Equilibrium Beach Profile: La Garrofera Beach Case Study

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Abstract

The constructive and destructive forces acting on a beach profile influence the beach cross-shore profile. For an equilibrium profile, the response to wave forcing should result in a constant shape depending on incident waves or sediment characteristics. A panoply of formulations can be found to represent this equilibrium beach profile in both tidal and non-tidal beaches and the presence or absence of longshore bars. The main objective of this work is to verify if some easy-to-apply and straightforward models can provide an excellent fit for the cross-shore profile of La Garrofera beach, located in the Mediterranean Sea at Valencia (Spain). Beach characterization is made in terms of its morphology, nature of the soil and sediment characteristics, and wave regime. Three models are tested against bathymetric field data, showing reasonable predictions of the measured beach cross-shore profile. Furthermore, they all correctly predict the expected concave-up form characteristically found on wave-dominated beaches.

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1 Introduction

The use of sandy coasts for tourist activities grew significantly in the last decades of the last century, becoming one of the most important economic activities of many Mediterranean regions. The strong demand for sea views and proximity to beaches resulted in new urban areas accommodating growing populations, and the coastal area has lost its natural setting (e.g., Garcia & Llorens, 2020). These urban areas may have significant negative impacts on coastal environments, aggravated by the impacts of climate change, such as erosion, flooding and sea-level rise.

The erosive processes entail social and economic issues associated with coastal property losses, including damage to nearshore infrastructures and assets. Various defence strategies can be adopted to maintain the beaches, including artificial nourishment interventions and other experimental solutions that help to reduce coastal erosion. The importance of studying equilibrium beach profiles is directly connected with the management and nourishment of beaches. Still, the equilibrium beach profile is never reached due to the constant changes in the sea state, and, consequently, the sediments on the beach are moving at all times. Therefore, coastal monitoring is a fundamental tool for assessing any adopted strategy's effectiveness and supporting management and decision-making initiatives.

This work aims to study La Garrofera beach, located in Valencia (Spain), more specifically in the south of Valencia's harbour, in terms of its equilibrium state. The beach is placed in La Albufera Natural Park and is a privileged spot in the shelter of the dunes. Characterization of the beach is made, providing information on its morphology, nature and sediment grain size and wave regime. Particular attention is given to the beach cross-shore profile, using three different models: Dean (1977), Bernabeu et al. (2002) and Yu & Slinn (2003).

2 Data and Methods

2.1 Study Site Characterization

La Garrofera beach is a Mediterranean sandy beach found in the natural Park of L'Albufera in the east of Spain. Located between two of the most important beaches in Valencia, called El Saler and La Dehesa, La Garrofera beach counts 2650 m in length and 35 m wide, being orientated NNW-SSE (Fig. 1).

The bathymetry of the beach was provided by Direccion General de Sostenibilidad de la Costa y el Mar (DGCM), belonging to the Spanish Secretariat of State of the Environment, and it shows a seafloor composed of sand with contour lines approximately parallel to the shoreline, denoting longshore uniformity (Fig. 1). The beach comprises a sandy coast and soft seabeds, where the sediments are cumulated. The composition of the beach consists mainly of uniform sand, presenting a median grain size of $d_{50} = 0.27 \pm 0.4$ mm. At deeper locations, the bottom is more irregular due to rocky outcrops.

During the last years, no appreciable changes were observed on the shore, but the reduced size of the beach reveals its vulnerability to erosion processes. One recognizes that the Port of Valencia influences sediment transport in this particular case. Since it was built, the natural longshore sediment transport was interrupted, and the beaches located in the south, such as La Garrofera beach, do not have sediment contributions coming from the north, suffering coastal erosion. On the other hand, this erosion is also affected by reducing sediment transport from Turia's River to the coast, resulting from river regulation works.

According to the information gathered on the Puertos del Estado website (www.puertos.es), Valencia's coastal buoy (Boya Costera de Valencia I) shows a wave regime essentially characterized by significant wave heights between [0, 0.5] m, with relative frequencies close to 55% and between [0.5, 1] m, with relative frequencies of 34%. A more significant dispersion can be observed for the wave peak period. The values range between 1.5 and 13 s. Most of the data (61.2%) are concentrated within [3.5, 6.5] s. The dominant directions of propagating waves result essentially from the first and second quadrants. It can be observed that swells from the first quadrant occur more frequently, presenting a NE direction. The second quadrant waves exhibit lower frequencies with a SE direction.

2.2 Beach Cross-Shore Profiles

Bruun (1954) introduced the concept of an equilibrium beach profile from field studies of beach profiles on the coasts of Denmark and California. The author noticed that the cross-shore profiles fit curved and concave shapes very well. Dean (1977) further examined this concept, proposing the generalized power law for each profile:

$$Z = Ax^m \tag{1}$$

where z represents the depth of the profile below the mean water level, x is the distance to the shoreline, and the parameters A and m are empirical coefficients based on representative profiles. For example, Dean (1991) proposed a mean value for m equal to 2/3 and established an empirical correlation between A and d_{50} (expressed in mm) $A = 0.21d_{0.50}^{0.48}$.

