IMPACTS OF COASTAL PROTECTION STRATEGIES ON THE COASTS OF CRETE: NUMERICAL EXPERIMENTS

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ABSTRACT

The impacts of several coastal protection strategies are studied for two field sites along the island of Crete through the application of a two-dimensional coastal morphology model. Rethymno beach is the first site, which is located on the Northern coast of Crete and represents a typical sandy beach of average slope 1:75. The second field site is Asfendou bay, which is located on the Southern coast of the island and has an average beach slope of 1:50. The long term application of the coastal morphology model is achieved through the Hierarchical clustering of wave records over each month. The effectiveness of the different coastal protection regimes for these sites is defined based on the results of the model.

1. INTRODUCTION

Coastal zones are very active zones of human development and recreation. The increasing development of coastal areas causes serious erosion and flooding problems. It is known that almost two thirds of the world’s population resides within 200 km of the coast. Therefore, continuous engineering activities are needed to protect the coastal areas.

Coastal morphodynamical models have demonstrated practical capability in predicting short- and mid-term beach evolution. In this paper an Integrated Coastal Engineering Model (ICEM) is used to assess the impact of different coastal protection measures for two field sites on the Island of Crete; Rethymno coast and Asfendou bay. The long term application of the model (over 3 to 5 years) is achieved through the clustering of the wave record using the Hierarchical technique.

2. ICEM – MODEL DESCRIPTION

The model consists of three main modules; the wave transformation module, the coastal circulation module, and the sediment transport module [1]. The wave transformation module employs a parabolic wave model [2], which simulates the nearshore wave conditions taking into account wave breaking, shoaling, refraction and diffraction for a monochromatic wave. The radiation stresses are calculated for all the grid points and accordingly the wave forcing terms are calculated. The hydrodynamic module is a 2D depth averaged model, which runs until it reaches a steady state. With the wave and hydrodynamic conditions available, the sediment transport model calculates fluxes on a staggered grid and the sediment budget equation is then applied to predict the beach evolution. The waves, currents and sediment transport fluxes are updated when the change in the beach morphology reaches the desired level. The ICEM was tested using field data from Ras El-

Bar, located on the Northern Mediterranean coast of Egypt, which includes shore parallel and perpendicular structures [2]. The ICEM was capable of simulating the beach deformations due to different coastal structures over the long term.

3. HIERARCHICAL CLUSTERING TECHNIQUE

A typical wave record in Asfendou or Rethymno is a 6 hourly wave record. In other words, if the measured wave record is used as an input to ICEM, the waves, currents and sediment transport fluxes would have to be updated each 6 hours, which is the main reason why this type of morphodynamical models is not applicable over the long term.

It is assumed that over one month, short duration storms which have the same range of wave heights can be grouped into a single prolonged storm. First, the monthly wave data time series is divided into wave directional bands of 20°-width. Then, the time series within each band is clustered and the similar wave records (wave period T and wave height H) are grouped to form a prolonged record, which has an average wave period and wave height of the constituting records. The clustering is based on the Hierarchical technique [3], which joins the most similar observation, then successively connects the next most similar observations to these. The Euclidian distance d_{ij} is used as a measure of the similarity between the variables at times i and j, which is given by:

$$d_{ij} = \sqrt{1/2\left(H_i - H_j\right)^2 + 1/2\left(T_i - T_j\right)^2}$$

where H_i and H_j denote the wave heights measured at times i and j, respectively whereas T_i and T_j denote the wave periods measured at times i and j, respectively. The smaller the value of the Euclidian distance d_{ij}, the greater the similarity between the pair i and j.

4. STUDY AREAS

Two field sites along the island of Crete are studied. Rethymno beach is the first site, which is located on the Northern shore of Crete, as shown in Figure (1). This site represents a typical sandy beach of average slope 1:75. The second field site is the Asfendou bay, which is located in the Southern shore of the island and has an average slope of 1:50.

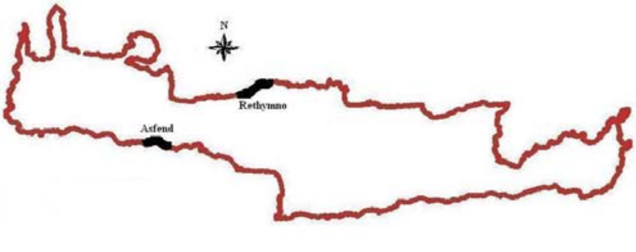

Figure 1: The island of Crete.

