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Beach nourishment effects on sand porosity variability

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ABSTRACT

A standard assumption in coastal engineering is that the porosity of natural beach sand (non-cohesive) is 40%. However, is this assumption correct for all beach sand? This paper proposes an accurate and simplified method to assess changes in sand porosity after beach nourishment by means of in-situ density surveys through a nuclear densimeter. This novel application has been applied to different beaches in the southwest of Spain according to the tidal range, grain size and beach morphology in several terms. General results show that sand porosities range from 25.6% to 43.4% after beach nourishment works. This research can be considered a support tool in coastal engineering to find shifting sand volumes as a result of sand porosity variability after beach nourishment and later marine influence.

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1. Introduction

Coastal erosion is a natural phenomenon that is a growing problem. Over the last few decades, there has been a gradual change from hard to soft coastal defence techniques. For example, beach nourishment has become the favoured erosion mitigation strategy in many areas of the world (Dean, 2003; Trembanis and Pilkey, 1999). Furthermore, periodic artificial nourishment is widely regarded as an acceptable method of beach and dune protection and restoration (Hanson et al., 2002). Several studies regarding the management and economic evaluation of beach erosion and nourishment around the world have been presented (Gomez-Pina et al., 2007; Hamm et al., 2002; Hanson et al., 2002; Muñoz-Perez et al., 2001a; Trembanis and Pilkey, 1999).

According to Dean (2003), after beach nourishment activities are performed, sand volumetric evolution, particularly the proportion of sand volume that remains within the region where the sand was placed, is of interest. The interstitial system of sandy beaches is lacunar, and its dimensions are defined by the sand granulometry and grain shape. The system can be described by features such as the pore size, density, porosity, permeability and water content (McLachlan and Turner, 1994). The bulk density is an indicator of soil compaction, which is related to its porosity and permeability. An important consideration in sediment motion (S_l) is the porosity index (η):

$$S_l = I_l/(\rho_s - \rho_w) \cdot g \cdot (1 - \eta) \quad (1)$$

where ρ_s and ρ_w are the soil and sea water densities, respectively, g is the acceleration due to gravity, and I_l is the underwater weight of material moved alongshore per second (Kamphuis et al., 1986).

The porosity is a primary determinant of the density and permeability of sediments; therefore, the porosity is a vital input for basin modelling (Chuhan et al., 2002). According to Poizot et al. (2013), the permeability of a sand bed may also be correlated with the sand grains' size (mean, sorting and skewness) and sphericity in addition to the bed porosity.

The porosity of dune and beach sand deposits was studied by Fraser (1935) and Pryor (1973), and the Holocene barrier island sand deposits were studied by Beard and Weyl (1973). Numerous studies of geological and geotechnical engineering applications to measure the maximum and minimum porosities for different grain size distributions and/or sorting coefficients have been conducted (Bloom et al., 2010; Curry et al., 2004; Gaither, 1953; King, 1899). However, none of these authors studied porosity for beach-monitoring purposes. According to the USACE (2002), good porosity data are often not available. The standard assumption in longshore transport computations is that the porosity of natural beds (non-cohesive) is 40% and the grain content is 60% (USACE, 2002), but the values for real sand bands are likely to vary significantly from these values (Galvin, 1979).

According to Dean (2003), after a beach nourishment project, some sand volume is lost because waves cause the sand to spread along the shoreline and move offshore, smoothing the shore profile. The primary purpose of this study is to demonstrate that much of the volume loss after beach nourishment procedure can be due to porosity decrease. Our primary hypothesis is that any type of beach nourishment activity results in a significant increase in sand porosity, largely due to the massive and disorganised dumping of a mixture of sediment and water (in this case 20 and 80%, respectively) on the backshore and

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foreshore by a trailing suction hopper dredge. The porosity subsequently decreases until it reaches its native value because of waves and tides cause spatial re-accommodation of the grains. An accurate and novel application of in-situ measurements of the density (and thus porosity) of beach sand using a high-quality nuclear densimeter gauge is described herein.

2. Study area

The coastline that is studied is located in the southwest of Spain near the Strait of Gibraltar (Fig. 1) and faces the Atlantic Ocean (Victoria and Camposoto beaches) and the Mediterranean Sea (Atunara beach). Both the Victoria and Camposoto beaches, the former located in the city of Cadiz, are dissipative beaches (Muñoz-Pérez and Medina, 2000; Poizot et al., 2013) composed of medium and fine moderately sorted sands. However, whereas Victoria has a seaside promenade, Camposoto is a natural beach with a backshore dune ecosystem. In contrast, Atunara beach, located just north-east of Gibraltar, is reflective (Masselink and Short, 1993), with a promenade and short transverse breakwaters, and is composed of coarse poorly sorted sand. Most beaches on the Gulf of Cadiz are composed of sands that are 90-95% quartz and 5-10% bioclastic material (Muñoz-Perez and Medina, 2010). In the case of the Victoria and Camposoto beaches, borrow sediments have been sourced from the nearby offshore Meca sand bank, a triangular submerged shelf (composed of medium sands) lying at 15 to 20 m depth 5 km west of Cape Trafalgar (36°12′ N; 6°05′ W) (Román-Sierra et al., 2011). In the case of Atunara beach, the borrow sediments were dredged from an adjacent fishing port. According to the scheme devised by Davies (1964), the study region can be classified as meso- (Atlantic beaches) and microtidal (Mediterranean beaches), with maximum ranges of 3.80 - 0.20 m and 1.50 – 0.00 m at spring and neap tides, respectively, exhibiting a semidiurnal periodicity.

