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Analysis of Shoreline Changes by a Numerical Model and Application to Altınova, Turkey

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ABSTRACT

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In this study, firstly, the shoreline changes for various wave heights, wave periods and angles have been investigated on straight and curved beaches. The "One Line Model" of Hanson and Kraus which determines the shoreline changes by explicit finite difference numerical model, has been utilized. Subsequently, this numerical model has been applied to the shores of Altınova Town in Balıkesir, Turkey. Altınova has a valuable coastal zone that is located on the Aegean Sea with a coastline running more than 13 km and has a very high potential for tourism. It has been assumed that sediments are transported along the shore due only to the sea waves. In order to evaluate bathymetric changes and shoreline movement in the Altınova coast, hydrographic measurements were made in August 1996 and December 1997. In the nearshore region coastal erosion has clearly been predicted by comparison of numerical model results and data obtained by field measurements. Coastal structures have been suggested to protect against erosion.

ADDITIONAL INDEX WORDS: *Longshore sediment transport, straight beach, curved beach, coastal structures.*

INTRODUCTION

Shore protection and beach stabilization are major responsibilities in the field of coastal engineering. Beach erosion, accretion, and changes in the offshore bottom topography occur naturally, and engineering works in the coastal zone also influence sediment movement along and across the shore, altering the beach plan shape and depth contours. Beach change is controlled by wind, waves, current, water level, nature of the sediment (assumed here to be composed primarily of sand), and its supply. These littoral constituents interact as well as adjust to perturbations introduced by coastal structures, beach fills, and other engineering activities. Most coastal processes and responses are nonlinear and have high variability in space and time (HANSON, 1991).

In this study, shoreline changes is analysed by a numerical model and the model is applied to Altınova coastline where chronic erosion are observed. Then the measures for stability of coastline are also determined.

THE SHORELINE MODEL

Basic Equations

In the present work, it will be sufficient to use the equation for the shoreline position in its most basic form:

$$\frac{\partial y}{\partial t} + \frac{1}{D}\frac{\partial Q}{\partial x} = 0 \qquad (1)$$

where y is shoreline position (m), t is time (s), D is depth of closure (m), Q is volume rate of longshore sediment transport (m^3/s) and x is distance alongshore (m).

For simplicity, only longshore transport of sand is considered. It is straightforward to generalize Equation 1 to formally include contributions for cross-shore transport, as well as sediment sources and sinks.

The longshore transport rate, Q, is usually calculated from the "CERC" formula (SPM, 1984):

$$Q = K' (H^2 C_g)_b \sin 2\theta_{bs} \qquad (2a)$$

$$K' = \frac{K}{16(S-1)a'}\left(\frac{1}{r}\right)^{5/2} \qquad (2b)$$

where K is dimensionless empirical coefficient, H is significant wave height (m), C_g is wave group velocity (m/s), θ_{bs} is angle of breaking waves to the shoreline (deg), S is ratio of sand density to water density, a' is volume of solids / total volume and r is conversion factor from Root Mean Square (RMS) to significant wave height, if necessary (equals 1.416). The subscript b indicates quantities at wave breaking.

Explicit Numerical Model

Equation 1 will be discretized using a staggered grid representation, as shown in Figure1. The x-axis, which runs parallel to the trend of the shoreline, is divided into N calculation cells by N+1 cell faces (solid vertical lines in Figure 1), with a general cell denoted by i. On this grid, Q-points and y-points are defined alternately. Q-points define calculation cell faces and y-points lie at the centers of cells. Subscripts denote locations of points along the beach. Both Q-grid points and y-grid points are separated by a constant distance Δx alongshore; the distance between a Q-point and an adjacent y-grid points is Δx/2. Lateral boundary conditions must be specified at the ends of the grid, e.g., at Q_1 and Q_{N+1}. Alternatively, it is possible to specify boundary conditions at y_1 and y_N, or impose a condition on y at one end of the grid and a condition on Q at the other end.

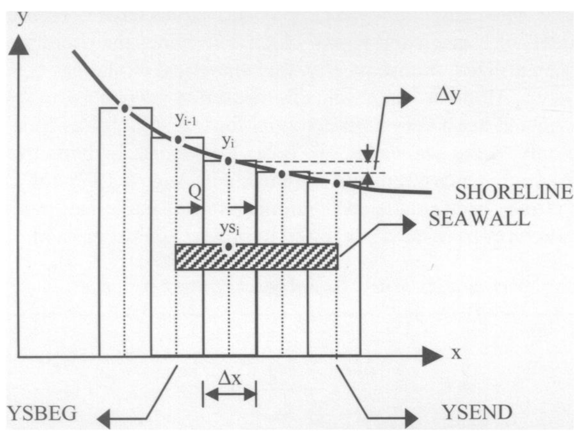

Figure 1. Definition sketch for finite difference discretization (HANSON and KRAUS, 1986).

