stretch with a wave regime typically from Northwest, characterized by a significant wave height between 1 m and 2 m, a peak period between 8 s and 12 s and an incident wave direction of about 10° (in relation to the shoreline orientation). The mean sea water level is +2 m above chart datum (CD). The potential alongshore sediment transport, mainly due to the wave action, is approximately 1–2 million m^3/year (Andrade and Freitas, 2002; Bettencourt, 1997, and Coelho, 2005). The potential alongshore sediment transport estimated using the CERC (1984) formula (Eq. (1)) is about 1.8 million m^3/year (considering the sediment transport coefficient of 0.22, empirically determined, a significant wave height of 2 m and an offshore wave angle with the shoreline of 10°):

$$Q_l = k\left(\frac{\rho\sqrt{g}}{16k_b^{\frac{1}{2}}(\rho_s-\rho)(1-n)}\right)H_b^{\frac{5}{2}}\sin(2\alpha_b) \quad (1)$$

where k represents the sediment transport coefficient, k_b the wave-breaking coefficient (defined as 0.78), ρ the fluid density, ρ_s the sediments density, n the sediments porosity, H_b the breaking wave's height, and α_b the wave's orientation at breaking.

The adopted median sediment grain size (d_{50}) was 0.5 mm. The beach face slope was assumed constant throughout the emerged zone, with a regular slope of 0.05. For a significant wave height of 2 m and a mean wave period of 12 s, Silva (2010) estimated that the active profile should reach a maximum depth of 8.7 m and the run-up limit would go up to 2.9 m. The wave height at breaking was defined through Komar (1998) formula with an estimated value of 2.9 m.

2.2. Model scale definition

The constructed three-dimensional movable bed physical model was defined accordingly to (Silva, 2010; Silva et al., 2011) model constructed in the wave tank at the Hydraulic Laboratory of the Civil Engineering Department of the Faculty of Engineering of Porto University (12 m width, 28 m length and 1.2 m depth) equipped with a multi-element wave generation system, which incorporates dynamic reflection absorption (*HR Wallingford*), placed at one end of the wave tank in a transversal direction. The beach model was built at the opposite end of the wave tank, also in the transversal direction in front of an existing dissipative gravel beach, making an angle of 10° with the generation system orientation (Fig. 1).

The model reproduced the prototype groin at a reduced scale. The model encloses the active profile of the beach, including the surf zone, between the beach berm (a greater emerged extension than the run-up limit) and the closure depth for a wave height of 5.4 cm. The physical model of the beach reproduced in laboratory was 6.2 m width, 8.4 m length, and 40 cm height (the emerged beach was 16 cm height and the water depth was 24 cm), with an average emerged beach face slope of 0.05. The analysis of the model scale, in the LTC and the analytical formulation, considered a more extended beach area, when compared to the physical model: 135 m coastal stretch length, 67 m width, and 3.75 m height (2.7 m emerged and 1.05 m submerged). The range of the selected sand grain size to prepare the beach model construction was between 0.1 and 0.3 mm, with a median sediment diameter, d_{50}, of 0.27 mm (Silva, 2010).

Due to the constraints of the wave tank and measuring devices precision limitation, the model is geometrically distorted ($\Omega = 2$), with a horizontal scale of $N_{x/y} = 74$ and a vertical scale of $N_z = 37$. Silva (2010) analyzed the model distortion effects in the wave propagation: refraction and diffraction. In the same work, the scale relations for distorted models were analyzed according to several authors: Le Méhauté (1970), Vellinga (1982), Wang et al. (1990), and Hughes (1993). Vellinga (1982) scaling laws, designed from a large number of physical model experiments and recommended by Dean (1985), were selected.

According to Novais–Barbosa (1985), it is possible to analyze the results from a distorted model when is pretended to study certain aspects and phenomena of a specific problem provided that the legitimacy of the results from the model is assessed.

From Silva (2010) studies, it was concluded that it is impossible to guarantee the complete resemblance between the prototype and the model. In order to guarantee ssome degree of hydraulic resemblance of the processes involved, the Froude resemblance was kept. This is one of the most used scale relationship in Coastal Engineering, where the main hydrodynamic action are the wind-generated waves that are "restored" by gravity (the inertia forces are compensated by the gravity forces).

By analyzing the run-up limit at the prototype scale, taking into consideration the established distortion, it was concluded that the groin at the model scale should have a height of 22 cm and a length of 3.4 m, which corresponds to a length at prototype scale of about 250 m ($N_{x/y} = 74$).

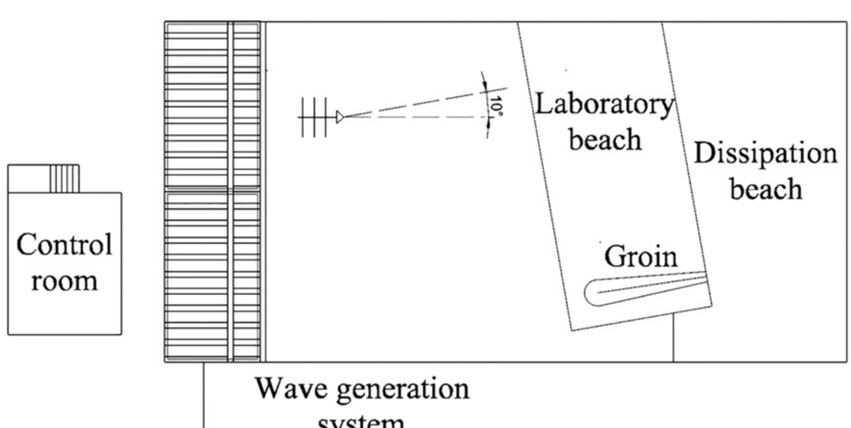

Fig. 1. Laboratory beach scheme (adapted from Silva, 2010).