

SHORE STABILIZATION BY ARTIFICIAL NOURISHMENT, A CASE STUDY: A COASTAL EROSION PROBLEM IN SIDE, TURKEY

by

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ABSTRACT

In this study, coastal erosion which is one of the major problems that coastal engineers face in coastal regions is discussed with a case study. A coastal erosion problem that is observed at Perissia beach, located in Side, Antalya has been investigated to find out the best solution for the problem. CSI (acronym for Coastline-Structure Interaction) numerical model which is developed in Ocean Engineering Research Center of Civil Engineering Department in Middle East Technical University is applied to the case study area for different alternative solutions. In this paper, fundamentals and inputs of the developed numerical model, alternative solutions with simulation results have been discussed in detail in view of effectiveness.

1. INTRODUCTION

Coastal erosion is one of the major problems in the world that coastal engineers face in coastal regions. The impacts of coastal structures might lead to serious problems like land or property losses. As a result, beautiful coasts and great scenes which are natural treasures are being lost, leading to economic and natural losses. For the purpose of understanding and predicting shoreline changes, a numerical shoreline change model, called CSI (acronym for Coastline-Structure Interaction) is developed by Middle East Technical University, Department of Civil Engineering, Ocean Engineering Research Center (Artagan, 2006; Baykal, 2006; Şafak, 2006; Esen, 2007). Application of the model is carried out for a coastal erosion problem at Perissia Beach, Side at the Mediterranean coast of Turkey (Figure 1).

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Figure 1: Side Beach; Shoreline retention due to erosion over the years, red line represents the shoreline position measured in August, 2006 (views from the sea, (a) western, (b) eastern part of the beach) (picture in 1999)

Before 1999, the width of the beach was approximately 50 meters. The beach was protected against the impact of waves by rocky formations which are located at 1.5 meter water depth 100 meters offshore and which behave as submerged breakwaters. In 1999, it was decided to remove the rocky formations at the

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western part of the beach concerning customer requests. After the removal of rocky formations, while the eastern beach conserves its balance, the western beach started to erode in serious amounts. Changing the sea bottom characteristics which strongly influence the sediment transport mechanism at the beach resulted in severe erosion in the western part of the beach and efforts to solve erosion problem by artificial beach nourishment were unsuccessful. As a scientific approach to the problem, in order to develop solution alternatives to the problem, CSI numerical model is applied to the case study area. The wave climate of the region, shoreline coordinates and coastal slope are the main inputs of CSI. Among the solution alternatives, it is suggested to apply the most effective solution.

2. A COASTAL EROSION PROBLEM

Perissia Hotel is located in Side, Antalya. The beach of the hotel is approximately 300 meters long (Figure 2). At the two edges of the beach, coastline extends into the sea like small headlands forming the two boundaries of the beach. At these locations there are several rocky formations which extend 25 meter into the sea. At the middle of the beach a 120 meter long pier exists. Underneath the pier, rocky formations lay all along the pier. At the eastern side of the pier, there are several rocky formations which lay 60 meters offshore and behave as submerged breakwaters. These rocky formations cause most of the incoming waves to break at this location. After the removal of the rocky formations at the western side of the pier and destruction of some of the rocky formations at the eastern side of the pier, beach has lost its protection against the impact of incoming waves. As a result, erosion has been observed throughout the whole beach. However, the amount of erosion is more severe and thus shoreline retreat (approximately 30 meters) is higher at the western beach. The trials in order to solve erosion problem by artificial beach nourishment have been unsuccessful up to now. In addition to artificial beach nourishment, in order to stop shoreline retreat, at the coastal edge of the pier, a 25 meter long and 2 meter wide groin was constructed. After the installation of the groin, some amount of accretion was observed at the eastern beach. On the other hand, shoreline retreat could not be prevented at the western beach. Therefore, the impact of waves resulted in huge damage and finally less effective use of the beach.