For simplicity, only one seawall will be considered. Its beginning and ending coordinates on the x-axis are denoted by YSBEG and YSEND, respectively, as shown in Figure 1 (HANSON and KRAUS, 1986). A general y-position at the seawall is denoted by ys_i.

In a standard explicit scheme, Equation 1 is discretized as

$$y_i^{'} = 2B(Q_i - Q_{i+1}) + y_i \qquad (3)$$

where B is $\Delta t / (2D\Delta x)$ (s/m^2), Δt is time step (s) and Δx is space interval (m).

In this study, variable wave heights, wave periods and the angle of breaking waves to x-axis have been tested for straight and curved beaches (Figures 6 and 9). In computer program DENOM is the value of physical quantities in the denominator of Equation 2b, evaluated for quartz sand. K1 is the empirical coefficient (K) in Equation 2b. The wave period is denoted by T (seconds).

The length of the hypothetical examples is 2 km and Δx is determined as 50 m (N = 40 number). A curved seawall is located 4 m landward of the initial shoreline (Figures 6 and 7).

ALTINOVA CASE

Altınova is a town in Balıkesir, Turkey, has a valuable coastal zone that is located on the Aegean Sea with a coast line running more than 13 km and has a very high potential for tourism (Figure 2). In view of the wind data of this region, dominant wind direction has been observed as SW. Annual mean wind speed 3 m/s, maximum mean wind speed 27.9 m/s in the direction SW and W.

Madra River located between Altınova and Dikili is main sediment source of coastal line. The dam located on Madra River, the erosion-control works in Kozak region and the sand taken from Madra River bed cause in the decrease of sediment amount at coast. In the last decade Altınova coastline have suffered because of chronic and permanent erosion having incredibly intense increase. As a result of this dramatic process, the shoreline had retreated approximately 600 m during the last two decades and 18 ~ 20 m in the last one year (KABDASLI *et al.*, 1996).

Fetch length is calculated as Fe = 37.984 km. The significant wave height and significant wave period which will be used in numerical model is calculated for Altınova:

$$H_s = 5.112\ 10^{-4}\ u_A\ Fe \cong 1.00\ m,$$
$$T_s = 5.926\ 10^{-2}\ (u_A\ Fe)^{1/3} \cong 4.3\ s$$

At Altınova coast the length of the selected application region is 5 km. First shoreline positions Y0(I) are determined with Δx = 100 m. (N = 50 number). Shoreline variations of 84 and 180 hours are obtained for DENOM = 2.362 and K = 0.12 (Figure 10).

Field Measurements

In order to evaluate bathymetric changes and shoreline movement in the Altınova coast near Madra River mouth, depth measurements were made on August 1996 and December 1997 and the cross-section locations are seen in Figure 2. The wave climate of Ayvalık and Dikili was made with SMB and CERC Methods and determined the nearshore properties of waves (IRTEM *et al.*, 1998).

That a deep pit exists in Altınova coast around Madra River mouth is the most interesting result of bathymetric measurements. This factor accelerates the erosion at coastal line. Because of this pit, the sand is removed by storms, and it can not return again. Generally, the slope of nearshore is invariable. This is an expected result since the effect of sea is constant. If the profile were surveyed to a distance further inland, the coastline would be observed to recede approximately 50-100 m. (Figures 3 and 5) (IRTEM *et al.*, 1998).

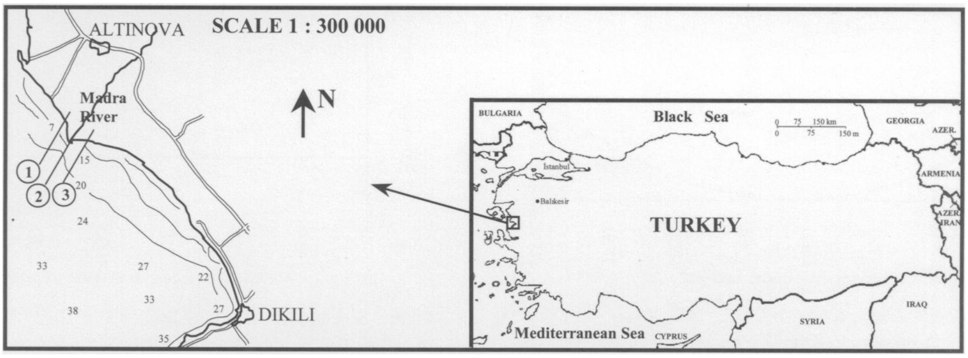

Figure 2. Map of the Altınova region and cross-section locations (IRTEM, 1998).

