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Suspended sediment transport and beach dynamics induced by monochromatic conditions, long waves and wave groups

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ABSTRACT

This study presents the analysis of the water surface elevation, velocity and suspended sediment concentration measurements obtained at a large wave flume under mobile bed conditions. The wave reproduced erosive and accretive conditions, and included monochromatic, short waves perturbed with a free long wave, bichromatic and random conditions. Each tested condition started from a handmade 1/15 slope and lasted for an approximate time period of 2.4 h (6 runs of the selected wave condition), to compare the different beach profile developments and, in particular, the events that control sediment transport in the swash and surf zones. All erosive tested conditions produced a shoreline retreat and a bar at the breaking area whose development in time is directly correlated to the length of the breaking area. On the other hand, not all accretive conditions present a shoreward transport, and random conditions do not seem to alter the initial profile. The processed data show the suspended sediment event control produced by the existence or absence of wave–backwash interactions in the swash zone. The existence of these interactions, and their number within the wave group, will be a key parameter in controlling the sediment stirring, water velocity magnitudes and, therefore, the suspended sediment fluxes in the inner surf and outer swash.

1. Introduction

The swash zone is that part of a beach that is alternately covered and exposed by up-rush and backwash, including from the point of bore collapse on the beach face up to the maximum up-rush limit. The swash zone is the link between the emerged beachface and the surf zone (Alsina et al., 2012; Hughes et al, 1997). The relevance of the swash zone is mainly due to the fact that a significant part of sediment transport (cross-shore and longshore) occurs in this area. But it is also important due to the control that the swash exerts over the sediment transport in that area, determining whether the sediment will be stored on the upper beach in the form of a berm or will move to the surf zone.

The berm and bar are the main morphological features to be found in a beach profile. While a great deal of effort has been put in the study of the bar evolution, the berm has received less attention. The berm formation processes has been previously studied considering the effects of wave height, tidal fluctuations, water level changes induced by storms, sediment fall velocity, grain size or permeability (Bagnold, 1940; Hine, 1979; Weir et al., 2006 or Jensen et al., 2009). But most of the studies dealing with berm formation, are qualitative studies, based on field experimental data highly affected by the tidal effect on gravel beaches. There are very few studies of berm development at intra-tidal time scale, and there is a lack of data linking the morphological and hydrodynamic measurements around the berm formation (Weir et al., 2006).

Butt and Russell (2000), Elfrink and Baldock (2002), Masselink and Puleo (2006), Bakhtyar et al. (2009) have described in their review papers the different forcing terms for the flow and sediment transport in the inner-surf and swash zone. In the last twenty years there has been a significant increase in the number of studies on the swash zone. Nowadays, there are different studies that deal with the terms that play a role in the dynamic at the swash zone: bore collapsing (Aagaard and Hughes, 2006; Jackson et al., 2004; Puleo et al., 2000), backwash (Horn and Mason, 1994 or Butt and Russell, 1999), advection (Jackson et al., 2004 or Alsina et al., 2009), infiltration/ex-filtration effects (Baldock and Nielsen, 2010; Elfrink and Baldock, 2002; Turner and Nielsen, 1997), asymmetries in velocity or acceleration (Houser and Barrett, 2010; Mariño-Tapia et al., 2007; Pedrozo-Acuña et al., 2011; Roelvink and Stive, 1989), long wave and wave groups (Baldock et al., 2011), etc.

The run-up and run-down movement in the beach face can be composed of a pure uprush or backwash movement (pure swash events) or of subsequent swash waves interacting. While the pure swash events have been widely studied (Blenkinsopp et al., 2011; Hughes et al., 1997; Masselink et al., 2009) and even numerically modelled (Hughes and Baldock, 2004 or Zhu and Dodd, 2013), the

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highly turbulent interaction between consecutive swash events lacks a proper characterization of the phenomena. Several authors have stated that the presence or absence of this interaction may determine the net direction of sediment transport and its profile change (Kemp, 1975 or Holland and Pulleo, 2001). Hughes and Moseley (2007) gave enough importance to the role of the interaction to divide the swash area into outer and inner swash sub-regions, according to the existence or absence of interactions in each sub-area. The outer swash is the region where wave–swash interaction occurs, while the inner swash is defined as the region where wave–swash interactions are entirely absent (only pure swash events without any interactions with previous or further swash events). Brocchini and Baldock (2008) presented the parameter $\check{T} = T_s/T$ to quantify the degree of wave–swash interaction, where T is the incident wave period and T_s the natural swash period. Values of $\check{T}$ greater than or equal to 1 are associated with a large number of interactions occurring in the swash zone.

