THE EVOLUTION TREND OF A BEACH IN CONSEQUENCE OF THE BUILDING OF COASTAL STRUCTURES

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ABSTRACT

The shoreline deformation produced by the interaction between waves and coastal structures have been analyzed by comparing two different analytical solutions. Starting from the same assumption, they converge to different profiles, according to the different way to take in account the phenomenon of the wave diffraction induced by the structure.

INTRODUCTION

The first mathematical model to foresee long-term shoreline change was the one-line shoreline model introduced by Pelnard-Considere (1956). Since then, different models have been developed to simulate shoreline change. The history of the one-line theory was summarized in Larson et al. (1997).

The analytical solutions derived from the mathematical models are either unrealistic or are unable to provide quantitatively accurate results of beaches involving complicated initial and boundary conditions, such those generated by the presence of coastal structures. However, they exhibit several advantages. They can reveal the essential response features of the shoreline using basic physics, which produces results more rapidly than the complex numerical and physical modeling. Moreover, the analytical solutions avoid inherent numerical stability and numerical diffusion problems, which are uncertainties in all the mathematical models (Larson et al., 1997). Despite many models have been developed on the concept of one-line model, nowaday four have become the standard applied for engineering applications since the 1980s, including GENESIS (Hanson and Kraus, 1989); UNIBEST (WL, 1992); LITPACK (DHI, 2001); and GenCade (Frey et al., 2012). A comprehensive comparison among them can be found in Thomas and Frey (2013) and Townsend et al. (2014). The mathematical approach proposed here moves from the same hypotheses of one-line models and considers the beach as an ideal absorber, which does not alter the wave motion in front of it. Therefore, it does not reflect nor transmit energy. With this assumption, we calculate the evolution trend of the shoreline in consequence of the realization of coastal structures.

THE LONGSHORE TRANSPORT AND BEACH PLANFOM EVOLUTION

The governing equation of the one-line model is given by

$$\frac{\partial y}{\partial t} = -\frac{1}{D}\frac{dQ}{dx}. \qquad (1)$$

It states that the alongshore variation in the longshore sand transport rate *Q*, determines a change in shoreline position *y*. [*D* is the sum of the berm height and the depth of closure.] The derivative $\partial y/\partial t$ gives the evolution trend. If $\partial y/\partial t$ is positive the dry beach grows; if $\partial y/\partial t$ is negative the dry beach gets narrower; the largest the absolute value of $\partial y/\partial t$, the larger is the deformation of the dry beach. Q depends mainly on the shear force $< f_{fa} >$, exerted by the wave motion on the seabed.

The bulk longshore sediment transport rate depends on the shear force exerted by the wave on the seabed. It can be expressed as

$$Q_s = k\frac{k}{\gamma_a} < f_{fa} > \sqrt{gd_b}, \qquad (2)$$

where *k* depends on the size of the sand, on the specific weight on the sand and on the sediment porosity; $\sqrt{gd_b}$ is the wave celerity at the breaking depth, and γ_a is the specific weight of the water.

According to Larson et al. (1997), the shear stress force can be evaluated as

$$< f_{fa} >= \frac{1}{32}\rho g H_b^2 \sin(2\alpha_b), \qquad (3)$$

being H_b, the wave height at the breaking depth and α_b, the angle at the breaking depth formed by the direction of wave advance and the shoreline alignment, assumed parallel to the x-axis. Note that Eq. (3) is valid under the hypothesis of contour lines straight and parallel to the shoreline, in the case of natural diffraction phenomena.

Assuming that the beach acts as an ideal absorber, and applying the linear momentum equation to a control volume with one side adjacent to the absorber, it can be shown that

$$< f_{fa} >= -R_{yx}, \qquad (4)$$

where R_{yx} is the longshore component (i.e. *x*-component) of the radiation stress of the wave field in the presence of the coastal structure. Hence, by means of Eqs (4) and (5), we get

$$\frac{\partial y}{\partial t} \cong -\mathrm{const}\frac{\partial R_{yx}}{\partial x}. \qquad (5)$$

The radiation stress can be obtained analytically for a few configuration of basic interest (i.e. a detached breakwater or a groin) or numerically, for more complex planform configurations of the structures. With this approach, it is possible to estimate the wave diffraction produced by structures placed near the coast, which is the main phenomenon responsible for the beach deformation.

SHORELINE DEFORMATION PRODUCED BY A BREAKWATER

Fig. 1 shows the evolution trend of a shoreline in consequence of the realization of a detached barrier parallel to the shore. The three profiles refer to the case of waves with normal attack to the barrier. In detail, the experimental profile (Shinohara and Tsubaki, 1966) corresponds to the initial deformation (the first detected after the beginning of the wave generation) of a shoreline subjected to regular waves. Profile (b) is that of Larson et al. (1997). Profile (c) represents the tendential deformation of the shoreline obtained with the present solution. In particular, it was calculated for the same conditions as the experimental profile of Shinohara and Tsubaki (1966) which are

$$B/L_0=1.12,\ d/L_0=0.19,\ S/L_0=0.56,$$

being, B=1.5m, the length of the reflecting breakwater, L_0=1.33m ,the wave length of the profile, equal to the wave length on deep water of regulars waves having H_0=0.06m and T=0.92s, d=0.25m is the still water depth, and finally S=0.75m, the distance between the structure and the original shoreline.

