ELSEVIER

Coastal Engineering 26 (1995) 225–239

COASTAL ENGINEERING

Coastal erosion in Eastern Black Sea Region, Turkey

Ömer Yüksek, Hizir Önsoy, Ali Remzi Birben, Ismail Hakkì Özölçer

Karadeniz Technical University, Civil Engineering Department, 61 080, Trabzon, Turkey

Received 5 July 1994; accepted 5 July 1995

Abstract

Eastern Black Sea Region, located in the north east of Turkey, has been exposed to severe coastal erosion and shoreline recession for the last 30 years. One of the most important reasons for this problem is the response of the coast on man made activities. As a result of sand mining by people and municipalities, the coastal balance was broken. Another important cause is the construction of a highway by filled soil near the shore. The wave energy increases by reflected waves from these slopes and causes a seawardly sediment transport. Finally, the other important reason for erosion and recession is incorrect site selection, planning and design of coastal structures such as harbours and fishery harbours.

In this study, general knowledge about wind data, wave hindcasts and sediment regimes of the Eastern Black Sea Region is introduced; the places in which coastal erosion is important are presented and some measures to diminish the erosion are studied. Possible remedies in order to re-establish the beaches are investigated and some design criteria are presented for various engineering structures to be planned against the erosion.

1. Introduction

In the Eastern Black Sea Region of Turkey, the migration problem from rural to urban areas since 1950s has caused several environmental and coastal problems. Unlawful and unconscious urbanization is one of the most important ones. As the urban population goes up, the need for various coastal structures and recreation areas also increases. These structures have broken the coastal balance and caused generally erosion and sometimes local siltation problems.

Since waves are the main factors to create erosion and siltation problems at coasts, adequate wave data are essential in studying coastal changes. In the studied region, however, there is no wave gauging. Thus, waves should be hindcasted by using wind data.

0378-3839/95/$09.50 © 1995 Elsevier Science B.V. All rights reserved
SSDI 0378-3839(95)00022-4

The State Highway, constructed in 1960s, was made by filling the soil. Waves reflected from these structures cause severe seaward sediment transport. In a study made for solving this problem, shore-parallel revetments were proposed and it was observed that these structures have diminished the damage to the highway. But, they have also broken the connection between people and sea and destroyed coastal aesthetics; moreover, in a long time they create additional shore erosion.

Especially in recent years, groins and offshore breakwaters have been succesfully employed in coastal protection schemes. Especially groins are supposed to be useful in the studied region.

Various large and small coastal structures have been constructed in the studied region. Since most of them were designed without taking into consideration their effects on the neighbouring coasts, significant erosion and sometimes siltation problems are often observed in the vicinity of these structures.

The above process have brought about severe coastal problems in the region. In order to determine the localities in which erosion problems are very important, to obtain an inventory of the coasts and to research possible measures, a two-yearly project has been carried out. In this project, the Eastern Black Sea Region was scanned step by step with respect to coastal changes; field, desk and laboratory studies were carried out and the results were published as a report (Önsoy and Yüksek, 1993). In this study, prepared by means of this report, wind, wave and sediment properties of the region are studied; the localities of severe erosion and recession are classified according to their priority and some measures to diminish these problems are presented. The present paper describes the main results of that study.

2. The studied region

2.1. Location

Eastern Black Sea Region is located in the north east of Turkey (Fig. 1). Shoreline length of the region is nearly 450 km. General alignment of the shoreline is west to east; however, also some coasts in a north to south alignment do exist.

2.2. Wind data

Wind data, employed in order to determine the wind climate of the region, are obtained from Hourly Windspeed Tables of Rize, Trabzon, Giresun and Ordu Provinces. Assuming that the average of these four provinces can represent the whole region, the mean wind rose is obtained and given in Fig. 2. As seen, dominant wind directions are SSW and SW. Since these winds blow from land to sea, they are not able to create incoming waves in the region. The windspeed distribution is given in Fig. 3. As seen, most of winds (89.4%) have speeds less than 3 m/s, a critical value assumed to create waves which cause important sediment transport in the region (Yüksek, 1992).

