Ocean & Coastal Management 105 (2015) 35–47

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Geometric properties of anthropogenic flood control berms on southern California beaches

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ARTICLE INFO

Article history:
Received 11 June 2014
Received in revised form
4 December 2014
Accepted 10 December 2014
Available online

Keywords:
Anthropogenic dune
Artificial sand dune
Sacrificial dune
Beach erosion
Beach scraping
Coastal management
Dune management
Flood mitigation
LiDAR
Sand embankment
Winter dune

ABSTRACT

Coastal flood risk from coincident high tides and energetic waves is concentrated around low-lying urban areas. Municipalities construct temporary sand berms (also known as sacrificial dunes) to manage potential flooding, however the relationships between berm geometry (e.g., height, width and length) and performance are not understood. Concomitant pressures of sea level rise and urbanization will increase active beach berming. Effective future coastal flood risk management will depend upon optimizing berm efficacy relative to geometry, placement, and water levels. Here, 34 individual berms at seven southern California locations are characterized using 18 LiDAR datasets spanning nearly a decade. Three berm classifications emerged based on deployment duration: event, seasonal and persistent. Event berms, deployed to manage specific storms or high water events, are triangular in cross-section, relatively low volume (~4 m^3/m) and low crest elevation (~5 m NAVD88). Seasonal berms are larger, volumes vary from 6 to 28 m^3/m, and average crest elevations are between 5.3 and 6.4 m. A persistent berm, captured in all LiDAR data for that area, is the largest (48 m^3/m), longest (1.2 km), and highest mean crest elevation (7 m NAVD88) of all study berms. Total water levels, estimated using observed tides and a regional wave model coupled with an empirical runup formula, suggest that overtopping is rare. Currently, event berms are vulnerable to wave attack only a few hours per year. However, even with modest sea level rise (~25 cm) or El Niño conditions, exposure increases significantly, and substantial nourishments may be required to maintain current flood protection levels.

1. Introduction

Urban coastal flooding is a global humanitarian and socioeconomic hazard. Over 20 million people reside below present day high tide levels, and 200 million are vulnerable to storm flooding (Nicholls, 2011). Sea level rise will substantially increase risks to human life and infrastructure (e.g., Hanson et al., 2011). In the context of coastal risk management, three prevailing options for addressing present and future flooding are to protect, accommodate or retreat (Linham and Nicholls, 2012). Although new development may be built to accommodate high water conditions, economically valuable legacy structures require protection. Hard armoring can increase passive erosion, damage ecosystems and limit recreation (e.g., Airoldi et al., 2005; Martin et al., 2005; Pendleton et al., 2012). Soft protection such as beach nourishment or artificial dune construction (e.g. Flick, 1993; Rogers et al., 2010; Cooke et al., 2012; Cooper and Lemckert, 2012; Pendleton et al., 2012) may be preferred in locations where beaches are central to culture and economy.

Extensive research efforts have considered the protective effects of beach nourishments (e.g., National Research Council, 1995; Dean, 2001; Hanson et al., 2002) and coastal dunes (e.g., van Rijn, 2009; Bochev et al., 2011; El Mrini et al., 2012; Hanley et al., 2014). van Rijn (2011) assessed the effectiveness of hard and soft erosion management practices on sandy beaches using a mix of numerical modeling, laboratory and field data. Matias et al. (2005) studied dune nourishment along an eroded barrier island and concluded that augmented natural dunes successfully mitigated overwash events. Sallenger (2000) developed a storm impact scale to assess dune vulnerability and Judge et al. (2003) proposed survival and failure indication parameters. Dune erosion modeling has received significant and sustained attention (e.g., Edelman, 1968, 1972; van de Graff, 1977; Vellinga, 1982; Fisher and Overton, 1985; Kriebel

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http://dx.doi.org/10.1016/j.ocecoaman.2014.12.014
0964-5691/

and Dean, 1985; Kobayashi, 1987; Kriebel, 1991; Overton et al., 1994; Sallenger, 2000; Erikson et al., 2007; Roelvink et al., 2009). Edelman (1968, 1972), Kobayashi (1987); Kriebel (1991) and Larson et al. (2004) developed simple analytical dune erosion models. Larson and Kraus (1989) presented SBEACH, an empirically based numerical model and Roelvink et al. (2009) developed a two dimensional flow and sediment transport model, XBeach, for predicting cross-shore beach evolution. Collectively, this work shows the beach-dune system's coastal protection utility. However, these studies do not examine artificial dunes constructed specifically to mitigate imminent coastal flooding hazards.