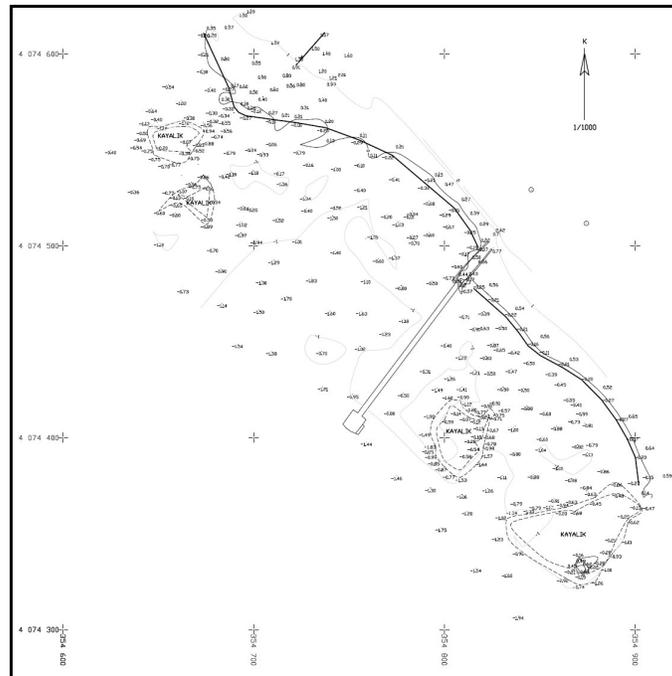


Figure 2: Bathymetry of Perissia Beach, Side

With the aim of preventing this situation, finding a permanent and effective solution, observations, investigations, bathymetry studies have been performed around the beach and the outcomes of corresponding works have been analyzed. According to these studies, in order to predict shoreline

changes and to understand the efficiency of the solution alternatives, application of CSI numerical model to the region is decided. During the application of the numerical model to the case study area, wave climate of the region, shoreline coordinates and coastal slope compose the main inputs. For this aim, long term wave statistics of the Side region and the corresponding significant wave heights for each wave direction are obtained.

3. WAVE CLIMATE

In this study, one of the main inputs of the numerical model is the wave climate data of the region. Therefore, wave measurements have to be used. However, there are no regular wave measurements taken at Side region. As a result, in order to obtain the wave climate of the region, wave characteristics that are obtained from the storms created in the past should be anticipated. Depending on the wave data between years 1993-2004 obtained from Alanya Meteorological Station which is the closest meteorological station to Side, hourly mean wind speeds and directions are used, storms are selected and by using these selected storms, characteristics of waves approaching from effective wave directions are calculated with a computer program. Fetch distances of Side region is illustrated in Figure 3.

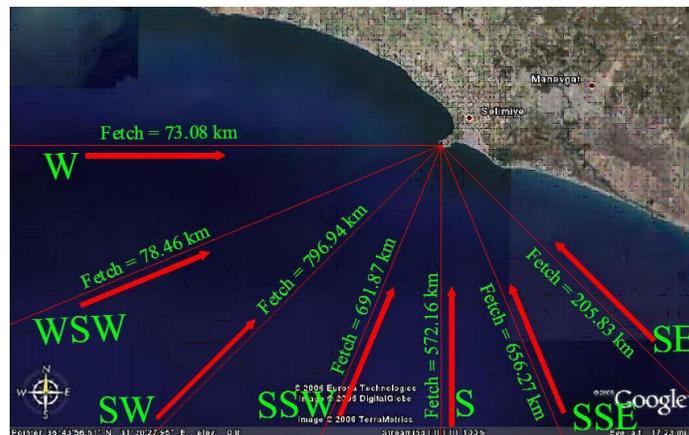


Figure 3: Fetch distances for Side region

For Side region, long term deep water significant wave height statistics are obtained for each direction by using the hourly mean wind waves and directions which are the measurements of Alanya Meteorological Station (Figure 4). According to these studies, it is derived that dominant wave directions are SSE, S and SSW for Side region in the order of importance and magnitude.

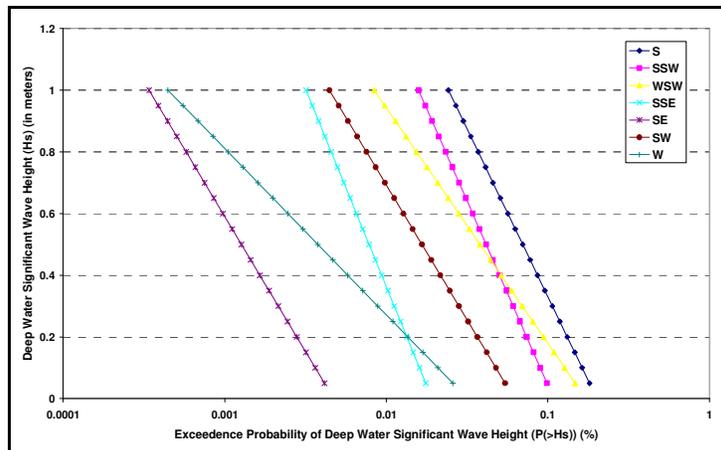


Figure 4: Deep water significant wave heights for all wave directions for Side region