2.3. Wave hindcasts

Since there are no gauged wave data in the region, waves were hindcasted by using wind data. These data can be obtained both from Hourly Windspeed Tables (HWT) and Surface

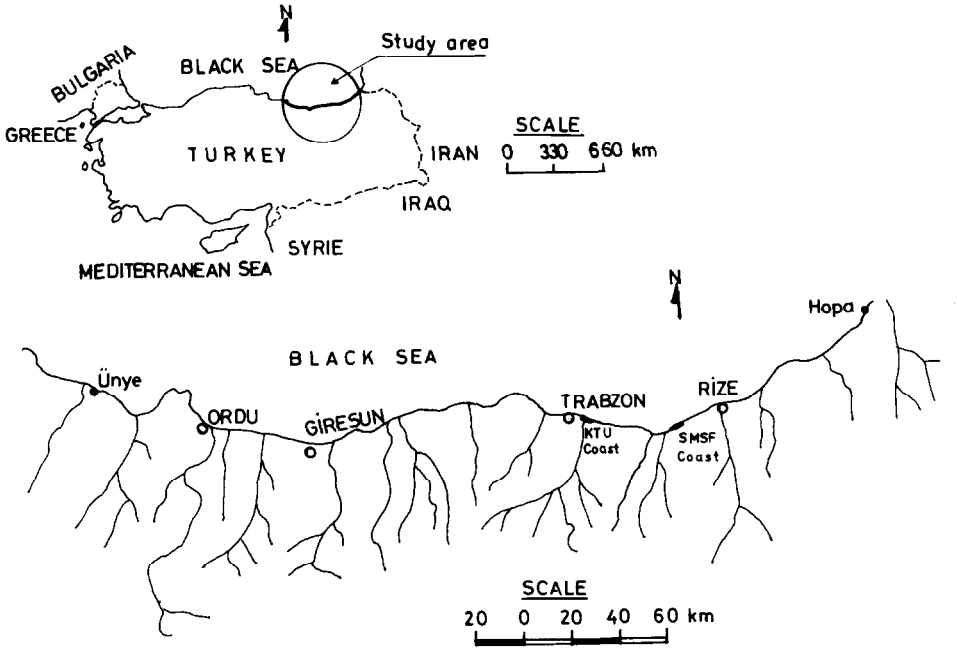


Fig. 1. Location map of the studied region.

Synoptic Charts (SSC). A study (Çam, 1986) has shown that the latter (SSC) gives more reliable and accurate results, while the former (HWT) gives rise to smaller wave estimates. Thus, in this study, SSC were used in wave hindcasting.

Taking into consideration the general alignment of shoreline, it is determined that the effective directions for wave occurring are ENE, NE, NNE, N, NNW, NW and WNW. Using nine yearly wind data of Hopa, Trabzon and Ordu Provinces and taking into consideration the above directions, significant wave heights ($H_{1/3}$) and periods ($T_{1/3}$) are hindcasted by using SMB method. 594 sea states are calculated of which $H_{1/3}$ is greater than 0.3 m which is assumed to be the smallest wave which can cause effective coastal changes (Çam, 1986). The cumulative observance probabilities (p) of these waves are given in Figs. 4 and 5 (p related to the small fraction of time that waves approach from northern directions).

As can be seen from Figs. 4 and 5, dominant wave directions are N, NNW and NW, which means that the net sediment transport direction is from west to east. This idea is verified by field observations. At the west sides of several coastal structures (harbours, groins, etc.) sand deposition (fillets) have indeed been observed; while, at the east sides of them severe erosion exists as a result of the interruption of the sediment flow.

By evaluating the 594 sea states, it can be said that the average significant wave heights and periods for waves from WNW to ENE of the region are 1.5 m and 5.5 sec and the estimated maximum values are 6.92 m and 10.3 sec, respectively.

2.4. Sediment regime

There are lots of rivers reaching the Black Sea in the region. The basins and bed slopes of these rivers are relatively large and it is estimated that they carry 3 to 5 million tons of

