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Morphological evolution of a submerged artificial nearshore berm along a low-wave microtidal coast, Fort Myers Beach, west-central Florida, USA

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ABSTRACT

Nourishment in the nearshore is becoming an increasingly utilized method for regional sediment management, particularly for dredged material that contains more fine sediment than the native beach. A nearshore berm was constructed at Fort Myers Beach, Florida, USA using mixed-sized sediment dredged from a nearby channel. The nearshore berm, which is the shallowest of its kind, was placed in water depths between 1.2 and 2.4 m with the berm crest just below the mean lower low water level. Based on time-series profiles surveyed from 2009 to 2013, the nearshore berm migrated onshore while the system was approaching a dynamic equilibrium. The distant passage of two tropical storms in the third year generated exceptionally high waves for the study area. Substantial profile change induced by the energetic conditions contributed to rapid evolution of the berm profiles toward equilibrium. Near the end of the fourth year, the berm profiles had returned to the equilibrium shape characteristic of the study area. Gaps in the berm allowed water circulation when the berm became emergent and watercraft access to the beach for recreational purposes. Gaps should be considered as a design parameter for future berm nourishments. Sediment samples collected and analyzed showed that the fine sediment content in the original placed material was selectively transported and deposited offshore, while the coarser component moved onshore. The dry beach maintained the same sediment properties throughout the study period and was not influenced by the fine sediment in the initial construction of the berm.

1. Introduction

Maintenance dredging of navigation channels along the coast is often conducted to sustain safe navigable depths. It is beneficial to reintroduce the clean dredged material into the littoral system as part of regional sediment management practices either in the form of subaerial beach nourishment or a submerged nearshore berm (Dean and Dalrymple, 2002). Nearshore berms are at times the preferred method of placement due to the potential lower cost of construction, fewer environmental restrictions, such as sea turtle and shore bird nesting, and more lenient requirements on grain size compatibility. For example, the State of Florida allows $<20\%$ fine sediment for nearshore berm placement rather than $<10\%$ for beach placement when using dredged material from navigation projects. Fine sediment is defined as less than 0.063 mm or as mud according to the Wentworth Scale (Wentworth, 1922) for grain size classification. Benefits of a nearshore berm can also include wave dissipation for erosion mitigation, nourishment of the beach through onshore migration, potential fish habitat, and additional retention of sediment to the littoral system (McLellan and Kraus, 1991). However, key factors involved in berm evolution are not well understood including forcing processes, temporal and spatial scales of cross-shore and alongshore movement and how sediment within the berm will redistribute based on grain size.

The concept of a nearshore berm was first realized in the mid-1930s when dredged material was placed offshore of Santa Barbara, California in hopes that the sediment would nourish the downdrift beaches (Otay, 1994). However, this berm was considered to be unsuccessful due to the fact that location and volume were unchanged for several years following placement (Hall and Herron, 1950). After two more placements in Atlantic City and Long Beach, New Jersey in 1942 and 1948, respectively (Hall and Herron, 1950), were also considered unsuccessful, nearshore berms were no longer considered a favorable option for the use of dredged material for several decades (Otay, 1994).

A series of studies on nearshore berm design and placement were conducted in the 1980s and 1990s (Beck et al., 2012). Many were conducted as part of the U.S. Army Corps of Engineers' Dredging Research Program (e.g. Allison and Pollock, 1993; Hands and Allison, 1991; Hands and Bradley, 1990; Hands and Deloach, 1984; McLellan, 1990; McLellan and Kraus, 1991; Scheffner, 1991). As a result, several predictive models of berm mobility were developed to provide

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qualitative planning level guidance (e.g. Douglass, 1995; Hands and Allison, 1991; Hwung et al., 2010; Larson and Kraus, 1992). A general conclusion was reached that detailed field studies are important in understanding the dynamics of cross-shore and alongshore berm migration and the associated temporal and spatial scales for berm profile evolution.

Nearshore berms can be designed to be either active or stable depending on their intended use. As defined by McLellan and Kraus (1991) and Hands and Allison (1991), active or feeder berms move within the first few weeks or months of placement, although the spatio-temporal extent of movement to be considered active was not defined, while stable berms retain their volume and remain in the same location for years. Whether the berm is active or stable depends largely on the hydrodynamic conditions, depth at which the berm is placed, grain size distribution of sediment, and design specifications of the berm (i.e. the height, length, width, and side slopes). Hallermeier's (1981) inner and outer depths of closure were used by Hands and Allison (1991) to determine the depth at which the berm should be placed in order to be active or stable.

Various studies on nearshore berms have been conducted worldwide (Otay, 1994). Two berms were placed and studied in the Netherlands: the Egmond aan Zee berm (van Duin et al., 2004) and the Terschelling berm (Kroon et al., 1994). Both study areas' nearshore profile exhibited a characteristic two-bar morphology. At Terschelling, the berm was placed in the trough between the two bars, while at Egmond aan Zee, the berm was placed seaward of the outer bar. Regardless of placement location, in both cases the profile eventually returned to its natural two-bar morphology after several years. It was also noted that during high wave energy events, the berms behaved similarly to submerged breakwaters by dissipating wave energy at the shoreline and were correlated to shoreline accretion on the leeward side of the berm. Andrassy (1991) and Juhnke et al. (1990) studied a nearshore berm placed at Silver Strand State Park in San Diego, California. This berm was placed shallower than the depth of closure, and was active, as expected. The berm moved onshore, and in addition to providing protection to the shoreline, an accumulation of sediment occurred within and above the intertidal zone. Based on a review of 27 artificial berms by Wang et al. (2013) and Brutsché (2011), the Silver Strand berm was the only case with significant subaerial beach accumulation. Browder and Dean (2000) studied a large nearshore placement in Perdido Key, Florida. Although the Hands and Allison (1991) model would predict this berm to be active, in contrast to the previously mentioned berms, the Perdido Key berm remained stable for the 8 years of the study period.