4. LONGSHORE SEDIMENT TRANSPORTATION

Longshore sediment transport rate is used to describe the longshore sediment transportation. This value gives the volume or weight of the sediment that passes through a certain plane perpendicular to shoreline within a unit time period (Q). Kamphuis (1991) obtained the below equation for longshore sediment transport rate;

$$Q = 7.3 H_{sb}^2 T^{1.5} m_b^{0.75} D_{50}^{-0.25} \sin^{0.6}(2\alpha_{bs}) \quad (m^3/hr) \quad (1)$$

In the equation, H_{sb} , T , m_b and α_{bs} describe the significant wave breaking height (m.), significant wave period (s.), bottom slope at the breaking point and significant wave breaking angle, respectively.

Longshore sediment transport rate, Q , is calculated with Kamphuis's formula in the numerical model. Actual longshore sediment transport rate may be different when gains and losses are taken into account in the coastal system. In these situations, it may be necessary to fix the computed longshore sediment transport rate by multiplying it with a calibration factor C_Q ($0 < C_Q < 1$).

5. WAVES CAUSING SEDIMENT TRANSPORTATION

Not all of the waves at a region may be effective at sediment transportation. During simulations of shoreline changes, instead of using highest significant wave heights approaching from all directions, it is proper to use representative significant wave height for each direction. In order to calculate representative deep water significant wave heights for all directions, occurrence probabilities of waves, P_i are calculated as;

$$P_i = [P(>(H_{si}-\Delta H/2))] - [P(>(H_{si} + \Delta H/2))] \quad (2)$$

H_{si} deep water significant wave height for the given P_i

ΔH wave height interval

$P(>H_{si})$ exceedence probability of waves with deep water significant wave height of H_{si}

P_i occurrence probability of waves with deep water significant wave height of H_{si}

Representative deep water significant wave heights for all directions are separately calculated as;

$$(H_{so})_R = \frac{\sum_{i=1}^n (P_i H_{si})}{\sum_{i=1}^n P_i} \quad (3)$$

$(H_{so})_R$ representative deep water significant wave height

H_{si} deep water significant wave height for the given P_i

Mean deep water wave heights and periods and annual exceedence frequencies of corresponding waves are given in Table 1 (Artagan, 2006; Baykal, 2006; Şafak, 2006).

Table 1: Deep water wave directions, representative deep water wave heights, wave periods and annual exceedence frequencies

Deep water wave direction	Representative deep water wave height (m)	Wave period T(s)	Annual exceedence frequency (hr/ year)
W	0.77	3.42	11
WSW	0.84	3.59	119
SW	0.88	3.67	53
SSW	1.01	3.93	137
S	0.97	3.84	229
SSE	1.04	3.99	26
SE	0.88	3.67	4

In the numerical model, wave breaking height, breaking depth, wave breaking angle, energy of waves at breaking and longshore sediment transport rates are calculated with subprograms for each direction.

6. ONE-LINE THEORY

Pelnard-Consideré's work (1956) constitutes the basics of one-line theory which institutes the basis of the numerical model. The main assumption in this study is that shoreline stays stable and only moves parallel to itself offshore or onshore upto the depth of closure (D_c). One-line theory assumes that all of the bottom contours have the same shape as if there is only one bottom contour (Kamphuis, 2000). Changes in bottom topography is illustrated with longshore sediment transportation that occurs due to waves and wave induced currents which are taken as the main factors in long term shoreline changes and are effective in monthly and yearly periods (Hanson, 1987). Another equation that constitutes one-line theory and one-line theory based models is sand continuity equation. Sand continuity equation which is the differential equation describing the coastal movements is derived by using the coordinate system (x,y) as;

$$\frac{\partial y}{\partial t} = -\frac{1}{D_c + B} \left(\frac{\partial Q}{\partial x} + q_y \right) \quad (3)$$

In the equation, y, t, D_c , B, Q, x and q_y define the offshore distance perpendicular to the shoreline, time, depth of closure, berm height above still water level, longshore sediment transport rate, distance parallel to shoreline and gains or losses along the shoreline, respectively.

