Coastal Engineering 112 (2016) 69–86

Contents lists available at ScienceDirect

Coastal Engineering

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

A morphological modeling study to compare different methods of wave climate schematization and evaluate strategies to reduce erosion losses from a beach nourishment project

L. Benedet [a,b,*], J.P.F. Dobrochinski [b], D.J.R. Walstra [a,c], A.H.F. Klein [e], R. Ranasinghe [d,f,g]

[a] Delft University of Technology, Faculty of Civil Engineering and Geosciences, Hydraulic Engineering Section, P.O. Box 5048, 2600 GA Delft, The Netherlands
[b] CB&I Brasil Coastal Ports & Marine Group, Rod. José Carlos Daux, 8600 Sala 102, Bloco 3, Florianópolis, SC 88050-000, Brazil
[c] Deltares, Unit Marine and Coastal Systems, Applied Morphology Department, PO Box 177, 2600 MH Delft, The Netherlands
[d] Deltares, Harbour, Coastal and Offshore Engineering, PO Box 177, 2600 MH Delft, The Netherlands
[e] UFSC — Universidade Federal de Santa Catarina, Laboratório de Oceanografia Costeira, Campus Universitário Trindade, Florianópolis, SC 88040-900, Brazil
[f] UNESCO–IHE, PO Box 3015, 2601 DA Delft, The Netherlands
[g] Research School of Earth Sciences, The Australian National University, Canberra, ACT 0200, Australia

ARTICLE INFO

Article history:
Received 9 June 2015
Received in revised form 4 January 2016
Accepted 26 February 2016
Available online 3 April 2016

Keywords:
Beach nourishment
Morphological modeling
Input reduction
Wave climate schematization
Delft3D

ABSTRACT

Beach nourishment on open ocean beaches not bounded by headlands or other structures suffers from high rates of lateral losses of fill volume as the nourished shoreline equilibrates with its surroundings. Estimates of lateral losses are essential for beach nourishment design, these predictions have been made in the last decade utilizing empirical formulations, one line models or lately, process-based coastal morphology models. Coastal morphology models are, however, complex and computationally intensive and in order to maintain a balance between model complexities, computational effort and processing capacity, schematization of model input (input reduction) is necessary. This paper is divided into two main sections. In the first section techniques of wave input reduction for morphological models are evaluated with focus on open ocean wave-dominated coasts. Subsequently, the optimized morphological model is applied to evaluate coastal engineering interventions aimed at reducing volume losses from the Delray Beach nourishment project. Wave input reduction is defined here as the process of reducing the full wave climate of a given coastal region to a set of representative wave-wind conditions, 'running' a model with these representative wave conditions in sequence for a smaller time period (*i.e.* a few tide cycles) and multiplying its effect on the morphology by a *Morfac* value, that is related to the frequency of occurrence of that wave condition in nature, or its weight in the overall wave climate. Five different techniques of wave input reduction were tested. Of all the methods of wave climate schematization tested the methods defined as 'Energy Flux Method' and 'Opti Method' showed best results in terms of representing accurately the sediment transport patterns of the study area. The tests conducted indicate that a number around 12 representative wave cases was enough to represent an annual wave climate compared to a very detailed wave climate used as benchmark. The optimized model was used to evaluate alternative engineering solutions to reduce volumetric losses from the beach nourishment project. Engineering solutions evaluated included a construction of a breakwater field, backfilling all dredge pits located offshore of the project site, construction of a groin field at the downdrift end of the project, and backfilling the deepest dredge pit. These engineering interventions caused a reduction in beach volume losses within the project limits with varying levels of effect on the downdrift beaches. Reduction of the volume loss from the project site is technically feasible and may be economically feasible pending further economic feasibility evaluation.

1. Introduction

Beach nourishment is the preferred method of coastal protection in the U.S. mainly because it preserves the aesthetic and recreational values of protected beaches by replicating the protective characteristics of natural beach and dune systems. The U.S. has more than 200 nourished areas and since the 1920s has placed more than half a billion cubic meters of sediments on its beaches (Campbell and Benedet, 2004).

Beach nourishment projects on open ocean beaches not bounded by headlands or other structures suffer from high rates of lateral losses of fill volume as the nourished shoreline equilibrates with its surroundings (*i.e.* Dean and Yoo, 1992). In order to reduce volumetric losses, thus

* Corresponding author at: CB&I Brasil Coastal Ports & Marine Group, Rod. José Carlos Daux, 8600 Sala 102, Bloco 3, Florianópolis, SC 88050-000, Brazil. Tel.: +55 48 3298 0900, +55 48 9616 2190(cell); fax: +55 48 3298 0900x232.
E-mail addresses: lindino.benedet@cbi.com, lindino.benedet@gmail.com (L. Benedet).

http://dx.doi.org/10.1016/j.coastaleng.2016.02.005
0378-3839/

increasing the interval of subsequent nourishments and reducing beach nourishment costs, engineering solutions can be designed and implemented. These engineering solutions can be classified in two macro-categories: (1) interventions to the incoming wave climate such as modifications to the offshore bathymetry or breakwaters aimed at reducing alongshore transport rates or (2) introduction of physical barriers to alongshore sediment transport such as groins.

Engineering interventions to reduce fill lateral losses, however, may impact downdrift shorelines therefore there is a fine balance between the amount of sand retention desired and the occurrence of downdrift erosional impacts. In the past such fine balance has been sought by analytical solutions such as Dean and Yoo (1992), 1D line models (Hanson and Kraus, 1989) or trial and error (*i.e.* construction of temporary structures and annual monitoring). In this work this fine balance between sand retention and downdrift impacts is evaluated utilizing a process-based morphological model. Initially, in order to simulate the beach nourishment behavior and the effects of engineering interventions efficiently, a detailed analysis of wave climate schematization methods is conducted. Subsequently, the model setup that exhibited best agreement against a benchmark is utilized to evaluate coastal engineering interventions aimed at reducing volume losses from the Delray Beach nourishment project.