4.1. Bathymetric data

The bathymetric data are given on a 20×20 meters grid for both sites. However, the data do not extend to include the shorelines. Therefore, in addition to the interpolation required between the given grid points, extrapolation of data is required to represent shorelines. The gridding is done using Surfer (professional gridding software) with the kriging technique, which is found to yield the most reliable results for both interpolation and extrapolation.

4.2. Wave data

The time series wave data over the period from September-99 to October-02 is available, where the significant wave heights and periods are given each 3 hours. Figure (2) and Figure (3) show the annual wave rose at Asfendou and Rethymno, respectively. The monthly wave roses for both sites were studied in order to obtain the design wave time series. It was assumed that over one month, short duration storms which have the same range of wave heights can be grouped into a single prolonged storm.

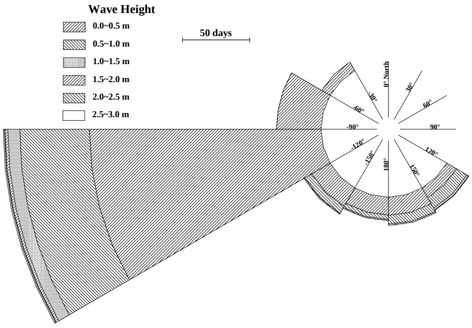

Figure 2: Annual wave rose at Asfend bay.

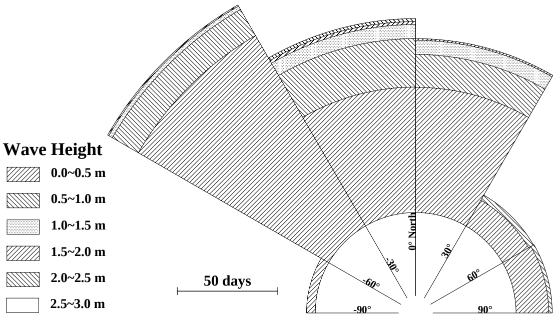

Figure 3: Annual wave rose at Rethymno.

5. COASTAL PROTECTION AT RETHYMNO BEACH

The dominant direction of waves in Rethymno beach is from 60° North-West to 30° North-East as shown in Figure (3). The beach at Rethymno is composed mainly of medium sand of average grain size 0.27 mm with an average slope of 1:75. A beach of this configuration is quite stable mainly due to the relatively large grain size. The ICEM is applied to a fairly long stretch of Rethymno beach as shown in Figure (4), where 5.76 km of the beach is studied. The whole grid has been rotated by 20° in order to better represent both the shore-parallel and –perpendicular coastal structures and to reduce the wave angles with respect to the grid. All the simulations are done over a full year, where waves less than 0.25 m in height are considered calm as they do not affect the sediment movement. The deformed beach of Rethymno after 1 year of wave attack is shown in Figure (5), where the initial bathymetry is shown in gray scale, while the deformed beach is shown as contour lines. The Rethymno beach is stable as shown in Figure (5) and seems that does not need major coastal protection measures. In order to study the various impacts of different coastal structures, finer sediment grains of average diameter of 0.12 mm is used (i.e. silty sand beach) so that the Rethymno beach is forced to be an eroding beach as shown in Figure (6). In the following sections several structural coastal protection approaches are tested.

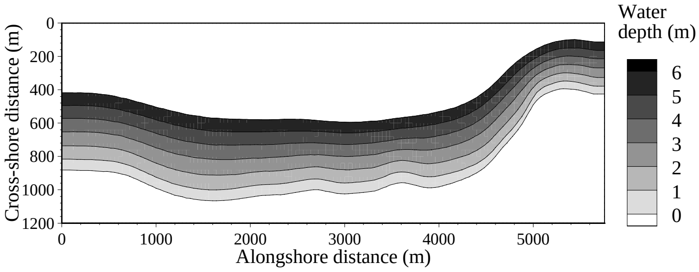

Figure 4: Initial bathymetry of Rethymno.

