OBSERVATION OF THE POST-CONSTRUCTION PERFORMANCE OF A SYSTEM OF GROINS ALONG AN ERODING BEACH

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Résumé - Etude de cas consacrée à la côte nord de la Crète où la construction d’un port de pêche a entraîné une vive érosion de la côte, avec pour conséquence également le rapide comblement du bassin. Un laboratoire a étudié diverses solutions possibles à cette évolution après une modélisation complète du système : celle-ci a permis de montrer l’existence d’une puissante dérive littorale, bien supérieure en volume à ce qui s’échange entre la plage et les petits fonds. Les épis ont semblé la meilleure des protections possibles dès lors qu’on n’envisageait pas le déplacement du port. L’implantation de 6 épis a fait l’objet d’un suivi dont les résultats provisoires sont présentés.

Mots-clés - Grèce, Crète, érosion de plage, ingénierie côtière, modélisation, protection côtière, système d’épis.

Abstract - A system of six groins was constructed along an eroding coast of reversing sediment transport. This paper describes the performance of the groin system in terms of the evolution of the shoreline, as function of angle of wave approach and the location of each groin within the system.

Key-words - Greece, Crète, beach erosion, coastal engineering, scale model, beach monitoring, groynes system.

Introduction

The coast of Aghia Marina-Platanias is located on the northern coastline of the island of Crete, Greece, at a distance of approx. 10 km to the west of the city of Khania (see Fig. 1). It has a length of approx. 1500 km, measured along the shoreline. The shoreline exhibits a curvature, which increases from west to east. A rocky headland at the eastern end separates the coast from an adjacent beach, where the shoreline changes orientation drastically (see Fig. 2). The sediment on the sea bed is medium to coarse-grain sand. The coast has a fairly high wave energy, as it is exposed to long fetches from the NW-NE sector corresponding to the dominant wind direction. A small island provides considerable protection against the NNE-NE sector. Maximum characteristic wave heights in the deep sea may be as high as 4 m and tides are almost negligible.

The construction of a small artificial fishing harbour at Platanias was completed in 1985 (see Fig. 2). The harbour consists of two rubble-mound breakwaters jutting from the coastline into the sea with a small opening towards the east. Before the construction of the harbour, the coast presented an unobstructed wave-induced longshore drift and was stable. After the harbour was constructed, the morphology of the coast began to change. Sediment accretion occurred both to the left and to the right of the harbour and erosion appeared in the central part of the coast (see Fig. 3). Intense sediment accumulation occurred in the harbour basin, which caused a considerable decrease in water depths and made the harbour unusable. The shoreline
Fig. 1.- Location maps

Fig. 2.- The coast of Aghia Marina-Platanias before and after the construction of the harbour

Fig. 3.- Modification of the coastline
immediately to the east of the harbour advanced almost 70 to 80 m within 3 years. The eroded coast had a length of more than 400 m. Depletion of the existing sediment layer created problems for the flourishing local tourist industry.

**Study**

The Laboratory of Harbour Works, National Technical University of Athens, was commissioned to undertake a research programme by the Khania Ports Authority. The main objective of the programme was to investigate the mechanisms causing changes in the local morphology.

The coast extending between the harbour to the west, and the headland to the east, could be considered to be an independent coastal unit. The harbour interrupts the longshore continuity of physical processes and the headland separates the coast from the adjacent beach. Long-term wind statistics from the Khania Meteorological Station were collected to evaluate the wave climate in the deep sea. A deep-sea wave model calibrated in a neighbouring coastal area was used in the computations. The maximum wave energy was found to originate from both the NW-N (mainly) and N-NE sectors. The topography of the sea bed from a detailed bathymetric survey was introduced into a refraction model to estimate the nearshore wave climate. The cross-shore bed slope was found to range between 1.7 % and 3 %. Design waves from each direction (W, NW, N, NE and E) were selected and the corresponding breaker lines were defined. The coast was found to be mainly of the dissipative type.

An extensive programme of sediment sampling from the sea bed and sieve analysis led to conclusions concerning the mobility of the sediment. Samples were collected from various sections along and across the coast. Statistical parameters of the grain population in each sample were estimated (see Fig. 4).