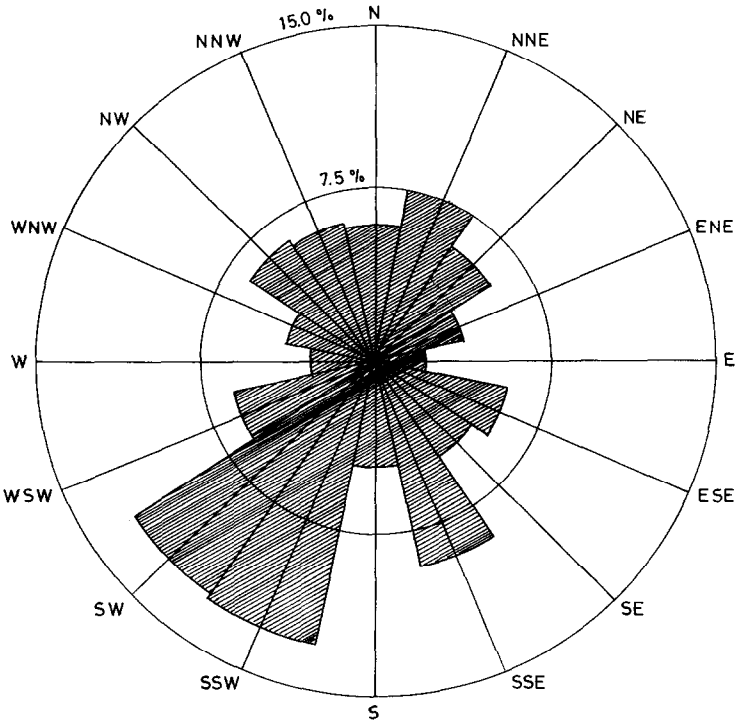


Fig. 2. Wind rose of the region.

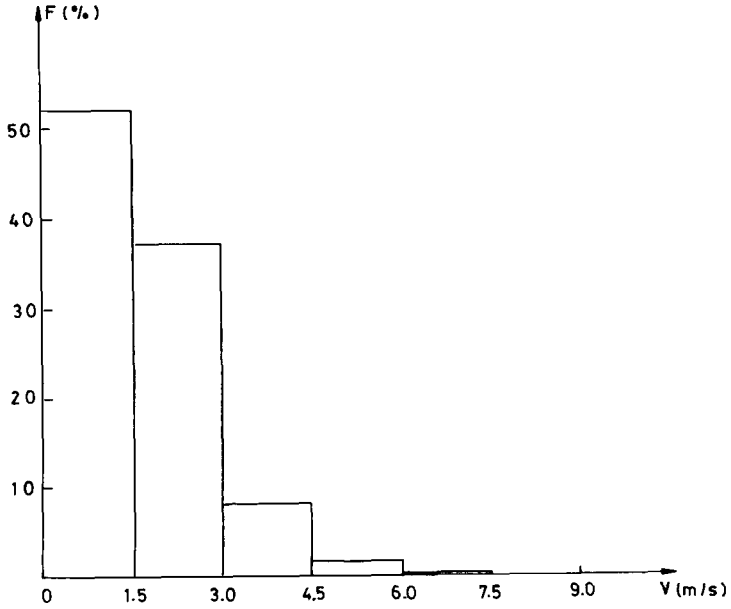


Fig. 3. Windspeed distribution of the region.