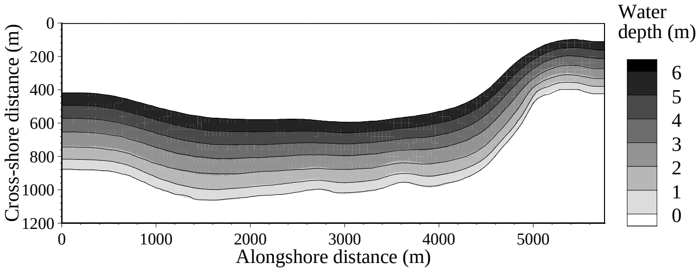

Figure 5: Deformed beach of Rethymno after 1 year.

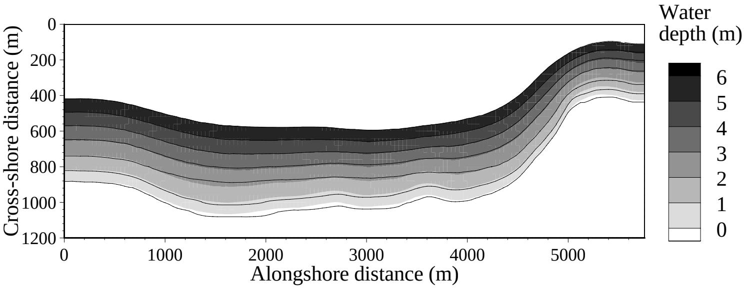

Figure 6: Deformed beach of Rethymno after 1 year (*D* = 0.12 mm).

5.1. Impact of an emerged groin system

Most of the littoral transport in Rethymno takes place in the 200 meters close to the shoreline. Therefore, the groins length shall not exceed that limit. The first system to be tested is composed of 9 equally-spaced groins at 400.0 meters and of 200.0 meters length. Figure (7) shows the deformed beach of Rethymno, where the groin system stops the erosion and protective beach slowly starts to build up. Due to the close spacing of the groin system, a significant amount of littoral transport is diverted offshore, which suggests that a groin system with wider spacing would behave better. Figure (8) shows the impact of the 5-groins system on the beach, where the littoral transport has more space to redevelop between the groins.

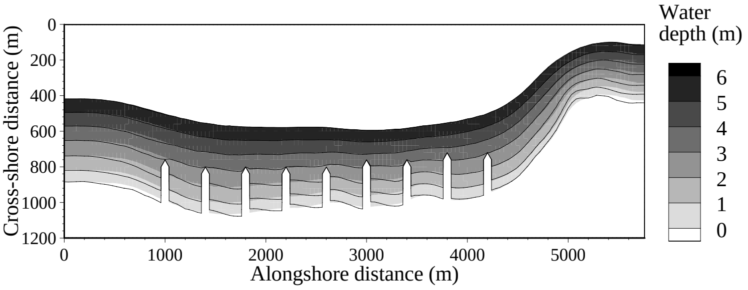

Figure 7: Deformed beach of Rethymno with a system of groins.

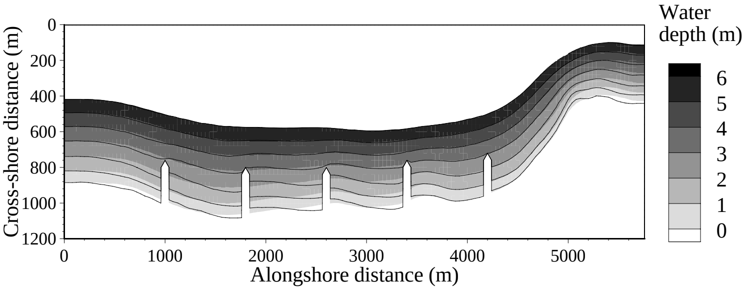

Figure 8: Impact of a system of 5 groins on Rethymno beach.

5.2. Impact of a submerged groins system

A system of 5 submerged groins of 2.5 m height above the seabed is tested. The advantage of the submerged groins over the emerged system is that they allow the littoral transport to pass over their crests. Their impact on the shoreline is almost identical to the emerged groins impact as long as the shoreline advance on the updrift of the groin is less than the length of its emerged-shoreward part, as shown in Figure (9). The submerged groin system, on the other hand, has less impact in deep water than the emerged. A submerged groin system of less height above the seabed (i.e. 1.5 m) results in a smoother shoreline as shown in Figure (10). The downdrift erosion is significantly reduced on the expense of a reduced updrift accretion.