<table>
<thead>
<tr>
<th>Sample</th>
<th>( M_z )</th>
<th>( M_y )</th>
<th>( \theta_1 )</th>
<th>( \theta_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>-0.37</td>
<td>10.34</td>
<td>-0.37</td>
<td>31.88</td>
</tr>
<tr>
<td>1-2</td>
<td>-0.39</td>
<td>26.32</td>
<td>-0.39</td>
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<td>2-1</td>
<td>0.14</td>
<td>0.91</td>
<td>-0.01</td>
<td>0.91</td>
</tr>
<tr>
<td>2-2</td>
<td>-0.46</td>
<td>5.56</td>
<td>-0.32</td>
<td>3.74</td>
</tr>
<tr>
<td>3-1</td>
<td>0.05</td>
<td>0.40</td>
<td>-0.26</td>
<td>0.32</td>
</tr>
<tr>
<td>3-2</td>
<td>-0.89</td>
<td>1.91</td>
<td>-1.32</td>
<td>1.36</td>
</tr>
<tr>
<td>4-1</td>
<td>-0.75</td>
<td>1.92</td>
<td>-0.37</td>
<td>1.92</td>
</tr>
<tr>
<td>4-2</td>
<td>-1.15</td>
<td>3.22</td>
<td>-1.86</td>
<td>3.22</td>
</tr>
<tr>
<td>5-1</td>
<td>-0.57</td>
<td>1.60</td>
<td>-0.56</td>
<td>1.60</td>
</tr>
<tr>
<td>5-2</td>
<td>-2.06</td>
<td>4.28</td>
<td>-1.91</td>
<td>4.28</td>
</tr>
<tr>
<td>6-1</td>
<td>-0.38</td>
<td>1.21</td>
<td>-0.26</td>
<td>1.21</td>
</tr>
<tr>
<td>6-2</td>
<td>1.16</td>
<td>7.74</td>
<td>3.43</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Figure 4 - Longshore distribution of sediment on the sea bed.
Computations along the western part of the coast showed that the longshore component of wave energy flux to the right, $P_{ls,r}$ is slightly higher than the component to the left $P_{ls,l}$ (see Fig. 5), as a result of the shoreline orientation and the protection provided by the island. Neglecting the protection provided by the island, the energy flux to the left (towards the harbour) is found to be higher than the flux to the right along the eastern part of the coast, which again is due to the changing coastline orientation. If the shadow of the island is taken into account, $P_{ls,r}$ and $P_{ls,l}$ tend to approach the same order of magnitude along the total length of the coast. Finally, it was concluded that both components of wave energy flux are roughly of the same order of magnitude all along the coast. On an annual basis, the direction of net longshore flux is from east to west.

The computed longshore components of wave energy flux and the cross-shore distribution of sediment, as found on the sea bed, were used to evaluate the potential longshore sediment transport rates to the left ($Q_{p,l}$) and to the right ($Q_{p,r}$). The method used was the one proposed by CERC, as modified by Moutzouris, 1988, to take into account the cross-shore sorting of sediment grain sizes. $Q_{p,l}$ was found to be larger than $Q_{p,r}$ along the eastern part of the coast (see Fig. 6), due also to the cross-shore distribution of grain sizes. As mentioned earlier, the storage capacity of the eastern end of the coast is limited, which means that sediment does not enter the coastal system from this region in considerable quantities. On the other hand, the harbour acts as a trap to the sediment moving eastwards. Therefore, the actual longshore rate to the left $Q_{r,1}$ would be larger than $Q_{r,2}$ along the western part of the coast. Both rates would be of the same order of magnitude along the eastern part.

From the above study it was concluded that the dominant mode of sediment transport is principally alongshore. A moderate onshore-offshore transport across the beach is also present, because the wave climate is mostly composed of rather steep waves. The origin of the sediment accreted inside the harbour basin and on the coast immediately to the east of the harbour is mainly the eroded zone of the coast. The accretion observed on the coast immediately to the
west of the harbour is due to sediment from the coast extending to the west of the harbour and also due to bypassing. The net direction of longshore transport is to the left, although there is a significant reversal in the direction of transport.