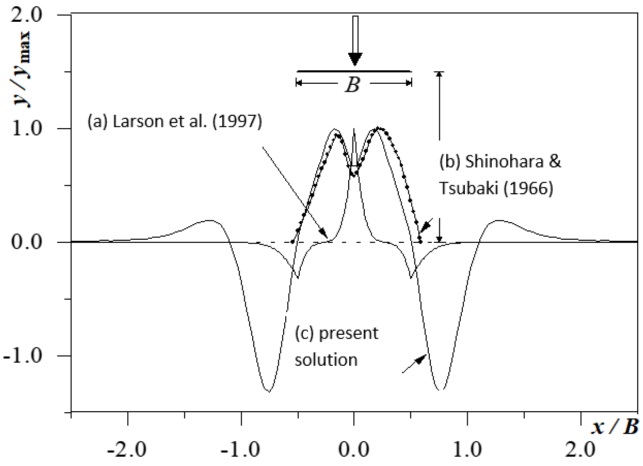

Figure 1 - Shoreline deformation produced by a detached breakwater.

As we can see the profile (c) is able to reproduce the peculiar shape of the experimental profile highlighting the typical formation of a double-peak salient. Unfortunately, no experimental data are available on the extremity side of the barrier so we are not able to compare the erosion zones predicted by profile (c). Furthermore, the position of the maximum erosion according to profile (a) is arbitrarily determined, whereas in the case of profile (c), it depends on the radiation stress tensor of the diffracted waves.

SHORELINE DEFORMATION PRODUCED BY A GROIN

Figure 2 shows the comparison between two different predictions of the beach platform evolution produced by a groin, located orthogonally in respect to the x-axis (and then to the original shoreline).

The present solution was calculated for the same conditions of the incident wave direction as Larson et al. (1997), α_H=23° and considering a random waves characterized by a mean JONSWAP-MITSUYASU spectrum, d/L_{P0}=0.1 and B/L_P=1, being L_P the wavelength relevant to peak period of the spectrum, evaluated at the depth d, and B the length of the groin.

As we can see, for both predictions, the maximum accretion of the beach profile occurs at the wave beaten side of the groin, whereas the maximum erosion occupies two different position on the lee side. As in the case of the breakwater, the maximum erosion has been also arbitrarily determined. Indeed Larson et al. (1997), in order to take in account the diffraction effect assumed that the direction of the propagation of waves varies linearly from α_H to the angle forming by the groin and the coast.

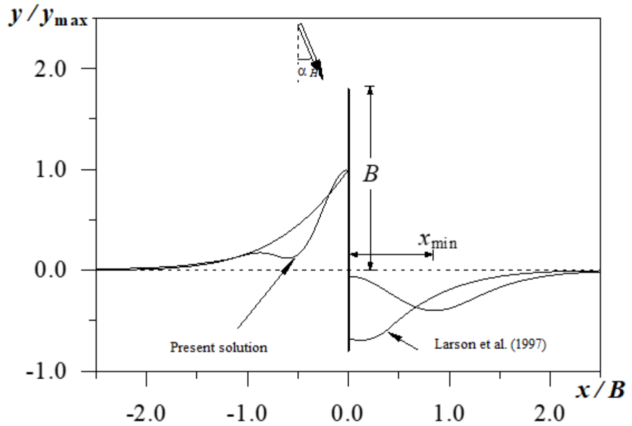

Figure 2 - Shoreline deformation produced by a groin: comparison between two different analytical solution.

On the contrary, the present solution applies the diffraction theory rigorously, taking in account both the effect of the wave direction and the effect of the wave height, which are not spatially homogeneous in a diffracted wave regime. Consequently, as we can observe in Figure 3, the position of the maximum erosion depends only on the length of the groin for a given direction of the angle of attack of the wave.

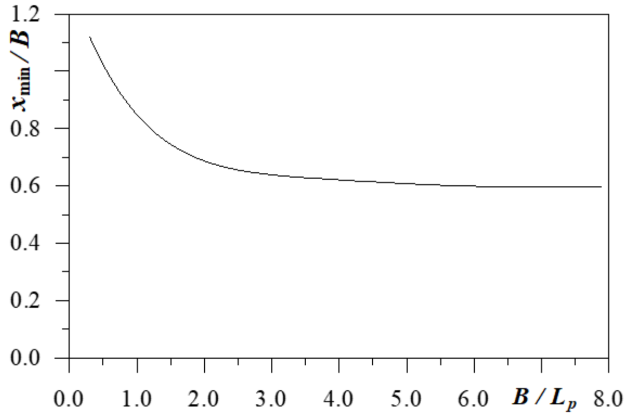

Figure 3 - Evolution trend of the maximum erosion as a function of B/L_p. for α_H=23°.

CONCLUSIONS

A comparison between different approaches finalized at evaluating the beach evolution platform, in presence of coastal structures, were investigated.

The model proposed by Larson et al. (1997) is based on an approximation of the expression to evaluate the force exerted on the sea bottom valid for natural shoreline with straits contour lines, in which no diffraction effects produced by structure are taken in consideration. Therefore, in order to take in account the diffraction effects an arbitrary schematization is used. As a result, these profiles are influenced sensitively by the schematization adopted and do not converge to an equilibrium profile in the time domain.

Conversely, the solution of the present study is based on the schematization of the beach as an ideal absorbing wall, which does not alter the wave motion in front of it and does not reflect nor transmit energy. The evolution trend of the shoreline is calculated by evaluating the radiation stress tensor of the wave field in presence of coastal structures. This can be done analytically in the case of simple planform geometry of the structure (i.e. detached breakwater and single groin), or it can be done numerically for complex configurations.

As a result, the present model is able to catch several noticeable details, as the formation of a double-peak salient in the case of the breakwater, and to provide a beach evolution trend in the time domain.

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