Beach berming, also known as beach scraping, bumping, reprofiling, and nature assisted beach enhancement (NABE), is the mechanical transfer of a thin layer of sand from the lower beach foreshore to the beach crest (Bruun, 1983) that originated primarily as an erosion control method (e.g., Bruun, 1983; Tye, 1983; Wells and McNinch, 1991; McNinch and Wells, 1992). In contrast to permanent dike structures found in continuously vulnerable regions such as the Netherlands, these berms are often sacrificial, intended only to deflect specific high water or energetic wave events. Temporary berming is a widely used coastal management strategy along the US coasts (e.g., Wells and McNinch, 1991; Clark, 2005; Kratzmann and Hapke, 2012), Australia (Carley et al., 2010) and Europe (e.g., Rogers et al., 2010; Harley and Ciavola, 2013). Kana and Svetlichny (1982) monitored a 14 km berming project along the US East Coast and found that beach berming provided relatively limited erosion protection. Froede (2010) concluded that although berms constructed on a barrier-spit island eroded in 15–27 months, they are integral to residential development protection. Recently beach berming has been used to mitigate flood risk (e.g., Harley and Ciavola, 2013). In California, Edge et al. (2003) recognized the importance of beach berms for seasonal coastal protection and Schubert et al. (in press) studied prototype flood control berm failures. Extensive studies of artificial dunes in Fire Island, New York (Kratzmann and Hapke, 2012) and Florida (Magliocca et al., 2011) focused on the morphodynamic consequences on adjacent beaches rather than on the berms themselves. Hanley et al. (2014) considered the effects of winter dune construction on macro-invertebrate population at heavily managed beaches along the Adriatic Coast, but did not geometrically characterize the temporary dunes. Finally, Harley and Ciavola (2013) recognized the importance of artificial dunes protecting flood prone stretches of the Emilia-Romanga coast in Northern Italy and proposed a design tool, DuneMaker, to integrate berm geometries into a hydro-morphological model. Clearly, beach berms play an important role in proactive coastal flood management. Near term sea level rise mitigation and adaptation strategies will increase berming activities, however fundamental berm design and performance data is absent in the literature. Understanding berm efficacy is crucial to optimal future beach management.

Laser scanning, also known as LiDAR has been widely used to characterize both urban infrastructure and beach sand levels (e.g., Brock et al., 2002; Sallenger et al., 2003; Sanders, 2007; Fewtrell et al., 2011; Gallien et al., 2011). Pietro et al. (2008) and Gares et al. (2006) monitored beach nourishment using LiDAR whereas Feagin et al. (2014) monitored dune volume change. Stockdon et al. (2002) used LiDAR to estimate shoreline change and extract dune crest elevations while Kratzmann and Hapke (2012) studied morphological consequences from berm building. In California, LiDAR has been used to estimate levee stability (Casas et al., 2012), cliff erosion (e.g., Young and Ashford, 2006; Young et al., 2011) and seasonal sand level changes (Yates et al., 2009). Here, a decade of southern California coastal LiDAR is used to locate and quantitatively characterize anthropogenic flood control berms ranging from small ad-hoc event specific berms (Fig. 1a,b,d) built in hours or days before a storm event, annual seasonal berms (Fig. 1c) to large sand

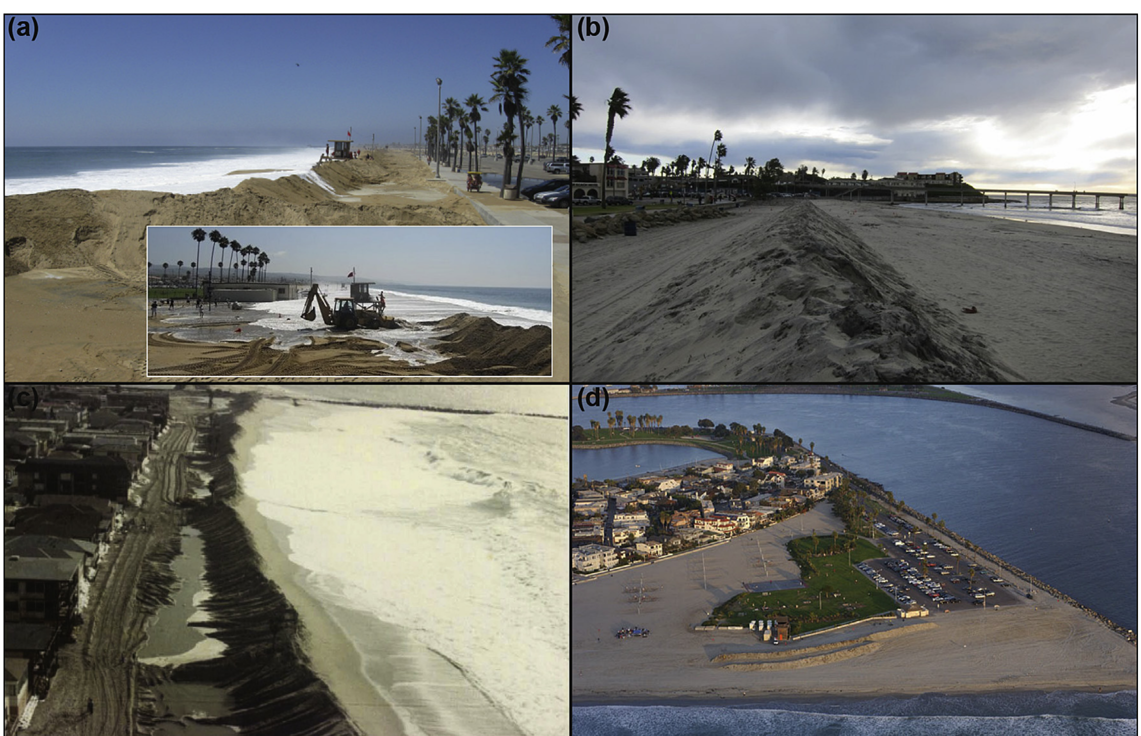

Fig. 1. Examples of anthropogenic beach berms at (a) Balboa Beach August, 2011, inset photo shows end flow around the berm edge (b) Ocean Beach December, 2011 (photo used with permission, George Fatell) (c) Seal Beach, 1983 (McMahon, 2009) and (d) Mission Beach, October 2006, photo used with permission, ©2002–2013 Kenneth and Gabrielle Adelman, California Coastal Records Project www.Californiacoastline.org.