As the harbour was not intended to be removed, the Laboratory recommended that a series of groins should be built along the coast to provide protection. Computations using the one-line theory of Pelnard-Considere gave rough indications concerning the advancement of the coastline Y as function of the distance X from a groin (see Fig. 7), although the longshore transport is not fully interrupted. The design breaking waves which were. Finally, it was recommended to construct a system of six rubble mound groins G_i (i = 1 to 6) along the coast. The geometrical and other features of the groin system are presented in Fig. 8. The system covered the total length of the coast between the harbour and the rocky part of the coast in order to avoid erosion in the downdrift zone.

![Fig. 7: Shoreline simulation based upon the one-line theory](image)

<table>
<thead>
<tr>
<th>Groin</th>
<th>Length (m)</th>
<th>Depth at the end (m)</th>
<th>Crest (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>85</td>
<td>-3.0</td>
<td>+1.0 to +1.5</td>
</tr>
<tr>
<td>G2</td>
<td>85</td>
<td>-3.0</td>
<td>+1.0 to +1.5</td>
</tr>
<tr>
<td>G3</td>
<td>85</td>
<td>-3.0</td>
<td>+1.0 to +1.5</td>
</tr>
<tr>
<td>G4</td>
<td>85</td>
<td>-2.7</td>
<td>+1.0 to +1.5</td>
</tr>
<tr>
<td>G5</td>
<td>85</td>
<td>-2.0</td>
<td>+1.0 to +1.5</td>
</tr>
<tr>
<td>G6</td>
<td>55</td>
<td>-1.8</td>
<td>+1.0</td>
</tr>
</tbody>
</table>

fig. 8 - the groin system.
Groins G1 to G5 were constructed during the summer of 1989. G6 was completed in the string of 1990. Therefore, the coast is now divided into seven compartments $C_k$ ($k = 1$ to $7$).

The groin system was left to act on the coast during the period October 1989 - March 1990, which is a winter period with considerable wave action. The post-construction performance was studied during the period from March to June 1990. The performance is described in terms of sediment accumulation/depletion observed in each compartment and also in terms of the shoreline evolution.

**POST-CONSTRUCTION PERFORMANCE**

Data from field observations of shoreline evolution found in the literature are mainly for single coastal structures. Only few quantitative data can be found concerning shoreline changes caused by a groin system. The general shoreline configurations for two or more groins with a net longshore sediment transport and also for two groins operating with transport reversal can be found in the Manuals of CERC, 1984. The so-called two-line theory of Bakker includes the effects of partial transport blockage. The same is true for numerical models, according to Hanson and Kraus, 1986. The number of studies dealing with shoreline changes caused by multiple structures is very limited. Furthermore, in most of the reported cases, the corresponding coasts were characterised by a clearly defined direction of longshore wave energy flux.

For the cases reported in the present paper, the groin system acts on a coast with reversal of the direction of longshore transport. Shoreline changes are controlled considerably by sediment trapping in/by the harbour. The rather small lengths of the groins produce small shadow zones and therefore diffraction does not play an important role.

The shape of the shoreline between two successive groins is found to be in dynamic equilibrium with the sediment supply and the wave climate, as observed in crenulate or zeta shaped bays between natural headlands (Silvester et al., 1980). U-shaped shorelines are observed under all wave conditions and in every compartment, which may be explained by taking into account the reversing direction of longshore transport. Downdrift sides of the groins also become filled due to sediment bypassing. Persistent wave action from one direction produces a uniformly curved beach. Secondary influences, such as wave reflection of diffraction, are not evident.

Accretion fillets are permanently formed on both sides of the groins, which indicates that all compartments have gained sediment in the vicinity of the groins. Recession of the shoreline is observed in the central part of each compartment, but in most cases the recessed shoreline has not reached the position of the shoreline before the construction of the groins. This means that most compartments have gained sediment in their central region.

As can be seen in Fig. 9, the compartments which did not gain sediment in the center are C1, C3 and C6. A first explanation for C1 is that part of the sediment load moving in the compartment enters the harbour and, consequently, does not contribute to the accretion within the compartment. A second explanation could be that groin G1 should be extended or should have been constructed closer to the harbour. The erosion in the center of compartment C6 will most probably vanish if the length of G6 increases. There is no obvious reason for the performance of the central region of compartment C3.

