NUMERICAL STUDY ON THE RESPONSE OF SHORELINE CHANGE TO THE TIDAL CHANNEL AFTER A BEACH NOURISHMENT PROJECT ON AN EMBAYED BEACH

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ABSTRACT: Beach erosion is a severe problem worldwide and beach nourishment is widely regarded today as an environmentally acceptable method to protect and enlarge beaches. In many beach nourishment projects on headland-bay beaches, artificial headlands were constructed on the natural headlands to form an embayed beach in static equilibrium to protect the beach more effectively. However, the construction of artificial headland would weaken the water exchange in the bay and make the water quality easy to deteriorate. In a beach nourishment project in Qinhuangdao, China to dispose this discrepancy an engineering measure was conducted: to reserve a tidal channel between the artificial headland and the natural headland to allow the tidal current to pass. In this paper, a shoreline change model was set up based on GENESIS model to evaluate the influence of the reserve of the tidal channel on the shoreline change after the project. The model was verified by reproducing the post-project shoreline. Four different project schemes with different scales of tidal channel were simulated and discussion was given based on the analysis of simulated results. The numerical evaluation of various scheme options indicates that it is feasible to involve the tidal channel in beach nourishment projects with artificial headland and the scale of the tidal channel should be designed based on the hydrodynamic processes and the state of the beach.

Keywords: Tidal channel, beach nourishment, headland-bay.

INTRODUCTION

Beach erosion is a severe problem worldwide. According to Bird (1985) 70% of sandy beaches in the world are retreating at a rate of 0.5–1.0 m a year. Among the various approaches to conserve sand, beach nourishment, which comprises the placement of large quantities of good quality sand in the nearshore system, is one of the most popular and established methods (Dean 2005).

A headland-bay beach is defined as a beach lying in the lee of a headland subjected to a predominated of wave attack. Such beaches characteristically have a seaward-concave plan shape resulting from erosion caused by refraction, diffraction and reflection of waves into the shadow zone behind the headland (Yasso 1965). According to the state of equilibrium, the headland-bay beaches can be classified into three categories: static equilibrium, dynamic equilibrium and unstable beach (Silvester and Hsu 1993). Static equilibrium is reached when the predominant waves are seen to be breaking simultaneously around the whole bay periphery. At this stage, littoral drift is almost non-existent, and the curved beach is stable without long-term erosion or deposition, except during a storm period. Because headland-bay beaches in static equilibrium are the most stable landform under the action of persistent swell in nature, construction of a bayed beach in static equilibrium has been recommended as a means of stabilizing eroding shorelines in beach nourishment projects (da Fontoura 2003) and it has been used widely in the world (Hanson et al. 2002; Hsu et al. 2006; Kuang et al. 2011).

However, as the beach is protected by the artificial headland the water exchange between the bay and the open sea is weakened, which in some cases causes the deterioration of water quality and the bloom of algae and seaweed, as seen in Fig. 1.

One of the solutions of the water exchange problem is the reservation of a tidal channel in the landside of the artificial headland enabling tidal current to pass. In this paper with a verified shoreline change model based on GENESIS (Generalized Model for SImulating Shoreline change) model, the response of the shoreline change to the length of the tidal channel is studied. The numerical study is conducted based on an actual beach nourishment

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project in Qinhuangdao, China. The model was verified by reproducing the post-project shoreline. Four different project schemes with different scales of tidal channel were simulated and discussion was given based on the analysis of the simulated results. The numerical evaluation of various scheme options indicates that it is feasible to involve the tidal channel in beach nourishment projects with artificial headland and the scale of the tidal channel should be designed based on the hydrodynamic processes and the state of the beach.

(a) Trébeurden, France (b) Xinghai Bay, China

Fig. 1 The bloom of seaweed on headland-bay beaches

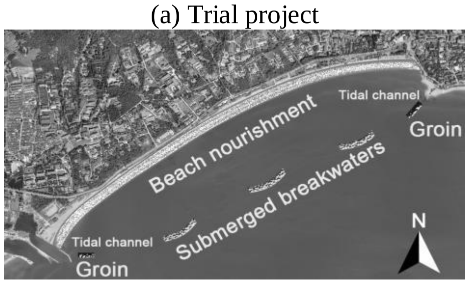
STUDY AREA AND PROJECT DESCRIPTION

West beach in Beidaihe is located at a famous tourist resort in the south of Qinhuangdao, northeast of Dai river, with several famous and scenic bathing sites. It is characterized by relatively short (about 3.5 km length) embayed beach bounded on either extremity by headlands. Statistical analysis of wave conditions in the region shows most of the waves are small waves from S direction, but for the strong waves with wave heights bigger than 1 m E direction dominates (Kuang et al. 2011). The beaches of Beidaihe are important to tourism and the economic well-being of the City of Qinhuangdao. In 2007, decisions were made by the authorities of Beidaihe district to initiate a beach nourishment project to protect and enlarge the beach.

