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Sinking of concrete modules into a sandy seabed: A case study

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ABSTRACT

Three submerged coastal structures on the sandy seabed at Santa Maria del Mar (SMM) Beach in Southwest Spain were monitored during the six months after installation, starting in November of 2005. The monitoring evaluated the self-burial phenomenon of the 40 precast modular concrete elements of the three structures. Assessment included scouring around the structures, their vertical movement, the sinking velocity of the modules and the resulting beach profiles. Pressure sensors and precision topographies permitted continuous monitoring of the self-burial process for the first time in a full-scale case. Comparison of two bathymetries (one performed immediately prior to installation and another performed six months after installation) indicated slight accretion of the seabed, whereas intermediate topographic surveys indicated extensive scouring around the structures. The three structures began sinking into the sandy bottom platform immediately after placement and continued until they reached the rocky bottom. This study implemented a new methodology using pressure sensors attached to the concrete modules to monitor the structural sinking. Unexpectedly, the average sinking speed was extremely rapid at approximately 3–6 cm/day; 50% of the height of the element was reached in three to six weeks. The results of this study are also compared with the results of other full-scale cases. Among other conclusions, data from this study indicated that the sinking rate of the modules in SMM Beach was one order of magnitude greater than the other values.

1. Introduction

Scouring and liquefaction are two physical phenomena that may cause extensive damage to marine structures. Scouring is one of the threats to the foundational stability of both riverine and maritime structures. Although flow-induced scour around bridge piers has received significant attention for many years, wave-induced scour around marine structures has not become a topic of interest to researchers till the 1990's (Bricker et al., 2012; Matutano et al., 2013; Negro et al., 2014; Sumer and Fredsøe, 2002; Whitehouse, 1998). The presence of marine structures in a coastal flow regime changes the flow pattern in the immediate neighbourhood of the structures. Changes in flow dynamics can increase shear stress in the sandy seabed and thus cause scouring, observed either at the toe of the trunk section or at the round head of the breakwaters (Sumer et al., 2005). Scouring and erosion processes in the sandy foundation of the marine structures cause sinking and structural failure.

In addition to scouring, liquefaction also has a disastrous effect on coastal structures in sandy platforms. Liquefaction is due to not only earthquakes, such as the catastrophic failures in Alaska and Niigata in 1964 (De Alba et al., 1976) or the recent disaster in Japan (Lai et al., 2013), but also waves. Momentary liquefaction occurs during the passage of wave troughs; more importantly, residual liquefaction occurs when the soil on the seabed is subjected to continuous wave loading (see Sumer and Fredsøe (2002) for a more in-depth explanation and Jeng (2003) for a comprehensive review).

Breakwaters are vulnerable to the liquefaction of seabed foundations. Inappropriate design or inadequate maintenance of breakwaters can lead to catastrophic coastal disasters (Jeng et al., 2013). Sutherland et al. (2000) experimented on the scour and deposition around a single detached offshore rubble mound breakwater. Scour and liquefaction around different marine structures has been widely studied in wave flumes. Although this study does not intend to present an exhaustive list of the experimental research previously performed, some noteworthy references and the subject of the research are reviewed in Table 1.

In wave dominated regions, the interaction between the hydrodynamic field and a breakwater has only been investigated either in the

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Table 1
References related to scour and liquefaction in maritime structures.

Research topic	Authors and year
Mechanics of the scour in the marine environment	Sumer and Fredsøe (2002)
Scour data obtained at roundhead and trunk of low crested breakwaters	Sumer et al. (2005)
The sequence of sediment behaviour during wave-induced liquefaction	Sumer et al. (2006)
Effect of seism on liquefaction	Ling et al. (2003)
Hydrodynamic forces on pipelines	Cheng et al. (2011)
Liquefaction around pipelines and guidelines for their stability	Teh et al. (2003), Damgaard et al. (2006) and USACE, United States Army Corps of Engineers (2002)
Behaviour of cover stones on a liquefiable soil bed exposed to a progressive wave	Sumer et al. (2010)
Scour around spherical bodies and self-burial	Truelsen et al. (2005)
Sinking of irregular shape blocks into marine seabed under wave-induced liquefaction	Kirca (2013)
Breaking wave-induced response of composite breakwater and liquefaction in seabed foundation	Jianhong et al. (2014)
Liquefaction around marine structures	Sumer (2014)

laboratory and/or in numerical and surprisingly, field studies have been rare (Olsson and Pattiaratchi, 2008; Sumer, 2014). Thus, little information about scour around low crested structures or submerged breakwaters has been obtained from actual case studies. Regrettably, there are inevitable scaling effects in physical modelling related to sandy bottom behaviour; for instance, certain parameters cannot be easily scaled in experimental studies, either geometrically or dynamically. Moreover, numerical models for wave-induced seabed response around marine structures have also been developed, e.g., Jeng et al. (2013), but only experimental data were used for their validation. Extensive experiments have been conducted in different wave flumes (e.g., Kramer et al., 2005); however, only some prototype-scale results have been presented (e.g., Dean et al., 1997 or Stauble and Tabar, 2003). Nevertheless, settlement or sinking has not been commonly surveyed, not even in the exhaustive paper presented by Lamberti et al. (2005), who plotted data of low crested structures in 6 different locations along the European coast.

Results of the continuous monitoring of the self-burial of concrete modules have not yet been presented for a real case. Therefore, the aim of this study is to present the scour and posterior sinking prototype results obtained from examining concrete modular elements placed over a sandy bed in Santa Maria del Mar (SMM) Beach (located in the Gulf of Cadiz, Spain) and to discuss these results in relation to literature data.

2. Study area

SMM Beach is a 450 m-long beach with a NNW–SSE orientation located in the Gulf of Cadiz, facing the Atlantic Ocean on the southwest coast of Spain, near the Strait of Gibraltar (Fig. 1).

The Cadiz coast responds to mesotidal characteristics, with two high tides per day separated by 12.42 h. The mesotidal range has a medium neap to spring variation (1.20–3.80 m). The tidal levels during the observation period are shown in Fig. 2. Additional details about the

Fig. 1. Location of the study area and position of the wave buoy.