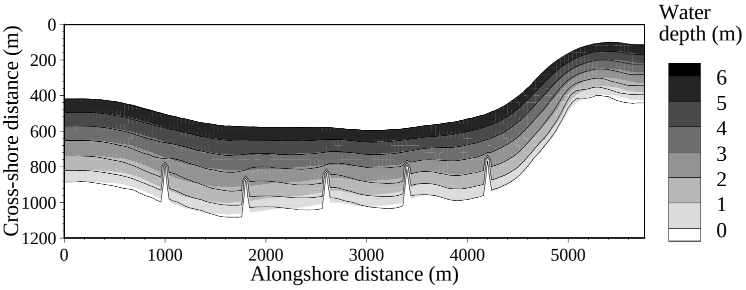

Figure 9: Impact of a system of 5 submerged groins of 2.5 m height on Rethymno beach.

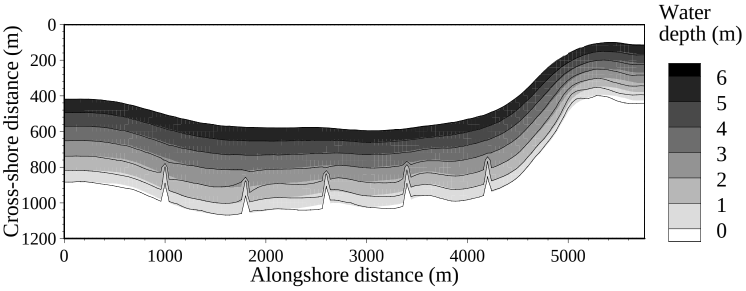

Figure 10: Impact of a system of 5 submerged groins of 1.5 m height on Rethymno beach.

5.3. Impact of an emerged offshore breakwater system

An emerged offshore breakwater system is tested on the eroding Rethymno silty-sand beach. The system consists of 8 offshore breakwaters of 200.0 meters length each and spaced at 200.0 meters to cover 3.0 km of the beach. The breakwaters are located 400.0 meters offshore on average so that tombolo formation is prevented. Figure (11) shows the impact of the breakwater system on Rethymno beach after 1 year. Salients form behind the breakwaters and form a protective beach. Although erosion between the breakwaters still exists, the beach is generally building. Unlike the groin system, the effect of the detached breakwater system on the neighbour areas is minimal due to the fact that the salients do not block the littoral transport.

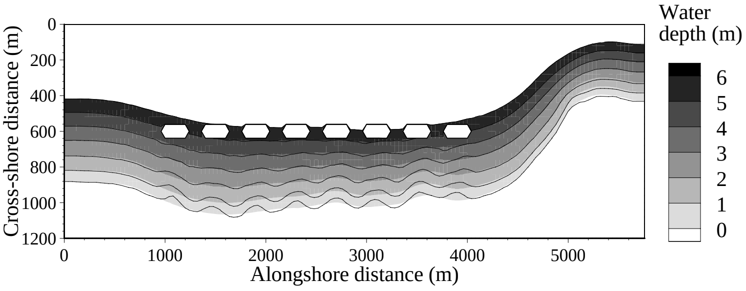

Figure 11: Impact of a system of 8 detached breakwaters on Rethymno beach.

5.4. Impact of submerged offshore breakwater system

The impact of a submerged detached breakwater system on the beach is similar to that of an emerged one with smaller amplitudes. This is due to the fact that significant amount of wave energy is transmitted to the shadow zone of a submerged breakwater. This has the advantage of preventing the tombolo formation. However, the shoreline advance rate is significantly slower than the case of an emerged breakwater system. Therefore, the submerged breakwaters can be placed closer to the shore than the emerged breakwaters. A system of 8 submerged detached breakwaters of 200.0 m length and 200.0 m spacing is tested. The height of the submerged sills (breakwaters) above the seabed is 2.0 meters so that large waves are forced to break at the crests of the breakwaters and therefore dissipate significant amount of their energy there. Small waves, however, do not break and the whole energy is transformed as if the submerged sills are not present. The breakwaters are placed 200.0 meters away from the shoreline. Figure (12) shows both the initial and deformed beaches of Rethymno due to the construction of the submerged sills. The submerged sills do not have a great effect on the shoreline due to the relatively calm wave activity at Rethymno.