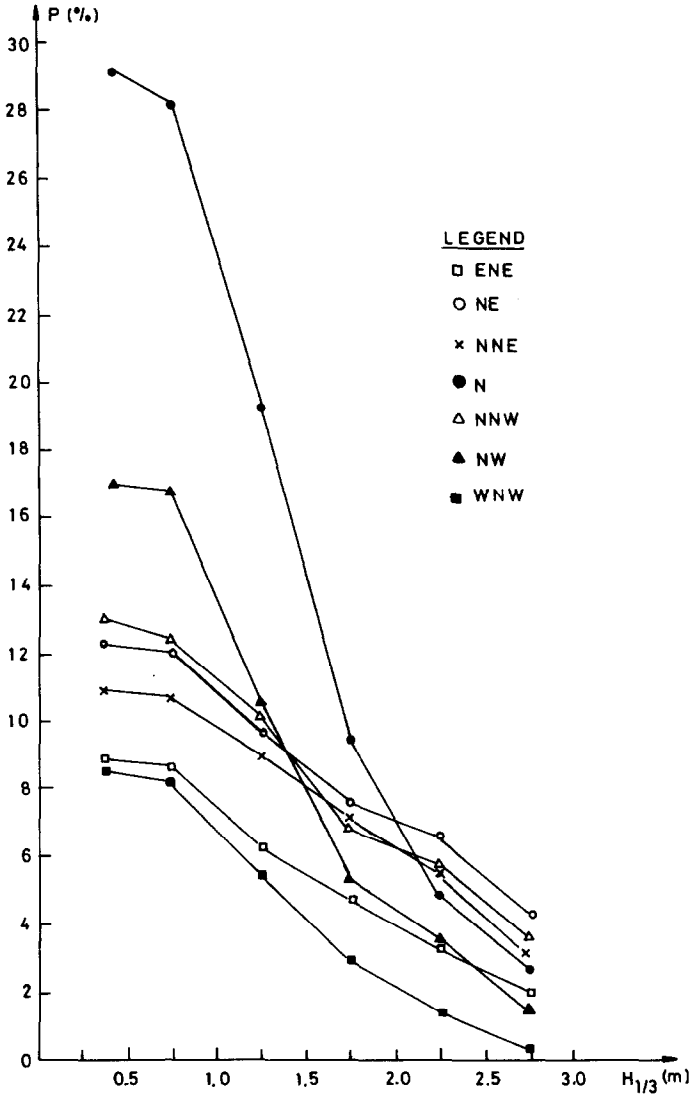


Fig. 4. Cumulative observance probabilities of significant wave heights.

sediment to the Black Sea in a year (Yüksek, 1992). Field studies carried out at various positions and depths (total 196 data were analyzed in a laboratory) have shown that the bed material consists of coarse sand and fine gravel with 0.33 mm mean diameter and 2650 kg/m^3 specific gravity.

3. Determination of erosion areas

3.1. General

Since the net sediment transport is from west to east in the region, sediment deposition at the west and erosion at the east side of coastal structures are prominent. Although the

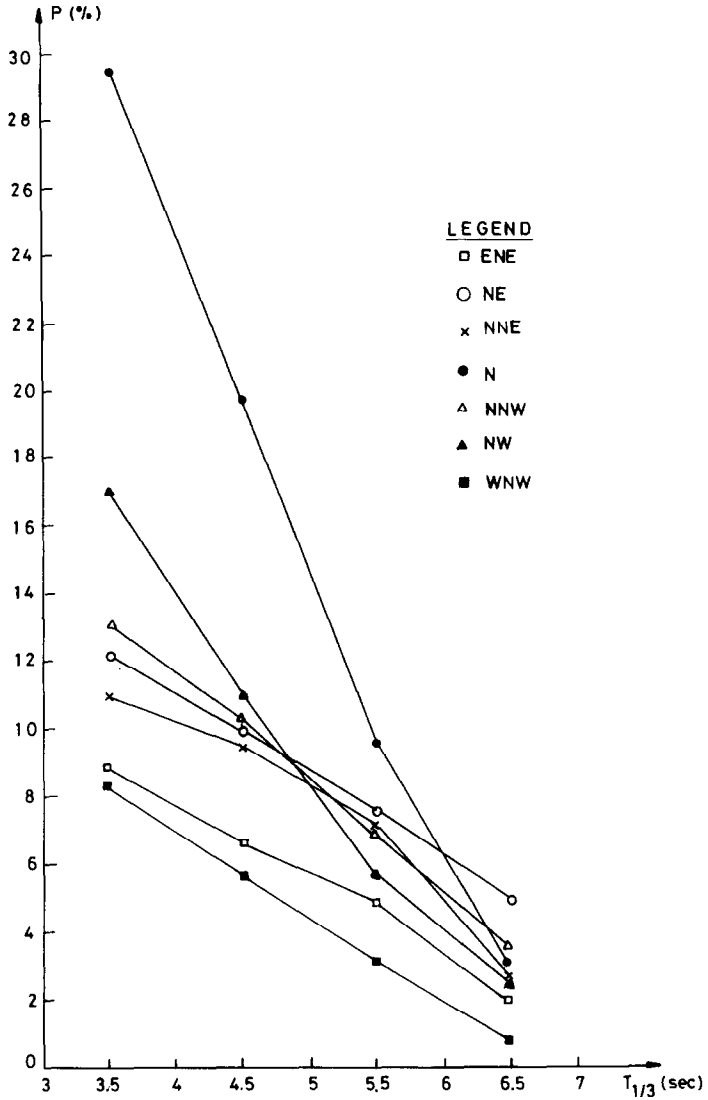


Fig. 5. Cumulative observance probabilities of significant wave periods.

volume of sediment transported by rivers to the coast is abundant, as a result of sand and gravel mining from coasts, erosion and recession is widely observed in various areas. Because of incorrect site selections and erroneous designs, siltation problems have taken place at the basins of harbours (Yüksek, 1992); thus, not only their functions have been decreased but also valuable sediment to be useful in protecting the coasts, has been wasted.

