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Laboratory experiments on beach change due to nearshore mound placement

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ABSTRACT

Movable-bed large-scale laboratory experiments were conducted to examine the fate and quantify the benefits of nearshore placed dredged material. Two tests were performed on a beach classified as eroding [19] for mounds placed in the active zone described by Hands and Allison [12] at two depths. Mound sand was dyed to provide contrast and to differentiate it from the native sand beach. Beach surveys were performed intermittently during each experiment with a laser scanner. In addition to beach change elevations, the scanner provided RGB color components, which permitted tracking of the mound sand. The experiments showed that the mound sand dispersed rapidly and was transported mainly downdrift. Sand accumulation was observed on the beach onshore and adjacent to the mounds mainly due to wave sheltering of the mounds described as the longshore effect by [28]. There was little contribution to onshore accretion from cross-shore migration of the mounds. Beach response was similar to that of an offshore breakwater in which the mounds provided a wave shadow zone to the leeward beach. The results from the experiment will provide validation data for the numerical morphological model C2SHORE [15].

1. Introduction

The U.S. Army Corps of Engineers (USACE) seeks opportunities for the beneficial use of dredged sediment. Frequently, USACE dredged material management plans include offshore placement of dredged sediment from navigation channels. The dredging operation may often remove sediment with a high sand content from the littoral or regional system. For the nation as a whole, maintenance dredged material from these areas is typically not compatible with adjacent beaches and therefore is not considered beach quality (typically > 88 percent sand, but the percentage varies by region). However, dredged material often includes 60 to 80 percent sand with the remainder being finer sediment.

Strategies for reducing dredging impacts include the nearshore placement of dredged sediment in several meters of water depth, outside of the calm-weather surf zone but within the littoral region. Wind waves, in theory, then act as the agent to winnow the fines from the mound, or berm, and facilitate onshore sand transport to the beach. Bruun [3] described how placement of material of suitable grain size at the proper depth would increase stability and reduce costs when compared to similar material placed as artificial beach nourishment. Additional benefits of sediment placed in shallower water include: decreased nearshore wave energy, conserved capacity of offshore dredged material placement sites, and enriched nearshore beach profiles.

The benefits of preserving the sediment in the littoral system and using the power of waves to winnow fines are attractive. However, nearshore mound locations, material, and configurations must be chosen judiciously to assure that the mound does not negatively impact the surrounding environment and that material remains in the littoral system and nourishes the beach. Sponsors of feeder berm projects want assurance that placed sands will move into and widen the breaker zone. They also are interested in whether placed materials will ever migrate onto the shore.

Several studies have been performed to study nearshore mound placement and response. The earliest attempts to place dredged material offshore with the intent that the material would migrate onshore were made at Santa Barbara, CA, in 1935, Atlantic City, NJ, between 1935 and 1942, and Long Branch, NJ, in 1948 [8]. However, the location and volume of these mounds were unchanged and the placements were considered unsuccessful. Hall and Herron [8] concluded that future mounds should be placed on or landward of the

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offshore bar. Placement at Long Branch was controlled by depth for safe operation of the dredge [13]; therefore, placement at shallower depths could not be achieved by dredges at that time. No nearshore mound studies were attempted in the field for two decades following these unsuccessful attempts [25]. The reported success of studies at Durban Beaches, South Africa [32], Copacabana Beach, Brazil [30] and at Limfjord Barriers, Denmark [24], along with expanded abilities to precisely place material closer to shore with shallow-draft split-hull dredges led to further nearshore field tests in the United States [12]. Several field and laboratory nearshore mound studies have followed, many of which are reported in Otay [25] and Van Rijn and Walstra [29]. Various predictive methods to determine berm mobility were developed from these studies [12,18,20,22,5].

Many nearshore mound, or berm, placement design studies have referred to the work of Hallermeier [10,9] to determine the location for mound placement. Hallermeier defined a seaward limit of the active littoral zone where significant net transport occurs. Offshore of the seaward limit, mounds do not evolve and have little effect on wave energy. Hands and Allison [12] evaluated 11 US berm placement sites and developed a stability graph based on sand characteristics, wave climate, and Hallermeier's findings to determine depths at which berm placement would be stable or active. The stability graph illustrated the stability of berms based on their depth and whether this depth is shallower or deeper in relation to the inner and outer depth of closure limits defined by Hallermeier [9,10]. The graph indicates that, relative to wave local wave climate, berms placed in shallower depths were active, or migratory, and berms placed in deeper water were stable, or non-migratory. McLellan [21], based on findings of Zwamborn et al. [32], Frisch [6] and Gunyakti [7], recommended that the berm must be considered an engineered structure, requiring a design template, and constructed as a linear feature rather than conical, to avoid wave focusing in the lee of the berm. McLellan and Kraus [22] classified berms placed within the active littoral zone as feeder or stable berms. Feeder berms are placed linear and shore-parallel in sufficiently shallow water with sufficiently high-relief. Feeder berms transport sediment shoreward and reduce wave energy under accretionary conditions and provide an indirect benefit by reducing the erosional demand of storms for sediment to be moved offshore. A stable berm is intended to be a relatively permanent bottom feature that attenuates higher waves. Additionally, [22] suggested criteria for mound placement including timing of placement, depth and length of berm, location of placement, and sediment grain size.