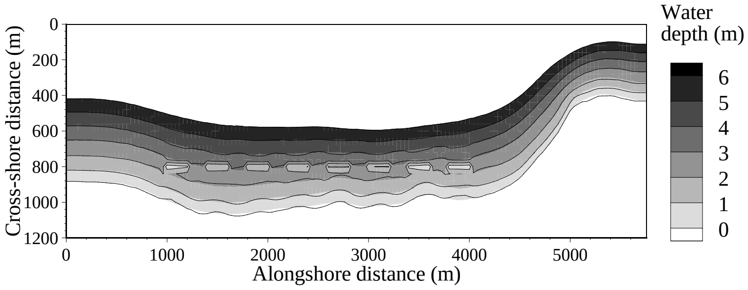

Figure 12: Impact of a system of 8 submerged detached breakwaters on Rethymno beach.

5.5. Impact of T-groins system

The T-groins system is a combination between the groin and the offshore breakwater systems. The shore-connected part of the breakwater acts as a groin, while the offshore-shore-parallel part of the breakwater acts as an offshore breakwater. This system is suitable when the wave climate changes from severe oblique waves, where the groins are preferred, to nearly normal waves, where the offshore breakwaters are preferred. In order to test this kind of system on Rethymno beach, the wave climate has to be modified so that both oblique waves and nearly normal waves are present. A yearly wave climate of 200 active days is assumed where the wave angle changes every 50 days between 75° to 0°. The offshore significant wave height and period is 1.0 m and 6.9 s, respectively. A system of 5 T-groins is tested. Each groin consists of a shore-connected breakwater of 200 m length and a shore-parallel breakwater of 240 m length. The groins are 800 m apart. Figure (13) shows the impact of this system on Rethymno beach after one year simulation. The system restores the beach very well as shown in the figure. The erosion on the downdrift sides of the groins is significantly reduced in the case of T-groins because this area lies in the shadow zone of the shore-parallel breakwater, which traps sediments from its vicinity. In conclusion, the T-groins system is an effective system for cases of random wave direction and can be used in cases of dominant wave directions as well.

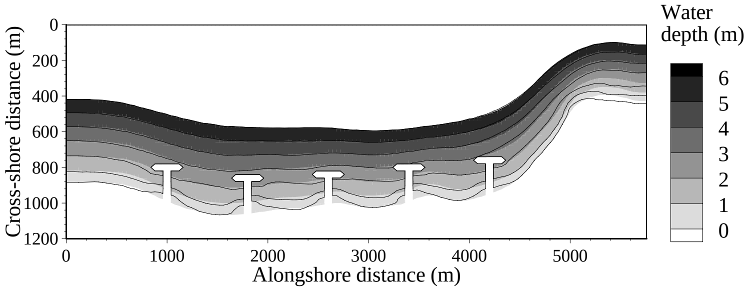

Figure 13: Impact of a system 5 T-groins on Rethymno beach.

6. COASTAL PROTECTION AT ASFENDOU BAY

The predominant direction of offshore waves at Asfendou is 75° clockwise from the south, as shown in. The average grain size of the beach material is 0.2 mm. The ICEM is used to investigate the stability of the bay under the wave attack for 1 year. The modeled area extends 4.6 Km alongshore, which includes the whole bay as shown in Figure (15). The wide angle parabolic wave model is chosen to model the waves for the bay, where the waves are attacking the beach at a grazing angle (75°). Figure (16) shows both the initial and deformed beaches of Asfendou bay after one year, where the initial beach is shown in gray scale and the deformed beach is shown as contour lines. Note that contour lines of depths more than 6.0 meters have been omitted for convenience. The bay seems to be very stable, where wave energy inside the bay is relatively small. The Eastern side of the bay is stable as well. The Western side of the bay, however, suffers significant amount of erosion due to the abrupt change in the magnitude and direction of the littoral transport at the bay entrance as shown in Figure (16). Due to the grazing wave angles at the bay, the only choice of a coastal protection regime would be the groin system, which traps significant amount of the littoral drift to build up the beach. Figure (17) shows the impact of two groins of 180.0 m length on the Western beach of the bay. The groin system stabilizes the shore and does not cause erosion in the bay.

The other alternative for the beach protection is the submerged groin system. Figure (18) shows the impact of a submerged groin system on the beach. The system is composed of two submerged groins of 180.0 m length and 2.5 m height above the sea bed. Comparing Figure (17) and Figure (18), it is concluded that the emerged groins provide better protection for the shore than the submerged groins.