As specified above, depth of closure (D_c) is the depth beyond which longshore sediment transportation is assumed as negligible. Thus, limiting depth of longshore sediment transport (D_{LT}) is used instead of depth of closure in the numerical model. Hanson's (1987) limiting depth of longshore sediment transport formula is used in the numerical model. Hanson (1987) suggested to compute the limiting depth of longshore sediment transport which is a function of breaking wave height (H_b) as;

$$D_{LT} = 2.28H_b - \frac{68.5(H_b)^2}{gT^2} \quad (4)$$

7. NUMERICAL MODEL, CSI

In order to simulate the longshore sediment transportation, CSI (Coastline-Structure Interaction), a numerical model based on one-line theory, is developed in Ocean Engineering Research Center of Civil

Engineering Department in Middle East Technical University (Şafak 2006, Artagan 2006, Baykal 2006, Esen 2007). Numerical model, CSI simulates the shoreline changes considering structure interference. CSI may be applied for longshore sediment transportation problems and to simulate shoreline changes that occur due to most of the coastal defence structures, especially for groins, T-groins, offshore breakwaters and seawalls. An important advantage of CSI is that combined diffraction and refraction calculations can be performed in the vicinity of coastal structures including different combinations of structural applications. CSI includes an option in which the user is given a choice whether to use an explicit approach or an implicit approach to determine the shoreline changes due to wind wave induced longshore sediment transport. CSI is a very user-friendly program in which breaking wave heights in the shadow zone of the structures are defined by modifying Kamphuis's approach (Kamphuis, 2000) which is based on Goda's diffraction diagrams (Goda et al., 1978). Moreover, breaking and diffraction within the sheltered zones of coastal structures defined for offshore breakwaters by using vectorial summation of the diffraction coefficients and as for T-groins shore-perpendicular part forms a boundary to define the shoreline changes separately at two sides of the structure. Basic inputs of CSI are wave data, shoreline coordinates and coastal slope. Wave data may be introduced to the program as representative wave data transformed to a chosen reference depth from deep water by performing diffraction, shoaling and refraction within the program. The reference depth is chosen according to structural and bathymetrical data.

8. APPLICATION OF THE NUMERICAL MODEL FOR SIDE REGION

In order to overcome the coastal erosion problem at the beach, simulations are performed with CSI. In this chapter, inputs of the numerical model and the chosen solution alternative among all simulation results is explained.

8.1. Inputs of the Numerical Model

Wave data constitutes one of the main inputs of the shoreline change models. Due to its easy handling, it is preferred to use wave data which defines the wave climate of a region through a certain time period instead of real wave time series. Wave data which is given in Table 1 is used in the numerical model. Simulations are performed using wave data from 7 different directions together.

Bottom topography of the region is another main input of the numerical model, CSI. Shoreline coordinates (x,y) are obtained by using the topographic maps and inputted in the numerical model. After the bathymetrical studies and analysis of obtained bathymetry, the topographic map which is illustrated in Figure 2 is used to determine shoreline coordinates which is one of the inputs of the numerical model.

8.2. Numerical Model Simulation Results

When shoreline changes and bathymetrical changes at both sides of the pier which is located at the middle of the beach are investigated, it is realized that the rocky formations below the pier behave as submerged groins. In addition to these rocky formations, when the groin at the shore edge of the pier is taken into account, the expected amount of sediment that is supposed to pass from the eastern side of the pier to its western side decreases. These factors explain the shoreline retreat observed at the western side of the pier. Rocky formations and the extension of these rocky formations separate the eastern and western beaches upto a certain degree. Shoreline retreat is sighted both during site observations and in the outcomes of the numerical model simulations. In order to develop a solution, several simulations are performed with the numerical model and the most appropriate and economical solution alternative is chosen.