Numerical models of coastal morphology simulate a range of coastal processes (*i.e.* wave generation and transformation, coastal circulation, sediment transport) and use the principle of conservation of mass to calculate coastal morphology changes. In these models, specific input forcing such as water elevation, discharge and wave conditions are prescribed at the boundaries in order to simulate the above mentioned processes over the model domain. Specific input reduction techniques were developed over the last few years to enabled simulations of morphological evolution of coasts over timescales of years to decades efficiently (Roelvink and Reniers, 2012, Lesser, 2009, Brown and Davies, 2009, Walstra et al., 2013).

The computational effort required by morphological simulations of time periods greater than 1 yr and the amount of information generated by these models are much larger than traditional hydrodynamic models. This is due mostly to the number of additional processes involved in morphological simulations and the numerical grid resolution needed to resolve processes such as surf-zone sediment transport and interactions between morphological change and coastal structures. Furthermore, as computational power evolves, model complexities also increase, so that computational time remains about constant. Coastal morphology models, for example, are getting increasingly more complex with the use of full baroclinic 3D models with 10 to 30 vertical computational layers, multiple sediment fractions (horizontally and vertically), interaction between physical and ecological processes and more sophisticated model formulations. In order to maintain a balance between model complexities, computational effort and processing capacity, schematization of model inputs (input reduction) is necessary.

Techniques of wave input reduction for morphological models are evaluated in detail in this work in order to develop an efficient morphological model of the study area, an open ocean wave-dominated coasts. Even though the overall principle is similar, the techniques used to reduce the full range of wave conditions to a set of representative conditions can vary greatly, so can the number of representative conditions selected, the total ‘weight’ applied to each wave condition and the chronology of wave events. All of these variables have direct implications to the quality of model results. In this paper six different techniques of wave input reduction are tested using Delray Beach, situated in SE Florida, as a case study. These techniques are compared against each other and against a benchmark in order to evaluate the accuracy of each technique and to provide recommendations for coastal morphological modeling studies in wave-dominated coasts.

The numerical model setup with a wave climate that showed the best fit against the benchmark is used to investigate coastal engineering interventions designed to reduce sand volume loss from the Delray Beach nourishment project. Alternatives evaluated include removing all the offshore dredge pits by sediment re-filling, re-filling the deepest dredge pits identified as the main causes for the erosional hot spot by Benedet et al. (2013) at the south end of the nourishment project, adding a breakwater field consisting of three breakwaters at the south end of the nourishment project and lastly adding a groin field consisting of three groins at the nourishment's downdrift (south) end.

2. Study area

The study area, Delray Beach, is located in the southeast coast of Florida, USA. The continental shelf in front of Delray Beach is relatively short and steep. Depths up to 200 m are found in a distance of just 9 km from the coast. The coastline is straight and aligned in the N–S direction. Coastal morphology changes at Delray Beach are controlled by natural and man-induced bathymetry anomalies located offshore (Benedet et al., 2007, 2006; Benedet and List, 2008; Hartog et al., 2008) (Fig. 1). The beach contains beach survey stations at approximately every 300 m which are surveyed annually. These survey stations are normally known as beach profile monuments, and are labeled as ‘R’ monuments, after the former Florida Department of Natural Resources (now FDEP, or Florida Department of Environmental Protection). The study area described in this paper extends from R178 to R190, with focus on the area between R180 and R188, the limits of beach fill placement.

The beach was initially nourished in July 1973 with the placement of 1,250,000 m^3 of sand. It was subsequently fully renourished with volumes ranging from 800,000 m^3 to 1,000,000 m^3 in 1978, 1984, 1992, 2002 and 2013. There was also a smaller nourishment (250,000 m^3) to respond to episodic hurricane-driven erosion in 2005. The nourishment project of 2002 was executed just before the acquisition of the bathymetry data used in this work. In the 2002 project about 940,000 m^3 of sand was deposited in a length of 3000 m of beach, or 313 m^3 per linear meter of beach. This sand was placed between the monuments R180 and R188 (see Fig. 1 for monument locations). A smaller emergency restoration project that used about 191,000 m^3 of sand was constructed in early 2005 to mitigate for sediment losses caused by two hurricanes that affected the project area in September and October of 2004 (H. Frances and H. Jeanne). The last beach renourishment occurred in 2013 where 813,000 m^3 of sand was placed along 3500 m of beach.

Previous studies indicate that volume changes at Delray Beach varies greatly in the alongshore direction (*i.e.* Benedet et al., 2007). The beach width in R178 (just north of the beach fill project) is relatively stable and wide, the beach extension between R184 and R185 is classified as a cold spot (a stable or accretion zone) and there are trends of erosion both in north and south sides of this cold spot. In the region between R186 and R187 the erosional trend is more pronounced, being considered a prominent hot spot of erosion. This zone extends for approximately 600 m alongshore. About 50% of total erosion losses from the project area occur within this erosional hot spot (Benedet et al., 2007).

3. Numerical model setup

A process based numerical model of coastal morphology developed by Deltares in close cooperation with Delft University of Technology (Delft, The Netherlands), is used in this study (WL Delft Hydraulics, 2007a, 2007b, 2005c; Lesser et al., 2004), the model is commonly known as Delft3D.

The Delft3D model is a process-based model containing a detailed description of relevant processes such as waves, tide, currents and sediment transport and the interaction with each other. This interaction may cause a varying flow field and bed level changes. The Delft3D-online module performs the hydrodynamic computations and simultaneously (“online”) calculates waves, transport of sediments and updates the bathymetry.