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Prediction of berm geometry using a set of laboratory tests combined with teaching–learning-based optimization and artificial bee colony algorithms

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ABSTRACT

Understanding sediment movement in coastal areas is crucial in planning the stability of coastal structures, the recovery of coastal areas, and the formation of new coast. Accretion or erosion profiles form as a result of sediment movement. The characteristics of these profiles depend on the bed slope, wave conditions, and sediment properties. Here, experimental studies were performed in a wave flume with regular waves, considering different values for the wave height (H_0), wave period (T), bed slope (m), and mean sediment diameter (d_{50}). Accretion profiles developed in these experiments, and the geometric parameters of the resulting berms were determined. Teaching–learning-based optimization (TLBO) and artificial bee colony (ABC) algorithms were applied to regression functions of the data from the physical model. Dimensional and dimensionless equations were found for each parameter. These equations were compared to data from the physical model, to determine the best equation for each parameter and to evaluate the performances of the TLBO and ABC algorithms in the estimation of the berm parameters. Compared to the ABC algorithm, the TLBO algorithm provided better accuracy in estimating the berm parameters. Overall, the equations successfully determined the berm parameters.

1. Introduction

Beach profile and sediment transport are highly important factors in the design of coastal structures. Various parameters, such as wave conditions, bed slope, and sediment characteristics, affect the cross-shore sediment transport discharge and, consequently, the beach profile. Transport during beach recovery results in such typical morphological features as intertidal bars and berms. In particular, berms are accretionary features that are attributed to onshore sediment transport during swash. They typically appear as sand or shingle bodies approximately parallel to the shoreline [1]. Berms provide many advantages for beaches. For instance, a wide berm and high dune provide storm protection and damage reduction, recreational and economic benefits, and biological habitats for plants and animals on the beach [2]. Therefore, characterizing the morphological structure and geometry of berms is important in solving some problems related to coastal engineering.

Previous studies on berm formation have been mostly descriptive or qualitative, or have focused on conceptual models of berm formation [1,3–10]. Hine [3] described three mechanisms of berm development in Cape Cod, MA, USA: the neap-berm, ridge-and-runnel, and berm-ridge mechanisms. Jensen et al. [1] conducted field experiments at Vejers, Denmark, to investigate the formation and development of berms on a gently sloping dissipative beach under low-to-moderate wave conditions. The stages of berm development agreed with the three developmental concepts proposed by Hine [3].

Okazaki [4] performed laboratory and field investigations of the relationships among wave breaker type, wave height, grain size, wave type, and berm development. The growth type and height of berms were dependent on the grain size, which greatly influenced the permeability of the beam and, therefore, the potential for the berm to stabilize. Bendixen et al. [5] presented a conceptual model to discuss the processes and formative agents of sandy berm formation, analyzing 33 high-water events. Suzuki and Kuriyama [6] used field data to propose a successful model for qualitatively predicting berm formation and erosion. Greenwood et al. [7] and Austin and Buscombe [8] described the hydrodynamics during berm formation, to define the nearshore sediment transport in the region of the beach step. They performed field studies at Slapton Sands, Devon, UK, over a tidal cycle on a macrotidal gravel beach. Suzuki et al. [9] investigated distributions of cross-shore sediment transport rates for berm formation and erosion. Weir et al. [10] found that berm development is largely dependent on swash and overtopping potential.

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Various researchers have examined the effects of certain factors, including the coastline shape, wave conditions, sediment properties, and tide level, on the formation of berms. Lakhan and Pepper [11] investigated whether there is a distinct relationship between a coastline's configuration (concavity/convexity) and its tendency toward erosion or accretion. Their findings suggested that, overall, convex coasts may have a greater tendency toward accretion than either straight or concave coasts. Kobayashi et al. [2] developed a numerical model to examine the effects of the wave period and incident wave angle on berm and dune erosion. They compared results obtained from the numeric model with those obtained by small-scale experiments. The proposed model predicted the measured berm and dune erosion within errors of a factor of two, but was unable to predict the deposited area accurately. Russell et al. [12] examined berm formation at high tide on sand and gravel beaches. Berms on the sand and gravel beaches accreted to similar heights, but the cross-shore extent and volume of the berm were larger on a sand beach.

Weir et al. [13] examined two different modes of berm development: vertical growth under spring tides, and horizontal progradation under neap tides. They developed a conceptual model for berm morphodynamics, based on the shape of sediment transport functions measured during the two modes of berm growth. Masselink et al. [14] documented the morphological evolution of the berm, beach face, and step region in response to changing tide level and wave conditions. They concluded that accretion and berm formation occur during waves with low steepness and under swell-dominated wave conditions (H/L < 0.01). Sunamura [15] examined sediment diameter-controlled berm formation in laboratory and field studies. Berms formed on profiles composed of coarse sediment (d_{50} > ~0.69 mm), whereas bars formed on finer grained sediment. According to Tanner and Stapor [16], berm development and berm height increase under higher tidal ranges and increasing wave-energy levels.