Our present knowledge is not adequate to justify the many ways a nearshore mound may be beneficial to local and regional stakeholders [31]. One of the difficulties in designing berm placement is sparse data on completed nearshore berms. At present, the USACE doesn’t require monitoring of completed nearshore berm placement, although monitoring is required by many states or sponsors [1]. Beck et al. state that broader monitoring performed at least annually is required to gain a better understanding of the nearshore berm placement benefits. Optimal placement and the mechanism of onshore sand migration are still largely unknown.

Improved predictive methods for nearshore mound design require an understanding of the processes that influence morphological changes due to nearshore mound placement. Van Duin et al. [28] present two hypotheses on morphologic changes due to properly designed feeder berms. The first hypothesis is defined by Van Duin et al. [28] as the longshore effect, and can be describe as a sheltering effect, in which higher waves breaking at the berm causes a calmer wave climate directly in the berm's lee, reducing the longshore current and transport capacity. The result is a decrease of longshore transport in the lee of the berm, accretion updrift of the berm, and erosion downdrift of the berm. The second hypothesis is the cross-shore effect, which occurs as higher waves break on the seaward side of the nourishment. The remaining shoaling waves generate onshore transport due to wave asymmetry and smaller waves generate less stirring of the sediment and wave-induced return flow, resulting in more onshore transport and less offshore transport. These hypotheses were confirmed by Van Duin et al. [28] through processed-based modeling of a nearshore berm at Egmond aan Zee, The Netherlands.

The objective of this study is to quantify beach change due to nearshore placed mounds, including the fate of the mound material, through the conduct of laboratory experiments. In particular, a goal was to determine if the mound sand stayed within the littoral system. The USACE District, Buffalo, and the USACE Engineer and Research Development Center's Coastal and Hydraulics Laboratory performed movable-bed physical model experiments to provide data for evaluating the fate of mounds placed in the nearshore. Additionally, the laboratory results will provide validation data for the numerical morphological model C2SHORE [15]. This paper describes tests with nearshore mounds placed at two locations in the active littoral zone as calculated by Hands and Allison [12] and classified as feeder berms [22]. Each mound was subjected to waves in a three-dimensional basin, and the resulting bathymetry was measured with detailed surveys to determine the benefits of nearshore placed sand to nourishing the shoreline. Additionally, the sand placed in the mounds was dyed, which provided contrast to the native beach. This enabled tracking of the mound sand to distinguish morphological changes with regard to cross-shore and longshore effects as described by Van Duin et al. [28].

2. The physical model

Experiments were performed in the Large-scale Sediment Transport Facility (LSTF), a basin that reproduces surf zone processes on natural beaches. The LSTF is a 30-m wide, 50-m long, 1.4-m deep basin, which included a 27 m (alongshore) by 18 m (cross shore) sand beach. The beach was composed of fine quartz sand having a median grain diameter, d_{50}, of 0.15 mm. Waves were produced by four synchronized unidirectional wave generators oriented at a 10° angle to the shoreline. To minimize adverse laboratory effects created by the boundaries of the finite-length beach, wave-driven currents were supplemented by an external recirculation system that consisted of 20 independent vertical turbine pumps placed in the cross-shore direction at the downdrift boundary. In the absence of an external recirculation system, the wave-driven currents would develop a gyre within the facility which could distort test results. The longshore current distribution was based on wave-driven currents on a long straight beach and the currents are fixed at the updrift and downdrift boundaries. This assumes the wave-induced current distribution returns to that of a long, straight beach at the downdrift boundary, regardless of the perturbation in current distribution that occurs on the beach. A plan view of the LSTF is shown in Fig. 1, along with locations of the two mound placements. More information of the LSTF features and capabilities can be found in Hamilton et al. [11].

High-resolution beach surveys were obtained with a 3D scanning laser with a camera attachment, which has a horizontal and vertical accuracy of 0.3 mm for the LSTF. The scanner produced bathymetric data as a point cloud between alongshore locations Y14 and Y36 (Fig. 1). The data were interpolated to a grid with cross-shore spacing of 0.005 m and longshore spacing of 0.2 m, which allowed direct bathymetric comparisons between surveys. Use of the laser scanner required a dry profile; therefore it was necessary to lower the water to a level that exposed the portion of the beach to survey. It was essential to lower water slowly, ~8 cm/hr, to allow drainage through percolation and prevent erosion of the sand bed from draining water. As a result of the time required for draining and refilling, only one test segment could be performed per day.

In addition to location and elevations, the laser scanner included an image scanner, which attached red, green, and blue (RGB) color components to each elevation data point. The sand in the mound was dyed, which provided good contrast with the light-colored natural sand, and the contrast could be distinguished in the survey data. Therefore,