The study discussed herein concerns a nearshore berm that was constructed at Fort Myers Beach, located in west-central Florida, in October 2009 as part of maintenance dredging of the navigation channel at Matanzas Pass and the north tip of Estero Island. The Fort Myers Beach nearshore berm was placed closer to the shoreline and in shallower water than all of the nearshore placements discussed previously, and therefore provided a unique opportunity to study coastal morphodynamics, as the constructed berm represented an “out of equilibrium” morphological feature similar to a nearshore bar.

This study is based on 57 beach profile transects established by the University of South Florida Coastal Research Lab (USF-CRL), and 32 beach profile transects established by the U.S. Army Corps of Engineers (USACE) within the study area. The profiles were surveyed 10 times approximately semi-annually within the four year study period. Sediment samples were collected twice during the study period to document change in sediment characteristics at the study area. This study documents the morphodynamic evolution of the nearshore berm and its equilibration process and associated temporal scale. The trend of selective sediment transport, specifically whether the fine sediment within the dredged material was transported and deposited on the beach or offshore, was analyzed.

2. Study area

Fort Myers Beach is located on Estero Island, a low lying extensively developed barrier island, in west-central Florida, USA. Estero Island is bordered by San Carlos Bay to the north, and Big Carlos Bay to the south. Matanzas Pass, a federally maintained channel located at the north end of the island, is often used for recreation and fishing, and provides passage to the United States Coast Guard station (Fig. 1). The channel was initially constructed in 1961, and has been dredged in 1986, 1998, and 2001. The material dredged in 2001 was used for beach nourishment, however, sediment dredged from the pass is no longer permitted to be placed on the subaerial beach due to the State of Florida's restrictions on the percentage of fine sediment in borrow material.

The morphology of west-central Florida barrier islands is dominantly influenced by the passages of cold fronts approximately every 10 to 14 days between October and April (Beck and Wang, 2009; Wang and Beck, 2012; Wang et al., 2011). During the summer months, wave conditions are mostly calm, with the exception of the (close or distant) passage of tropical systems. When not affected by cold front or tropical system passages, nearshore waves in the study area are typically low (0.1 to 0.3 m), and generated by local winds. During the study period, onshore directed wind (from 130 to 310°) occurred approximately 36% of the time with an average speed of 4 m/s. On average, the strongest and most frequent onshore winds originated from the south-southwest and west. The study area is influenced by a mixed tide regime. Spring tides tend to be diurnal with a range of approximately 1.2 m, while neap tides are semi-diurnal with a tidal range of roughly 0.75 m.

There are no existing wave measurement buoys near the study area. Wave information for the study period was obtained using the nearest National Oceanic and Atmospheric Administration's WAVEWATCH III (NOAA WWIII) hindcast station located 7 km offshore in 8 m water depth to provide general wave information. The average significant onshore wave height, Hs, during the study period was 0.16 m, and average peak wave period, Tp, was 4.4 s. Waves tend to be higher during the winter season than during the summer season. Distant passages of two tropical systems affected the study area within a 2-month time during the third year post berm construction: Tropical Storm Debby (June 2012) and Hurricane Isaac (August 2012). Tropical Storm Debby moved very slowly, affecting the study area for approximately four days, while Hurricane Isaac affected the study area for two days. Tropical Storm Debby had a peak significant wave height of 1.75 m (or 10 times the average) and peak period of 8 s, while Isaac produced waves with a peak height and period of 1.3 m and 8.2 s, respectively.

Direction of net longshore sediment transport varies along the study area. The morphological trend of growth at the northern end of the island suggests a local northward longshore transport. A USACE (1969) report determined that the north end of Estero Island, which is defined as 3 km south of Matanzas Pass (or approximately the middle of the nearshore berm placement area; Fig. 1), experiences longshore sediment transport to the north at a rate estimated to be 17,000 m^3/year. The south end of the island exhibits southward longshore sediment transport, consistent with the west-central Florida regional trend (Walton, 1973), at a rate of approximately 50,000 m^3/year (USACE, 1969). Another USACE (2001) report states that the longshore transport rate varies along Estero Island from 0 to 53,000 m^3/year, citing Walton (1973) as evidence for the maximum value. Poff and Stephen (1998) estimated that the maximum longshore transport rate for the island is 22,000 m^3/year. The protrusion of Sanibel Island blocking waves from the north and northwest creates the longshore sediment transport reversal along the northern portion of the island (Balsillie and Clark, 1992; USACE, 1969, 2001).

Construction of the berm was broken into four stages (Brutsché and Wang, 2012; Wang et al., 2013). Placement of the material began at the northwest end of the project area and moved to the southeast.