In nearly a one year period, Eastern Black Sea Coasts were scanned step by step and all of the shoreline and coastal changes (urbanization, recession, progression, erosion, accumulation etc.) occurred over the last 30 years were estimated. In these studies, coastal maps

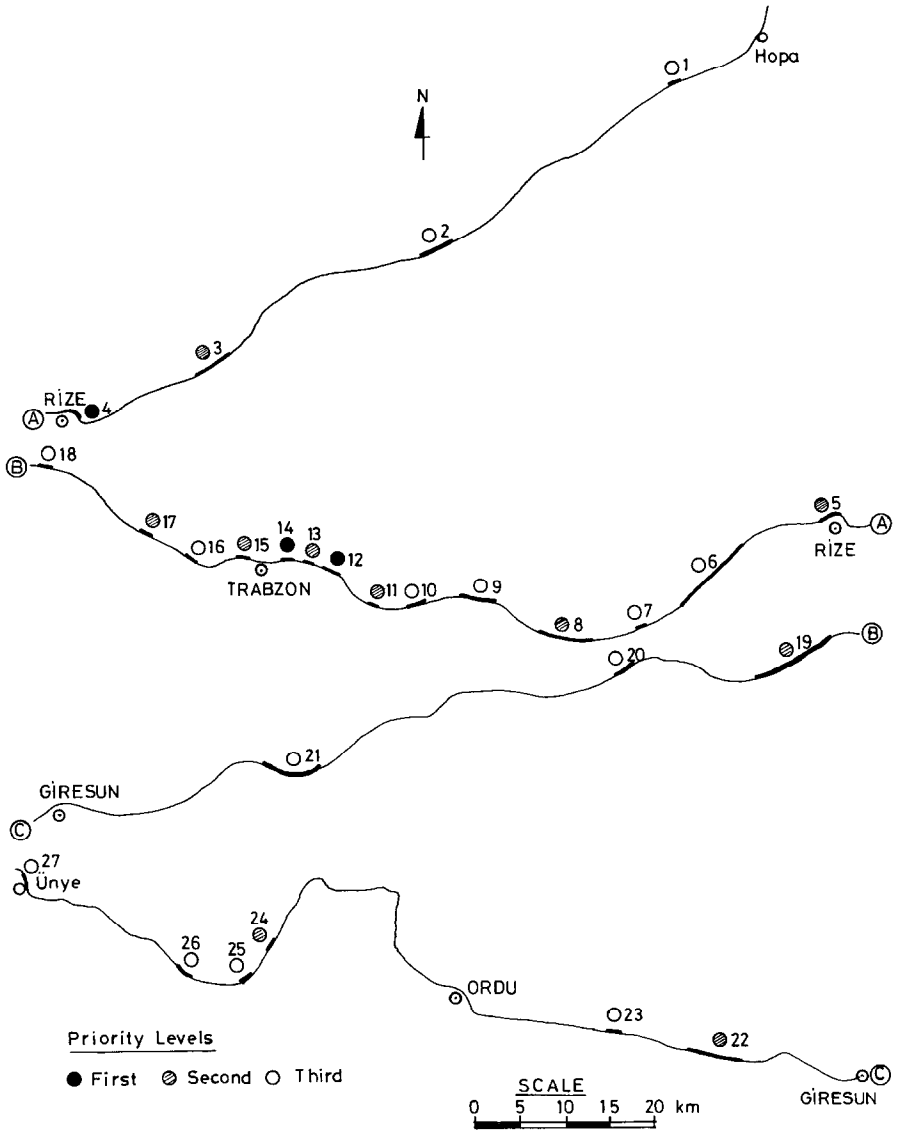


Fig. 6. Numbers, priority levels and locations of the areas to be protected.

of the region were researched and useful knowledge was obtained both from official people and residents.

