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Analysis and modelling of cross-shore profile of gravel beaches in the province of Alicante

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ABSTRACT

The great scientific interest in the gravel beaches is due to the growing use of coarse materials in the nourishment of eroded sand beaches. The objective of this research is to obtain a model for an equilibrium profile of gravel beaches, which has been divided into the three parts of the transverse profile: Profile in the backshore, intermediate profile submerged and profile *Posidonia oceanica* area. Furthermore, the results are compared with other models used today. Initially, there had been a historical survey of the development plan and profile of each beach to determine the stability of the same, and see if there have been longitudinal or transverse movements within the analyzed profile. Here are various mathematical models generated from different mathematical functions (potential, exponential and rational) Profile for each zone. They are statistical parameters analyzing the surface error between real and estimating those selected as the best model data. Finally, due to the importance of *Posidonia oceanica* in the set of studied beaches (94.11%), and to determine the best model profile for this area, it analyzed the relationship between the slopes of the meadow and the land near the beach.

1. Introduction

Gravel beaches are an important natural coastal defense, protecting the cliffs from erosion and backshore region (*e.g.* urban areas, agriculture, natural habitats, recreational and environmental areas) from storms and wave run-up (Bagnold, 1940; Lopez de San, 2003; Poate et al., 2013; van Hijum, 1974). This is due to the features offered by this type of sediment, such as the hydraulic roughness and permeability (Bagnold, 1940; Kobayashi et al., 1987; Van Gent, 1995; Van Wellen et al., 2000).

The gravel is defined by classification of Udden–Wentworth (Udden, 1914; Wentworth, 1922) as sediment whose diameter is between 2 and 60 mm, and its shape is heterogeneous (Carter, 1988; King, 1972; Zenkovich, 1967). Within the physiographic context, the development of l gravel beaches is glacial due to the weather of the mountains. Therefore, gravel beaches are mainly in high latitudes, but there are areas where due to topographic relief near the coast and the short length of its ravines and gullies that makes its eroded elements to be deposited on beaches without having virtually decanted. So when on the same beach, there are two different supply sources (rivers and ravines), differences in grain size can be seen visually (Parker, 2008).

In coastal regions, the shape and form of the beaches are controlled by transport processes of sediment, depending on the nature of waves, currents, geological and morphological characteristics of the zone (*e.g.* headlands, harbors, …) as well as supply and removal of sediments (Jamal, 2011).

On the other hand, the beach management plans are increasingly using the filler material or mixture of coarse sand and gravel as an alternative to regenerate eroded beaches (Mason et al., 2007). It is important to highlight the economic implications that this may have for the precise definition of the profile morphology prediction for beach regeneration. Hence the importance of studying the equilibrium profile of such beaches.

As for the formulations of equilibrium profile, we highlighted Dean (1977), who confirmed the simplest form of the power law of Bruun (1954) to the sandy beaches. While the gravel beaches highlights the points proposed by Powell (1990), based on the study previously done by Van der Meer (1988) and from data obtained from tests performed on channel, where he developed a parametric model to predict the profile, even Powell (1990) observation was divided into three part profile called: the berm/crest on the top of the profile, transition/step in the middle and the base at the bottom of the profile.

In recent years, there have been a lot of process-based models to explain model behavior of the wave profile from the swash zone to the crest of the beach (Jamal, 2011), Li et al. (2002) and Horn

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and Li (2006) among those highlighted. These have simulated the interaction of wave run-up/run-down, beach groundwater flow, swash sediment transportation, and beach profile changes. They showed that swash infiltration will cause swash asymmetry and enhance onshore transportation. Therefore accretion of the upper beach is produced. Karambas (2003) joined a porous model based on the equations in shallow water, allowing the infiltration/exfiltration, although his work is mainly based on the research of Van Gent (1995). Hence, he found that transportation to the coast increases the coarse sediments invested on the fine sediments. Stoker and Dodd (2005) included the effects of infiltration into their model and found that it was essential for the prediction of the formation of the berm on beaches steep gravel. Meanwhile, Pedrozo-Acuña et al. (2006) investigated changes in the cross-shore profile of numerical and experimental observations from a Large Wave Flume (GWK), and found that by adjusting the flow direction in the area depending on the swash and backwash up-rush, better prediction of sediment transport was obtained. One of the last authors used the process-based models by Jamal et al. (2014) who describe the progress made in the modification and application of XBeach code for the prediction and explanation of the observed behavior of the coarse-grained beaches in laboratory and field.

Moreover, seagrass such as *Posidonia oceanica* provides stabilization services sediments and coastal protection to colonize the shallow marine habitats (Fonseca, 1996; Hemminga and Nieuwenhuize, 1990; Koch et al., 2009). Submerged plants increased bottom roughness, which reduces bed velocity and modifies sediment transport (Koch et al., 2006) as well as increasing wave attenuation (Kobayashi et al., 1993; Mendez and Losada, 2004). In addition, seagrass rhizomes and roots extended into the sediment and contributed to its stabilization (Fonseca, 1996). Nevertheless, it can also affect coastal hydrodynamics depending on size, location, density, distribution and morphology (Mendez and Losada, 2004).