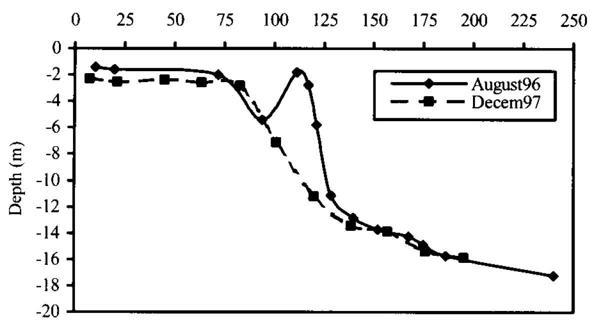

Figure 3. Depth measurements (Cross-section 1).

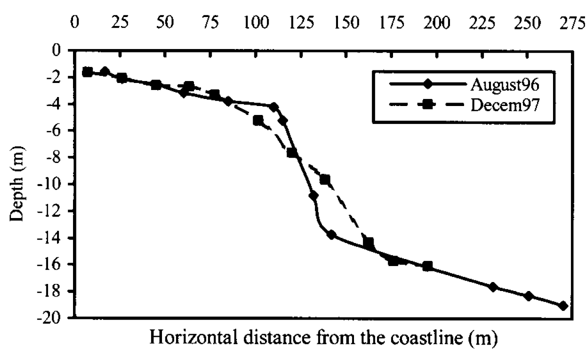

Figure 4. Depth measurements (Cross-section 2).

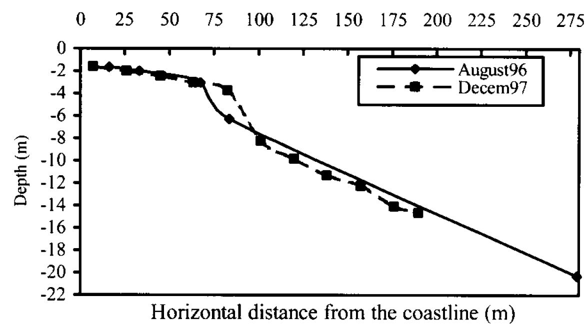

Figure 5. Depth measurements (Cross-section 3).

RESULTS

It has been assumed that sediments are transported along the shore due only to the sea waves in the numerical model. The existence of seawall and jetty are taken into account. The results are as following:

- For the straight beach when the denominator value of Equation (2.b) (DENOM) increased, accumulation at the unit which is adjacent to the jetty in the end of beach decreased. The same work was carried out for the curved beach and the same results were obtained. Increase in the DENOM value means increase in the ratio of sediment volume to total volume. This means decrease in the ratio of void and decrease in the transport Q along shore (Figures 6 and 7).

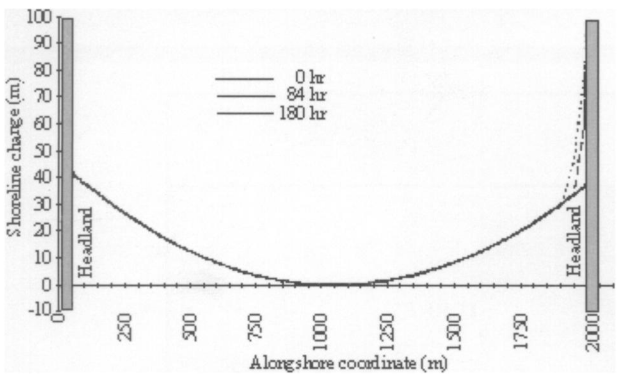

Figure 6. For DENOM = 2.362, K1 = 0.12, T = 8.0, YS(I) = YO(I) - 4, RADIUS = 12000, H = 1.00, θ = 45 shoreline change on curved beach.