Before the practice of the beach nourishment of West Beach in Beidaihe, a small-scale trial project was carried out previously to gain the field measurements of shoreline responses needed for project design and numerical model verification. The trial project involves both beach nourishment and submerged breakwater as illustrated in Fig. 2(a).

50-m wide beach nourishment along with two groins and three submerged breakwaters was planned to be practiced. Tidal channels were to be reserved in both of the groins as shown in Fig. 2(b). The median grain size of the borrowed sand ranges between 0.42 and 0.61 mm, while the median grain size of native beach is 0.34 mm. The designed beach slope is 1:10 above low water level and 1:8 below low water level. Designed berm height is 3 m and sand fill volume is 2.567×10^6 m^3 with a overfill factor 1.12 as calculated according to Coastal Engineering Manual.

(a) Trial project



(b) Whole-beach-scale project

Fig. 2 The two-step scheme of the nourishment project of West Beach

MODEL SETUP AND VERIFICATION

The shoreline change model was set up based on GENESIS model. A detailed description of the model is provided by Hanson and Kraus (1989). Here only the main equation and parameters are described to aid the understanding the choice of model parameters. The governing equation for the rate of change of shoreline position is (Hanson and Kraus, 1989):

$$(\frac{dy}{dt})+(\frac{1}{D_B+D_C})(\frac{\partial Q}{\partial x}-q)=0 \qquad (1)$$

where x indicates the distance alongshore, y indicates the distance offshore, D_B is the berm height, D_C is the closure depth, q is the offshore sand transport rate, and Q is the longshore sand transport rate.

The modeling area covers the whole of West Beach. Approximately perpendicular to the shoreline, x axis of the computational gird has an azimuth angle of 328° (meteorological convention) and a length of 3200 m; the mesh spacing is 20 m. The input parameters for the model are: berm height D_B = 2 m, according to the profile measurement; closure depth D_C = 7 m, according to previous study on sand transport of this area, and K_1 = $2K_2$ = 0.76 according to the model sensitivity study. The median grain size D_{50} = 0.40 mm is used for both filled sand and local sand. Wave data utilized are provided by Qinhuangdao Ocean Station.

The model was verified by the comparison of simulated and measured post-project shorelines 8 months after the trial project. The comparison is shown in Fig. 3.

As it can be seen good agreement is achieved. More details of the model set-up and verification can be found in Kuang et al. (2011).

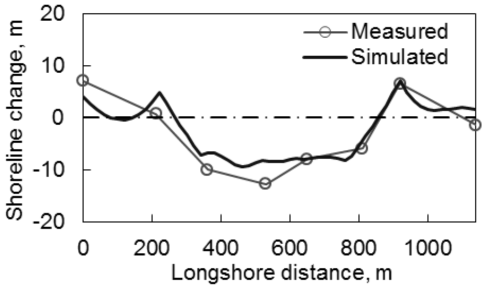


Fig. 3 Comparison of simulated and measured shoreline changes after the trial project, the plotted shorelines are relative to the shoreline at project completion.

MODELLING SCHEMES

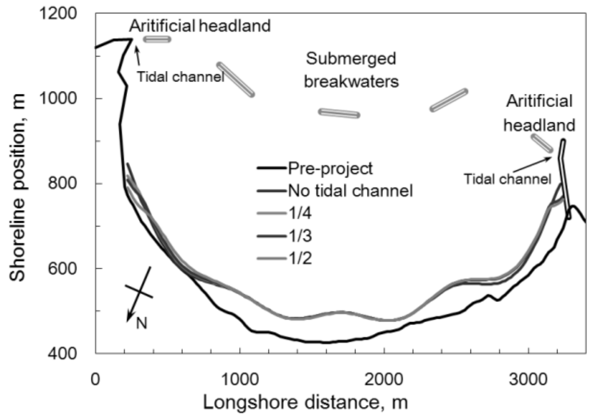
Four project schemes with different length of tidal channel were simulated to understand the responds of the shorelines to changes of the length of the artificial headlands. Tidal channels are reserved in both of the artificial headlands at the two ends of the West beach. In four cases the lengths of the two tidal channels (in each case the same length is adapted for the two tidal channels) are set to 0, 1/4, 1/3 and 1/2 of the length of the artificial headland respectively. Other parameters are set to the same as the verified model.