Bernabeu et al. (2002) discussed a two-section equilibrium profile based on different dissipation processes acting on the beach for tidal environments (e.g., turbulence and
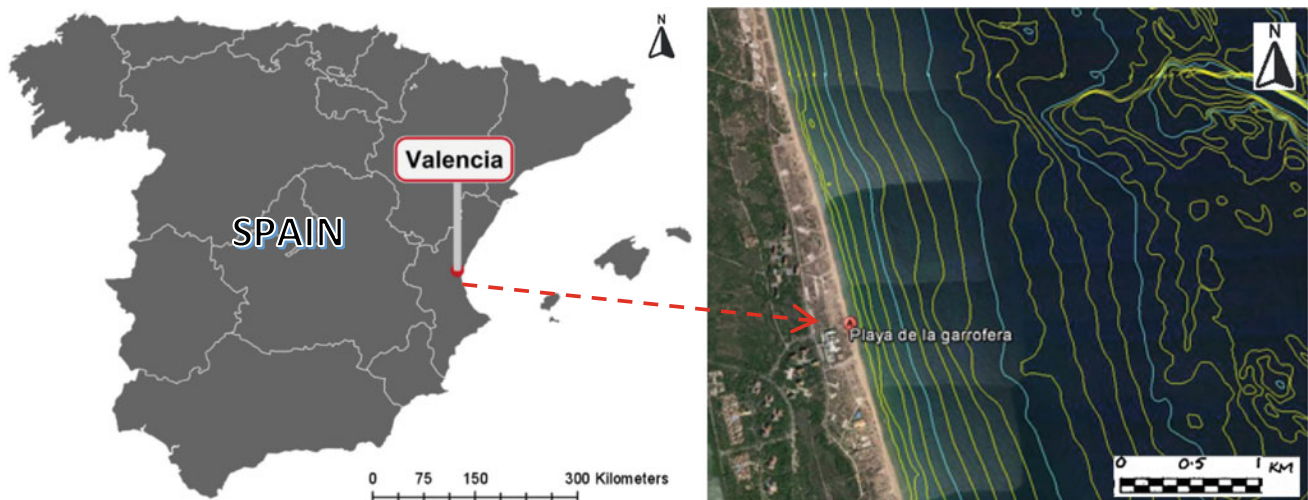

Fig. 1 Localization of La Garrofera beach and corresponding bathymetry

bottom friction). The profile is divided into a shoaling and a surf profile, and each section is treated independently. The developed expressions to characterize each profile section are presented in Eqs. (2) and (3):

$$x = \left(\frac{z}{a_1}\right)^{3/2} + \frac{a_2}{a_1^{3/2}} z^3 \text{(surf profile)}, \qquad (2)$$

$$x = x_0 + \left(\frac{z}{a_3}\right)^{3/2} + \frac{a_4}{a_3^{3/2}} z^3 \text{(shoaling profile)}, \qquad (3)$$

where the horizontal distance, x_0, depends on the tidal range, measured from the start of the surf profile and the virtual origin of the shoaling profile over the mean sea level. The coefficients a_1 and a_3 are associated with dissipation mechanisms, and the coefficients a_2 and a_4 are with energy reflection.

Both Dean and Bernabeu's profiles do not consider the existence of longshore bars. That shape can also represent an equilibrium profile, but few studies can be found concerning

barred beaches. Yu and Slinn (2003) proposed the following expression to reproduce longshore uniform barred profiles:

$$z = k\left(1 - \frac{\beta_2}{\beta_1}\right)\tanh\left(\frac{\beta_1 x}{k}\right) + \beta_2 x$$
$$- A_b \exp\left[-W_b\left(\frac{x - x_b}{x_b}\right)^2\right], \qquad (4)$$

where x_b is the position of the bar crest and β_1 and β_2 are the nearshore and the offshore slopes, respectively, A_b is the bar amplitude, W_b is the bar width, and k is a calibration parameter.