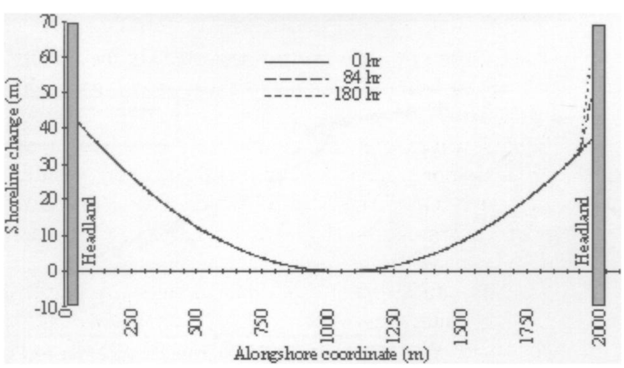

Figure 7. For DENOM = 5.00, K1 = 0.12, T = 8.0, IS(I) =YO(I) – 4, RADIUS = 12000, H = 1.00, θ = 45 shoreline change on curved beach.

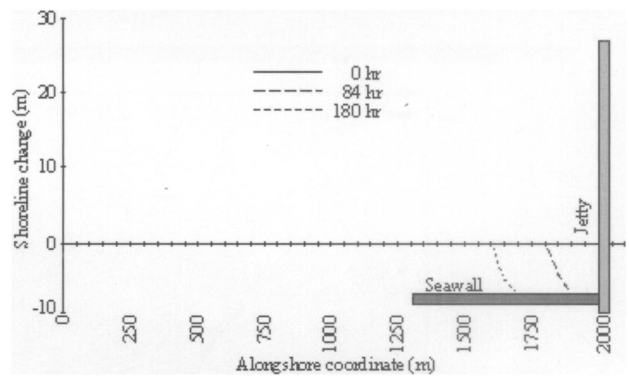

Figure 8. For DENOM = 2.362, K1 = 0.12, T = 8.0, YS(I) = - 7 m, H = 1.00, θ = 90 shoreline change on straight beach.

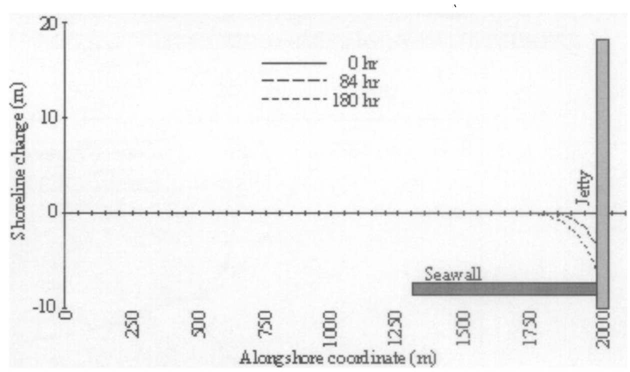

Figure 9. For DENOM = 2.362, K1 = 0.12, T = 8.0, YS(I) = - 7 m, H = 1.00, θ = 135 shoreline change on straight beach.

- The accumulation at the unit which is adjacent to the jetty increased with decreasing period. When the period is increased, the sediment movement decreases due to decrease in the wave effect and this result could be expected. For the curved beach, the same results were obtained (IRTEM *et al.*, 1998).
- For straight beach, if the angle of breaking waves to x-axis (θ) is kept constant, and the wave height increased, the erosion also increased (IRTEM *et al.*, 1998).
- For straight beach, if the wave height is kept constant, and the angle of breaking waves to x – axis increased, the variation begins at the units which are closer to jetty. For the curved beach, the same results were obtained (Figures 8 and 9).
- The explicit numerical model has been applied to the shores of Altınova. It is seen that the erosion taken place at many units (Figure 10).

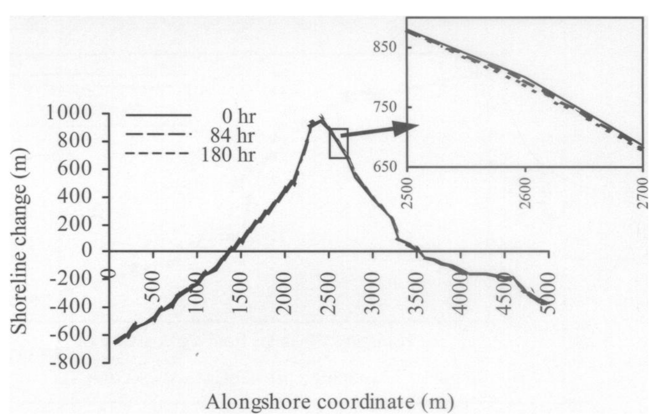

Figure 10. For DENOM = 2.362, K1 = 0.12, T = 4.3, H = 1.00, , θ = 90 shoreline change on Altınova beach.