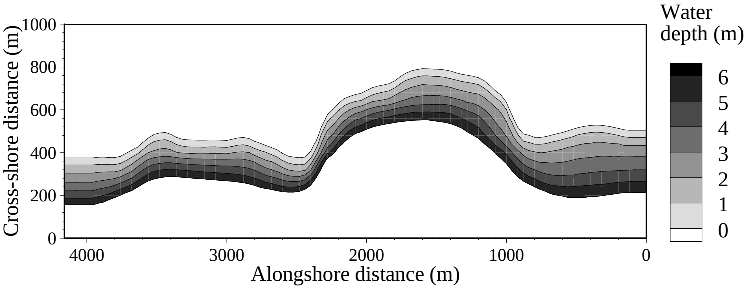

Figure 15: Initial bathymetry of Asfendou bay.

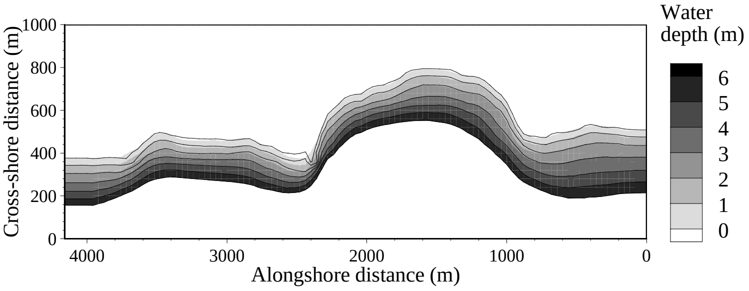

Figure 16: Deformed beach of Asfendou bay after 1 year.

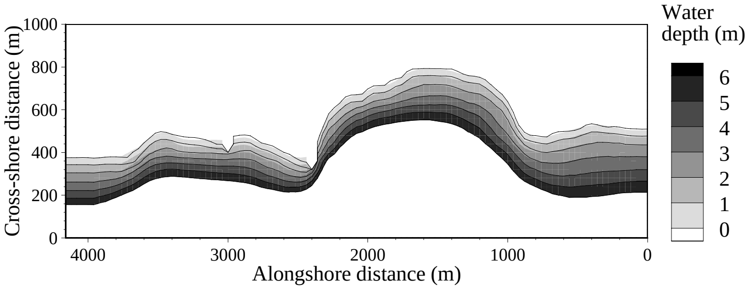

Figure 17: Protection of the Western side of Asfendou bay by two emerged groins.

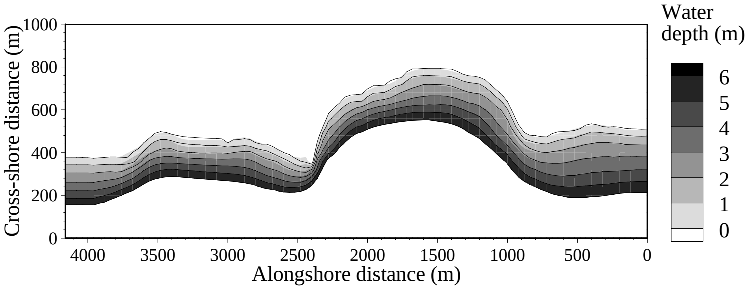

Figure 18: Protection of the Western side of Asfendou bay by two submerged groins.

7. CONCLUSIONS

Several coastal protection measures have been studied. An integrated coastal engineering model (ICEM) is used to assess the effectiveness of some of the structural measures. It was applied to two coastal areas along the island of Crete. The model is proven to be applicable to large computational domains over the long-term after proper wave climate clustering is done. The analysis showed that the model can be used as a design tool for structural coastal protection measures. The groin system is shown to be effective in cases of obliquely dominant wave direction, where it acts as littoral barrier. The spacing between the groins is an important parameter, which can be optimized by the model. The model is used to test the impacts of submerged groins as well, which has the same shoreline impact as the emerged groins as long as the emerged part is not filled. The detached breakwater system is mainly used for eroding beaches of nearly perpendicular waves. The model can be used to simulate the salients and/or tombolos behind the breakwaters. Submerged sills are used to dissipate the wave energy by forcing the high waves to break over their crests. Therefore, these kinds of structures are used to build the shore in cases of high waves, while stay ineffective in calm wave conditions. T-groins can be viewed as a combination between a groin-system and a detached breakwater system. This system is an effective system for cases of random wave directions.

8. REFERENCES

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