3. Materials and methodology

Monitoring the behaviour of several beaches through topographic levelling enables comparison with previous studies and prediction of future sand requirements to optimise environmental and economic impacts (Muñoz-Perez et al., 2001a). According to the USACE (2002), it is essential to evaluate the behaviour of the grains and void index at different sand beaches, especially before and after beach nourishment. An accurate sand volume can thus be useful for beach nourishment projects. Moreover, knowledge of the sand's density, sand's porosity, sand's grain size, wave height and topography is crucial for achieving these objectives because the wave and tidal climate can change the sorting, grain size and porosity within a sediment bed (Kakinoki et al., 2011).

Other authors have developed different methodologies for determining sand density and porosity. Pryor (1973) used volumetric methods, whereas Lundegard (1992) quantitatively estimated the amount of porosity loss through compaction and cementation. Atkins and McBride (1992), Curry et al. (2004) and Dickinson and Ward (1994) point-counted the upper surface of thin sections of epoxy- or superglue-impregnated samples in reflected light. Among the various methods that have been applied by different researchers (Beard and Weyl, 1973; Roberts et al., 1998), it is worth mentioning the use of diver cores with in-situ conductivity probes and X-ray computed tomography (CT) scanning techniques (Bloom et al., 2010; Briggs et al., 2010). However, Dickinson and Ward (1994) have noted the difficulty of obtaining in-situ sand samples in which porosities can be measured without disturbing the loosely packed grains. In contrast with other techniques, sediment disturbance does not occur during in-situ nuclear densimeter measurements. This technique is also much less laborious, very accurate and non-destructive (Roberts et al., 1998). These properties are very important because grain crushing can result in tighter grain packing and a reduction of the primary porosity (Chuhan et al., 2002), thereby yielding an incorrect measurement.

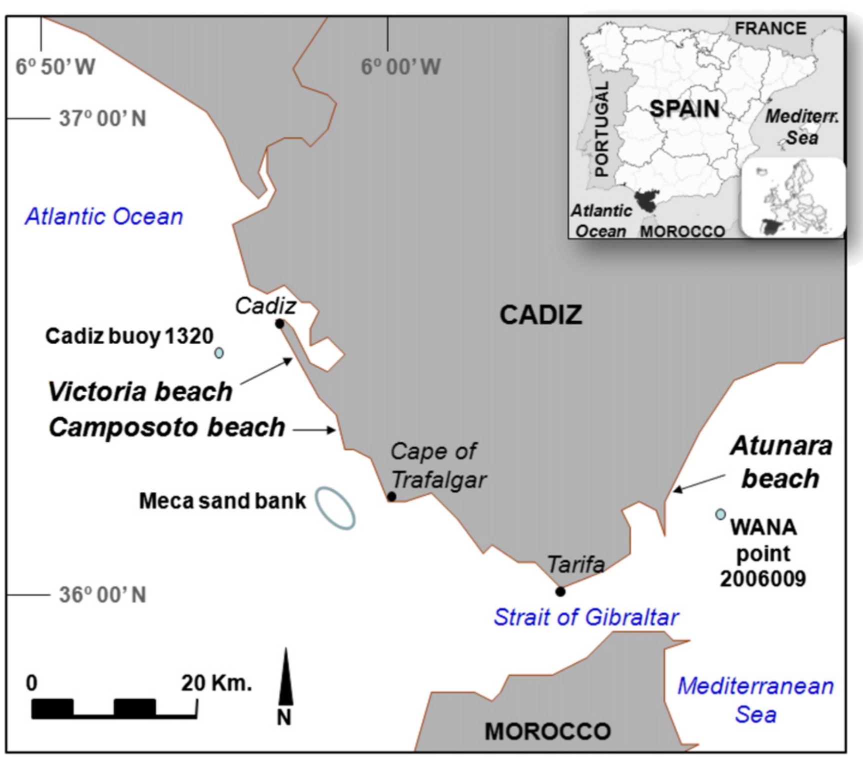

Fig. 1. Locations of the three studied beaches (Victoria, Camposoto and Atunara) and the Meca sand bank (the source of borrow sand for the first two beaches) in southwest Spain.

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