Three different kinds of wave–swash interactions have been previously described: wave capture or catch-up, weak wave–backswash interaction, and strong wave–backwash interaction (Cáceres and Alsina, 2012; Erikson et al., 2005 and Hughes and Moseley, 2007). The wave capture interaction occurs when a second wave captures the previous one during both up-rush stages. The weak wave–backwash interaction occurs when an incoming wave advances across the front of an existing swash lens as it recedes down the beach as backwash. The receding backwash has a limited amount of energy and the incoming up-rush overrun results in an onshore flow. Finally, the strong wave–backwash interaction occurs when the backwash is stronger than the incoming up-rush, resulting in a stationary bore that has been compared to a hydraulic jump by several authors (Elfrink and Baldock, 2002; Hughes and Moseley, 2007; Puleo et al., 2000). The resulting flow, once the up-rush has lost all of its energy in the bore momentum exchange, is offshore directed.

Based on the physics of the events described above and previous data analysis (Alsina and Cáceres, 2011; Cáceres and Alsina, 2012), strong wave–backwash interactions and backwash events tend to induce erosion, while incident wave/bore events, wave capture events and weak wave–backwash interactions tend to produce accretion.

The data analysis performed throughout this paper aims to gain a better knowledge of the wave–backwash interactions and pure swash events under monochromatic, combination, bichromatic and random erosive and accretive conditions. The paper also focuses on the bar and berm formations along the beach profile during the tested conditions. Section 2 deals with the Experimental description. Section 3 presents the results of the bottom evolution profiles, spectral analysis and direct analysis of water surface elevation, velocity and suspended sediment concentration. Section 4 discusses the observed data and, finally, Section 5 sets out the conclusions of this study.

2. Experiment description

The data set out in this study were obtained in the Swash zone response Under grouping Storm COnditions (SUSCO) project. The SUSCO data set was obtained at the Canal d'Investigació i Experimentació Marítima (CIEM) at the Universitat Politècnica de Catalunya (UPC), Barcelona. It is a large-scale wave flume of 100 m in length, 3 m in width and 4.5 m in depth. The beach commenced 43 m from the wavemaker, with the toe of the beach at an elevation of −2.5 m relative to the SWL and approximately 45 m seaward of the shoreline. The beach consisted of commercial well-sorted sand with a medium sediment size (d_{50}) of 0.25 mm, with a narrow grain size distribution (d_{10} = 0.154 mm and d_{90} = 0.372 mm) and a measured settling velocity (w_s) of 0.034 m/s.

The equipment distribution is presented in Fig. 1 and Table 1, where the x-coordinate origin is at the initial shoreline with a still water level of 2.5 m, negative towards the wave paddle (offshore) and positive towards the beach face (onshore). The wave height was measured by means of resistive wave gauges in the deeper part of the flume (hereinafter WG), pore pressure sensors (PPTs) in the surf zone and acoustic displacement sensors (ADSs) in the swash zone. The three different devices used for recording the water surface elevation were selected based on previous experiments in the flume, in order to obtain the best possible measurement at each deployment location. The velocity field was mapped by means of acoustic Doppler velocimeters (ADVs),

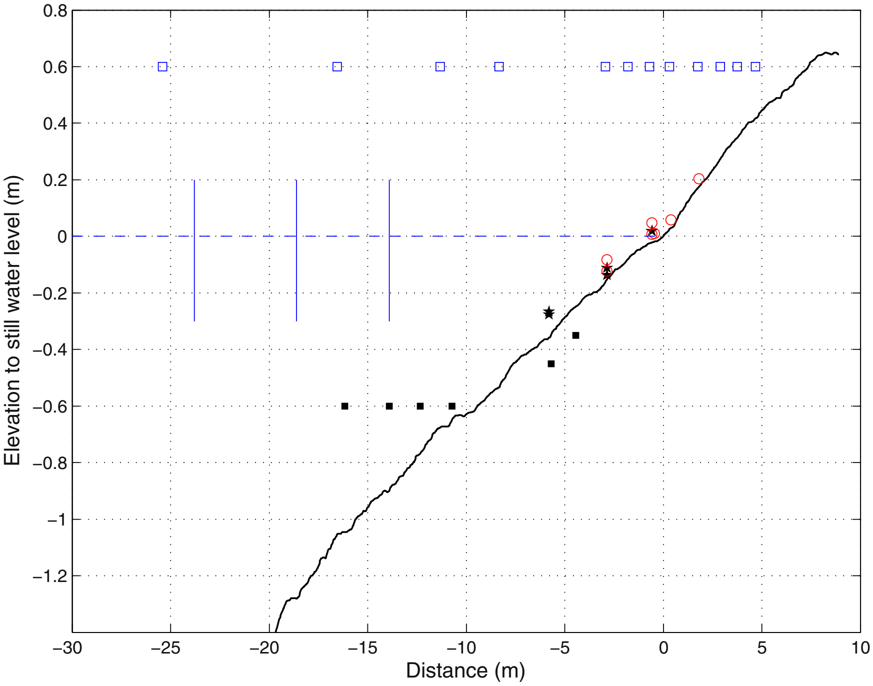

Fig. 1. CIEM configuration for the SUSCO experiments. A standard 1/15 initial profile is plotted with a solid black line. The marks show the position for WG (solid blue lines), PPT (solid black squares), ADS (empty blue squares), ADV (solid black pentagram) and OBS (empty red circles).