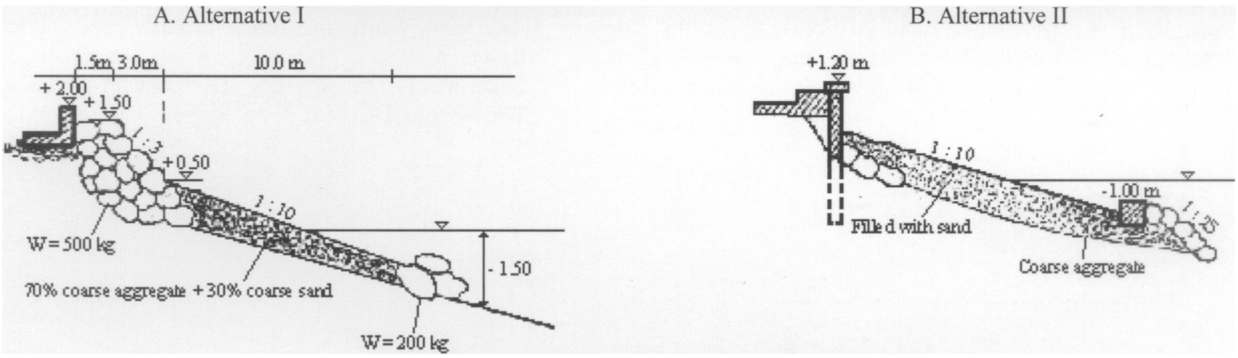

Figure 11. Suggested Structures. (A) Alternative I. (B) Alternative II.

THE SUGGESTED STRUCTURES FOR ALTINOVA

In Altınova, coastal structures are suggested to stop the erosion.

a) In the locality of Altınova the one of the two alternatives given in Figure 11.a and Figure 11.b can be suggested.
b) The locality of Dikili may be protected with a rubble mound structure on the natural shoreline.
c) Madra River mouth may be stabilized with rubble mound structures.

Under these applications, the new coastal plan is given in Figure 12.

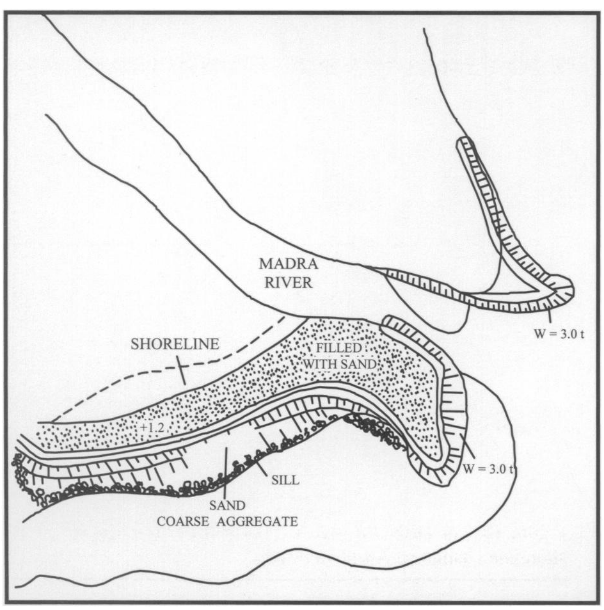

Figure 12. The new coastal plan.

CONCLUSION

Longshore sediment transport caused by the effects such as wind flows, shore currents, waves, tides, etc., change the shoreline by the time. Longshore current formed by the refracted waves and the components of wave energy along with the shore generate sediment transport parallel to the shore. The "One Line Model" which is one of the numerical models determine the shoreline development, is widely in use in the recent years.

In this study, the shoreline change by explicit finite difference numerical model of Hanson and Kraus has been determined. Various wave heights, wave periods and refraction angles have been tested.

Numerical model has been applied to Altınova coastline in Balikesir. In view of the wind data of this region, dominant wind direction is observed as SW and significant wave height is computed as H = 1m. It is assumed that sediments are transported along the shore due only to the sea waves. The equation used for the shoreline is the equation of continuity for the beach sediment.

In order to evaluate bathymetric changes and shoreline movement in the Altınova coast hydrographic measurements were made on August 1996 and December 1997.

The coastal erosion has been clearly predicted by comparison of numerical model results and data obtained by field measurements.

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