3 Results

The numerical values of the input coefficients of Eqs. (1)–(4) were obtained by minimizing the differences between estimated and observed depth values. The results for the three models are shown in Fig. 2.
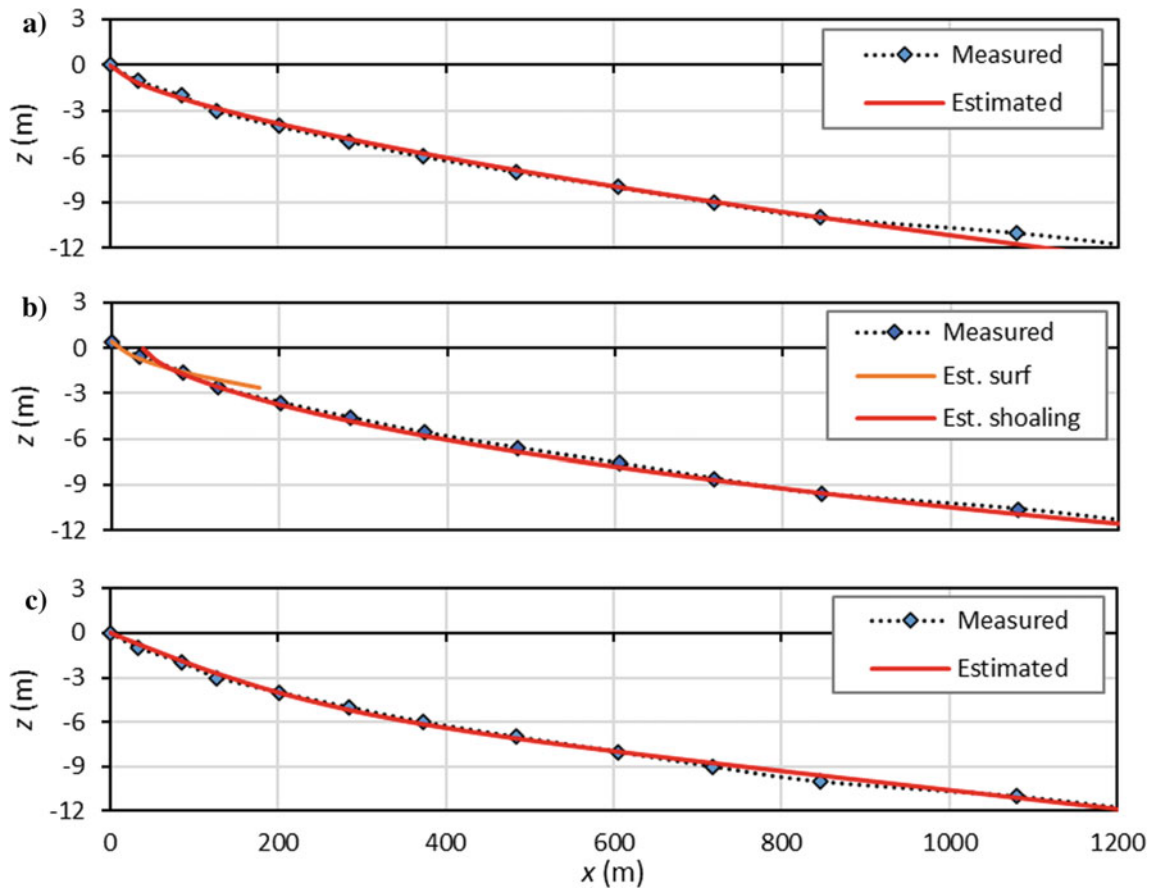
Fig. 2 Comparison of La Garrofera cross-shore profile with **a** Dean's, **b** Bernabeu et al.'s and **c** Yu and Slinn's models

4 Discussion

Dean's equilibrium beach profile theory assumes that the turbulence of breaking waves is the main destructive force acting on a beach. This assumption leads to developing a conceptual framework where the sediment of a given grain size can withstand wave energy dissipation per unit volume. It is noteworthy to mention that the obtained data, coming from a cartographic study of Valencia and Alicante regions made by DGCM, registers a relevant diameter for La Garrofera beach equal to $d_{50} = 0.27 \pm 0.4$ mm, confirming the value of $A = 0.111$. Therefore, it can be said that this beach adjusts reasonably well to Dean's equilibrium profile. Such adjustment is probably reflected in the stability revealed by the beach in the past decade.

Bernabeu et al. (2002) presented parameterization coefficients for nine locations along the Spanish Coast. In particular, for the Mediterranean Sea, values are given for El Vendrell beach ($a_1 = 0.14$, $a_2 = 0.05$, $a_3 = 0.2$ and $a_4 = 0.01$), which is located slightly north of La Garrofera beach. Our proposed values only differ for a_1 and a_3, which are proportional to the slope of the upper part of the surf and shoaling zones and are related to dissipation processes. By adopting $a_1 = A = 0.111$, the surf profile tends to the Dean profile, and the almost similar reasonable adjustment with $a_3 = 0.13$ suggests sand grain uniformity along with the cross-shore profile. The lower values of a_2 and a_4 suggest that this is a dissipative beach, and the reflection phenomenon is not so relevant.

Yu & Slinn (2003) expression shows an excellent adjustment to the La Garrofera beach profile. Furthermore, since there are no longshore bars, it is seen that their expression can be simplified, depending only on three parameters (β_1, β_2, k).

5 Concluding Remarks

This study analyses how several formulations representing equilibrium beach profiles adjust to the cross-shore profile of La Garrofera beach, located in Valencia (Spain).

The results show that the suggested Dean's equilibrium profile reasonably agrees with the La Garrofera beach cross-shore profile. Interestingly, it is seen that the observed concave curve can be obtained from the simple knowledge of the median grain size present on the beach. This good agreement probably reflects the beach stability observed in the past decade. Both Bernabeu et al.'s and Yu and Slinn's models provide good representations of the cross-shore profile as long the calibration parameters are correctly considered. Furthermore, it is possible to verify that Yu and Slinn's expression can also provide good estimations even if there are no longshore bars.

An understanding of equilibrium profiles is helpful in a few types of coastal engineering projects, helping to propose appropriate nourishment of beaches and other coastal management strategies.

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