The aim of this study is to obtain a model for the equilibrium profile of gravel beaches. Their evolution and stability in plan and profile are analyzed and discussed. Moreover different types of gravel beaches are studied either by morphology or by their size distribution at the dry beach (Aragonés et al., 2014). Changes in the dry beach and the influence of the movement of the swash zone are studied. Furthermore the two parts of the submerged profile are adjusted using different models and compared with existing models used in beach regeneration such as the parametric model of Powell (1990). Finally the influence of marine vegetation in the stability profile is studied.

2. Study area

The study was conducted in 34 gravel beaches found in the northern part of the province of Alicante, southeast of Spain (Fig. 1). This area comprises almost two thirds of beaches situated in the area of study (Province limit to Huertas Cape) and consists of various mountain ranges and river valleys. The surrounding mountains are part of the Baetic System, is more parallel chains ranging from southwest to northeast, and dividing the area into two areas dominated by the presence of meadows of *Posidonia oceanica*. The northern zone up to Nao Cape is dominated by limestone cliffs and wave direction ENE, the strongest being NE. The south meanwhile consists of small gravel and silt cliffs and a higher frequency of waves from the E.

In the Alicante coast area, the most prominent waves are those originating from the ENE-E direction (Fig. 2). The ESE is also important but the intensity is considerably less than rough weather originating from the ENE-E. The storms, with wave heights greater than 2.5 m, typically occur twice a year, between the months of October and February, and have an average duration of between 7 and 12 h. Storms highs can reach up to 4.5 m with a maximum period around 10–12 s. Besides the high waves more frequent (44.2%) are less than 0.5 m. The wave height is less than 1 m for 85.3% of the time (Fig. 2). Sea wave data have been obtained from the data of the directional buoy Alicante (hourly data), provided by Organismo Público Puertos del Estado. Regarding astronomical tides they range from 20 to 30 cm in the study area, which when combined with meteorological tides can reach up to 75 cm (ECOLEVANTE, 2006).

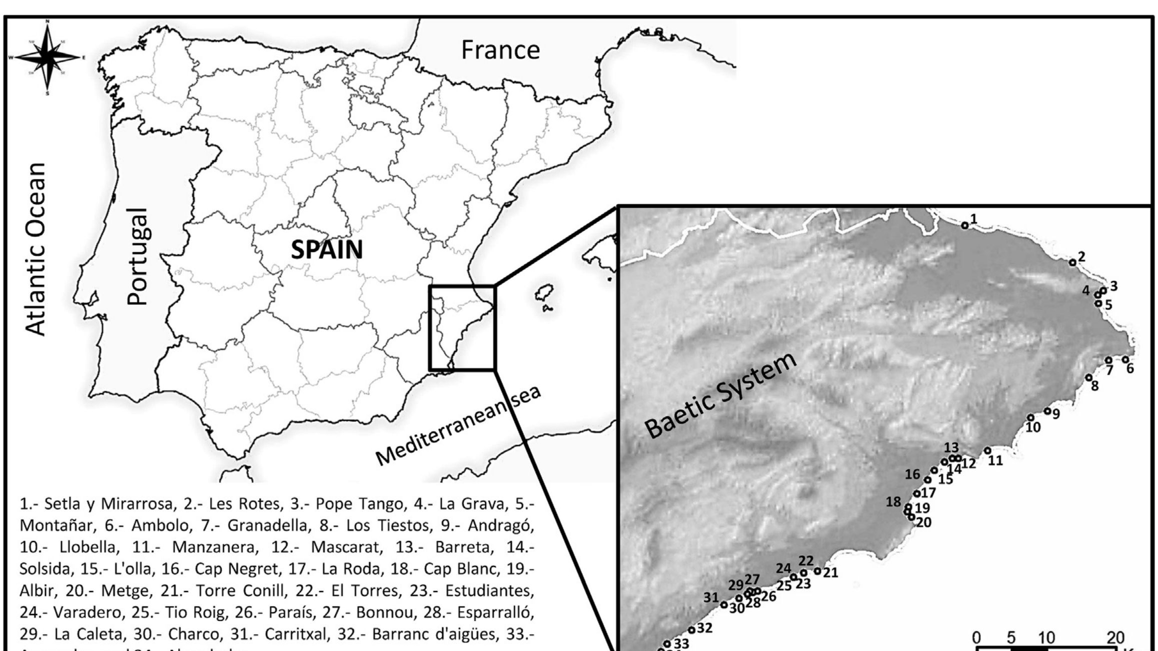

Fig. 1. Location of the study area.