The beach adjustment near groins was studies as function of both the angle of wave approach and the location of each groin within the system. Fig. 10 shows the advancement of
the shorelines at groins G2 and G3 following the action of waves over a long period from various directions. As stated earlier, sediment fillets form on both sides of the groins due to the accumulation of long shore drifting sediment and to bypassing. The changes in shoreline position depend upon the quantities of sediment entering and leaving each compartment. Let $l_{i,r}$ $(l_{i,l})$ be the maximum advancement of the shoreline observed on the right hand (left hand) side of groin i after the persistent action of waves from a certain well-defined sector. As determined from measurements, the following conclusions were arrived at concerning the values of $l_{i,r}$ and $l_{i,l}$:

- Maximum values were found following the action of waves from the N-E sector, as would have been expected on the updrift face of groins with obliquely incident waves.
- Minimum values were observed after the action of waves from the east due to reduced quantities of longshore drifting sediment from this direction and due to the angle of approach.
- Intermediate values of $l_{i,r}$ result from waves from the W-N sector, which means that a considerable bypassing of the groins takes place.

Concerning $l_{i,l}$
- Maximum values were found for waves from the W-N sector.
- Minimum values were measured when waves approached from the N-E sector.

The trapping capacity of the successive compartments is now examined. Let $Q_{k,1}$ and $Q_{k,r}$ be the longshore transport rates to the left and right, respectively, observed in compartment k. $Q_{k,1}$ and $Q_{k,r}$ depend upon the longshore wave energy flux in the compartment, the sediment available in the compartment and, finally, the quantity of sediment bypassing from the previous compartments.

According to the so-called "one-line theory", for given values of active depth, angle of wave approach and duration of wave action, the advancements of the shoreline $l_{i,r}$ and $l_{i,l}$ at groin i $(i = 1$ to 6) depend upon the square root of $Q_{i+1,1}$ and $Q_{i,r}$ respectively. Let $v_{i,1}$ (=...
Qi,1/Qi + 1,1) and \( \phi_{i,r} (= Q_i + 1,1/Q_{i,r}) \) be the trapping coefficients of groin \( i \) for sediment moving to the left and right, respectively, and let \( \psi_{k,1} (= Q_k - 1,1/Q_{k,1}) \) and \( \psi_{k,r} (= Q_k + 1,1/Q_{k,1}) \) be the corresponding trapping coefficients of compartment \( k \). Various characteristic values found along the coast are as follows:

\[
\phi_{2,1} = 1 \\
\phi_{3,1} = 1 \\
\phi_{4,1} = 2.9 \text{ to } 4.8 \\
\phi_{5,1} = 2.5 \text{ to } 6 \\
\psi_{2,r} = 1.2 \text{ to } 2.5 \\
\psi_{4,r} = 0.1
\]

(depending upon the sector of wave approach)

In Fig. 11 are presented characteristic values of \( l_{i,r}/l_{i-1,r} \) as function of the sector of wave approach.

The values of advancements \( l_{i,r} \) and \( l_{i,1} \) were also examined as functions of the location of groin \( i \) within the system (see Fig. 12). It is seen that \( l_{i,r} \) and \( l_{i,1} \) are almost equal at groins on the eastern part of the coast (15,r = 15,1), probably due to the fact that \( Q_{r,1} \) is of the same order of magnitude as \( Q_{r,r} \). Along the western part of the coast, where \( Q_{r,1} \) is larger than \( Q_{r,r} \), \( l_{i,r} \) is found to be almost always greater than \( l_{i,1} \).
DISCUSSION

The coast of Aghia Marina-Platanias was an eroding coast of reversing sediment transport before the system of six groins was constructed. The cause of erosion was an artificial harbour constructed in the middle of the coast, which acted as a sediment trap. The groin system was quite successful in reversing the erosion trends. The shape of the new shoreline is in dynamic equilibrium with the sediment supply and the wave climate. Accretion fillets have now formed permanently on both sides of the groins. Longshore drifting sediment is mostly trapped by the groins. Bypassing of the groins is significant because of the rather small lengths.

Observation of the post-construction performance of the groin system is continuing. Further research will concentrate on the cross-shore and longshore distributions of sediment grain sizes. The distributions will be compared to the sediment sorting before the construction of the groins in order to detect the influence of the groins.

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