Berm formation on a sandy beach is closely related to the behavior of bars and associated wave-related processes near the water line. Researchers have extended considerable efforts to determine the bar parameters and the geometric characteristics of the erosion profile [17–29]. Table 1 summarizes the methods and forecasting parameters used in these studies. Previous studies have focused on estimating the bar parameters and the coastal erosion geometry. However, despite the prevalence of berm formation-related studies in the literature, no available study has looked at the prediction of berm parameters.

Different artificial intelligence techniques, such as artificial neural networks and genetic algorithms, have recently been successfully used to solve geophysical problems in ocean and coastal engineering applications [28–33]. These models have been used to study bar parameters [28,29], the temporal rate coefficient of the equilibrium bar volume [30], harbor tranquility [31,32], and ripple geometry [33]. The artificial bee colony (ABC) and teaching–learning-based optimization (TLBO) techniques are recently proposed meta-heuristic methods that are generally used to solve combinatorial optimization problems. The ABC technique has been successfully used to solve such different problems as prediction [34], designing [35], clustering [36], and scheduling [37]. The TLBO technique is a simple and robust algorithm that is superior to other advanced optimization techniques, including particle swarm optimization, ant colony optimization, and differential evaluation [38,39]. It has been tested on multiple constrained and unconstrained benchmark problems in various engineering fields, including electrical [40], civil [41–44], computer [45], manufacturing [46], and thermal engineering [47].

In this paper, experimental data for berm parameters were obtained under various wave conditions (H_0 and T), beach slopes (m), and bed material properties (d_{50}) in a two-dimensional wave channel using a physical model (Fig. 1). The main purpose of this study was to develop dimensional and dimensionless equations by the ABC and TLBO algorithms, for the accurate prediction of berm parameters. Then, the best-fit equations were compared with the experimental results. The results of this comparison are discussed in detail. To the authors' knowledge, this study is the first to use the ABC and TLBO algorithms in coastal engineering, as well as to determine the berm geometric parameters.

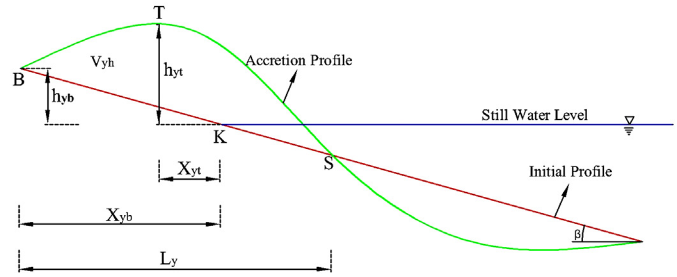

Fig. 1. Investigated berm parameters in accretion profile.

2. Investigated berm parameters

As a result of interactions among the bed topography and the bed material properties, an erosion or accretion beach profile can form [29]. In this study, only berm (accretion zone) parameters in the coastal profile were investigated. These parameters are presented in Fig. 1, in which B, T, and S are the starting, crest, and final points of the berm, respectively; K is the original shoreline; and β is the angle between the initial profile and the horizontal ($\tan\beta = m$). The following berm parameters in the coastal profile were estimated: the horizontal and vertical distances from B to K (X_{yb}, h_{yb}) and from T to K (X_{yt}, h_{yt}), the width of the berm perpendicular to the coast (L_y), and the volume of berm (V_{yh}) [48].

3. Laboratory experiments

The hydrodynamic characteristics of the swash zone are poorly understood compared to those of the surf zone; hence, the formation of berms is still under debate [5,49]. Many studies have discussed what constitutes a berm. While most authors have stated that elevated water levels and high-energy waves during storms are essential for berm formation [50–55], some researchers have argued that berms are commonly formed during nonstorm conditions and are eroded during storm conditions [6,14,56–58]. On the other hand, Bendixen et al. [5] has indicated that berms can be constructed under either fair-weather periods or storm events. Preliminary experiments made in the scope of this study showed that berm formation is larger under nonstorm conditions on sand beaches. Therefore, to investigate the geometric characteristics of berms, fair-weather conditions were considered during the laboratory experiments in this study.

In this context, 31 experiments were performed to investigate the variation of the accretion profile under different scenarios. As shown in Table 2, six wave heights, four bed slopes, two wave periods, and three sand particle sizes were used for the experiments. Table 2 also provides a list of the physical conditions used in the tests.

3.1. Wave flume and measuring method

Experiments were carried out at the Hydraulics Laboratory wave flume at the Civil Engineering Department of Karadeniz Technical University in Trabzon, Turkey. The wave flume is 30 m long, 1.4 m wide, and 1.2 m deep. Thus, there were only considered