RESULTS AND DISCUSSION

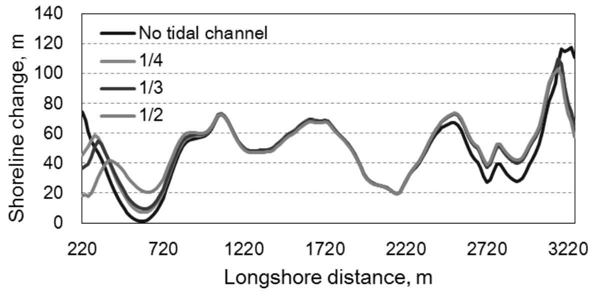
The simulation results of 10 year shoreline change for this configuration with different lengths of tidal channels are shown in Fig. 4. Fig. 4(a) shows the simulated results of different cases, from which it can be seen that the tidal channel has the effect of weakening the protection to some extent in the east end of the beach and to a less degree at the west end. It can be explained by that the longshore transport of sediment of the beach is from east to west, because of which the east end of the beach is eroded and the west end is silted (Kuang et al. 2011). Because of the east-to-west longshore transport and the strong waves from east direction, the east groin plays a more important role in the protection of the beach. Therefore the main impact of the reservation of tidal channel on the shoreline change is on the east end

Fig. 4(b) shows shoreline changes in different cases. The plotted shorelines are relative to the pre-project shoreline. From Fig. 4(b) it can be seen that the east end of the beach is more sensitive to the length of the tidal channel, while at the west end the change of the length of tidal channel (from 1/4 to 1/2 of the length of the artificial headland) has no significant impact on the shoreline change. It also can be explained by that the east end of the beach is eroded and the west end is silted. That is to say, the response of the shoreline change to the change of tidal channel length is to some degree influenced by the beach state, therefor the design of the tidal channel should involve the longshore transport direction and the state of the beach.

Another interesting finding is that the impact scale of the changes of the tidal channel length to the shoreline change is limited between the shadow zone of the artificial headland and the adjoining submerged breakwater. The shoreline changes between the shadow zones of the submerged breakwaters are seldom impacted, as indicated in Fig. 4(b).



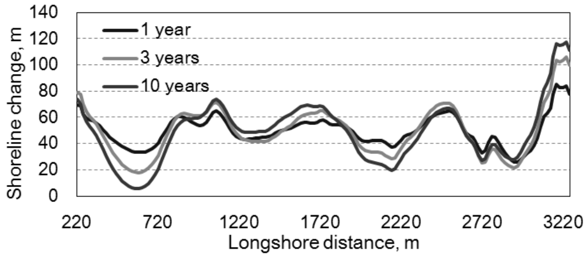
(a) Shoreline positions



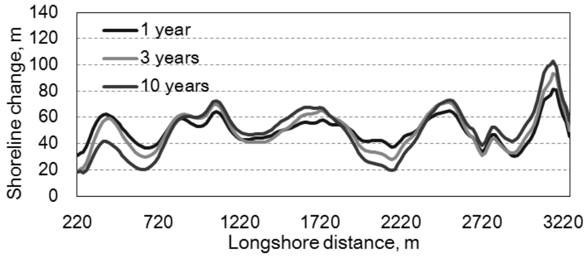
(b) Shoreline changes in positions, relative to pre-project shoreline

Fig. 4 Shoreline change response to the alterations of the length of tidal channel.

In order to see the impact of the tidal channel on the evolution rate of the shoreline, the simulation results in 1 year, 3 years and 10 years periods for the case with no tidal channel and the case with tidal channel of 1/2 length of the headland are plotted in Fig. 5(a) and Fig. 5(b) respectively. The plotted shorelines are again relative to the pre-project shoreline. As seen, at most of the positions around half of the erosion happens in the first 3 years in both cases except for the shoreline near the two ends of the beach. That is to say the tidal channel has little influence on the general evolution rate of the shoreline.



(a) No tidal channel



(b) 1/2 length of the artificial head land

Fig. 5 Shoreline evolution processes with and without tidal channel.

CONCLUDING REMARKS

In this paper the response of the shoreline change to the length of the tidal channel reserved in artificial headland is studied based on an actual beach nourishment project via a verified shoreline change model. The details of the model set-up and verification can be found in Kuang et al. (2011). A number of conclusions can be drawn as follows:

1. The tidal channel has the effect of weakening the protection to some extent in the eroded part of the beach and to a less degree also weakens the beach in the silted part of the beach.

2. Eroded part of the beach is more sensitive to the length of the tidal channel, while in the silted part the change of the length of tidal channel has no significant impact on the shoreline change.

3. The impact scale of the changes of the length of the tidal channel to the shoreline change is limited between the shadow zone of the artificial headland and the adjoining submerged breakwater.

4. The tidal channel has little influence on the general evolution rate of the shoreline.

In future study, the hydrodynamic and water quality responses of the project area to the tidal channel will be studied.

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