In the numerical model simulations;

1. Conservation of the 25 meters groin which is located at the shore edge of the pier (existing groin),
2. Construction of a 25 meters groin at the western border of the beach,
3. Nourishing the western beach artificially by using proper sediment sizes,

4. Construction of a 40 meters long submerged breakwater which is 30 meters away from pier and 60 meters offshore the western beach,

are investigated and shoreline changes after 1 year are obtained. Alternative given in Figure 5 is suggested as an appropriate solution to the problem. According to this alternative, it is understood that the shoreline retreat phenomenon at the western side of the pier will be eliminated with the submerged breakwater. Moreover, as expected, accretion is observed at the updrift side of the groin at the western boundary of the beach. There is some accretion at the middle part of the western beach but accretion stays in minimum amounts and in acceptable limits. Thus, this numerical model simulation (Figure 5) gives the most effective solution.

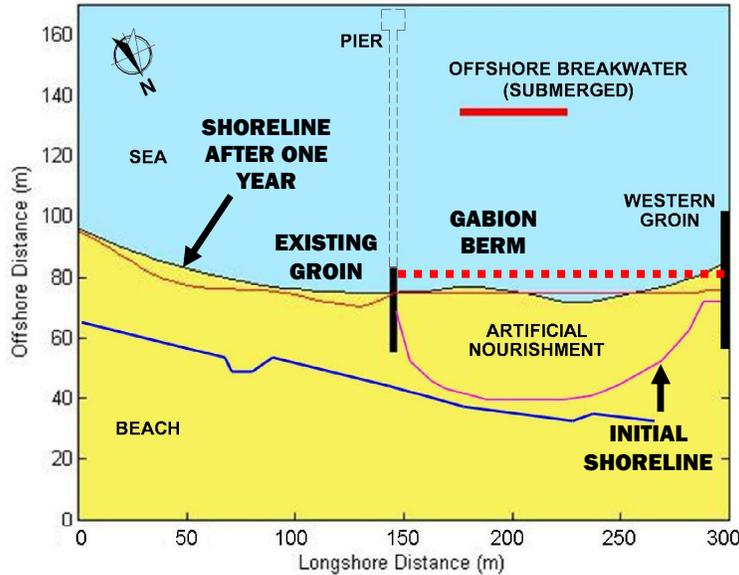


Figure 5: Shoreline changes in 1 year after the application of suggested solution alternative

In addition to this solution system, in order to protect the artificial nourishment berm which is composed of gabion units is decided to be placed in front of the artificial nourishment line. In addition to gabion berm system, in order to decrease the impact of storm waves on the beach, construction of a submerged breakwater that is composed of gabion units is necessary at the western side of the pier. Leaving the choice to the administrative board of the hotel, two options are developed for the groin at the western boundary of the beach one of which is for rubble-mound and the other is with gabion units. After the completion of the system that is illustrated in Figure 5, shoreline changes will be measured in the future to understand the efficiency and effectiveness of the system.

Stages of the solution alternative are decided as;

Stage 1

1. Construction of a 40 meters groin, 15 meters of which is at the land part, at the western border of Perissia beach in addition to the existing groin at the mid-beach,

Stage 2

1. Construction of a 40 meters submerged breakwater which is 30 meters away from pier and 60 meters offshore at the western part of the pier,

Stage 3

1. Nourishing the western beach artificially between two groins (at least 30 meters from the existing shoreline with sediments having proper sizes which were determined as having mean grain sizes around 1 mm),
2. Protection of artificial nourishment with gabions which have

- a. sizes of 6.0 m x 1.0 m x 0.3 m and 6.0 m x 1.0 m x 0.5 m
- b. mesh sizes around 8 cm

8. CONCLUSION

In this study area, an example on how a beach faces serious coastal erosion if the characteristics or the balance of the coastal area are changed or damaged is illustrated. For this case, this change is observed as damaging and removing the rocky formations which naturally act as submerged breakwaters or reefs and thus, protecting the beach from harm that may be caused by waves. As a remedy to the erosion problem, several solution alternatives are tried by using a numerical model based on one-line theory, CSI. The reason for using this model is that it has simple inputs and it is a user-friendly program. Moreover, it performs refraction and diffraction processes by taking into account the structural effects. Among all the solution alternatives, the most effective and suitable one is suggested as the solution. As seen from Figure 5, this alternative is the closest one reflecting the previous natural characteristics of the beach. This alternative includes a submerged breakwater, a groin at the western end of the beach, artificial beach nourishment which is applied to the western beach and a gabion berm system in front of the artificial nourishment in order to protect artificial nourishment. It is decided that after the construction of this system, it is necessary to monitor the shoreline changes periodically. This is vital for calibration and upgrading of the numerical model, CSI.

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