3.2. *Classification of erosion areas*

At the end of field and desk studies, the areas which need to be protected against erosion and recession were classified according to their importance and severity of erosion as first, second and third priority places (Önsoy and Yüksek, 1993).

Table 1
Summary of the areas to be protected

No.	L (km)	Summary of the case	Proposal	Priority [a]
1	1.8	Sand and gravel, 4 groins	No measure	3
2	5.0	Sand and gravelly beach at east (1 km in length), sediment deposition by river at east of the area	No urgent measure	3
3	5.5	Sediment transported by river at east, gravel at west	Enlarging at east by groins	2
4	3.0	Large erosion at the center, incorrectly designed groins	Additional groins for eroded areas	1
5	3.5	Highway very near to sea, at east of harbor large erosion, at west revetment	Groin field in eroded areas	2
6	12.0	Deposition by river sediment at east, wide beach at center and at west	No urgent measure	3
7	0.8	L groins to reduce erosion of harbour extension	No additional structures	3
8	6.3	Revetment is dominant, people connection with sea broken	T groins instead of revetments	2
9	5.0	Revetments at east, a beach with 10 m width at center, 50 m recession for last 20 years at west	Groin field in eroded areas	3
10	2.8	Shoaling at fishery harbour, 15 m width recession in last 20 years, revetments at west	Groins in eroded areas, dredging at fishery harbour	3
11	1.0	Shingle beach at east, inadequate protection via groins because of large gap	Additional groins or extension of existing groins	2
12	3.0	Big erosion at east, fillings by soil, significant sand mining at west	Protection by groins, checking of sand mining	1
13	0.8	Significant erosion due to sand mining	Checking of sand mining, groins	2
14	1.5	Significant erosion due to sand and gravel mining	Check of mining, groins to enlarge shoreline	1
15	1.2	Inadequate erosion control by groins because of large gap, insufficient sediment flow	Artificial nourishment and additional groins	2
16	1.2	3 T groins	No measure	3
17	1.6	Filling at east, shoaling at fishery harbour, a fillet at west side of exciting groin	Groin field to protect shoreline and highway	2
18	0.3	Shoaling and agitation at fishery harbour	A secondary breakwater at fishery harbour	3
19	12.0	Revetment at center, a groin at west	Additional groins	2
20	3.5	Shoaling at fishery harbour, vast sandy and shingle beach at west, no important erosion	Groin field to enlarge beach and trap sediment	3
21	7.5	A long and wide beach, enough sediment input via river	Groin field to enlarge beach and trap sediment	3
22	7.0	50 m recession in 20 years and endangering of highway because of sediment mining, sand input by river at west	Check of sediment mining, groins at west to trap sediment	2
23	1.0	No significant problem	Groins to enlarge	3
24	1.3	50 m width beach because of existing groin, enough sand input via river	Groin field for trapping sediment	2
25	1.0	Filling and revetment, sediment transport by stream	Groin field to enlarge beach	3
26	3.0	No significant erosion, sand flow by stream at west	Groin field for trapping sediment	3
27	1.5	A long sandy beach with 15 m width, no erosion	Groin field to enlarge beach	3

[a] Priority levels: 1: First, 2: Second, 3: Third priority.

Areas with narrow beaches and coasts which need urgently to be protected and where severe erosion and recession is observed for a long time, are classified as first priority areas.

Settlement areas with damage and areas where the existing structures are to be protected are classified as second priority areas.

Areas with no urgent erosion, but can be developed by widening beaches are assumed to have third priority.

Numbers, lengths and priority classification of the 27 areas to be protected are given in Fig. 6. A summary of the 27 cases and the proposed measures for these areas are presented in Table 1.

4. Measures against erosion

In this chapter, some measures which can be taken to prevent, or at least to diminish the erosion and recession in the Eastern Black Sea Region of Turkey are presented.

4.1. Checking of sand and gravel mining

A great percentage of the sediment transported by rivers to the sea (annual amount 3 to 5 million tons), is being dredged by various traps both in river banks and in coastal areas. The material at the coasts and at the sea bed is also mined by various vessels. The aggregate necessary for several structures should be carefully provided by sand traps and an uncontrolled consumption should be urgently prevented.

4.2. Correct designing of coastal structures

Because of incorrect site selection and design errors, some of the coastal structures cause erosion. Deposition occurs at the updrift side of a groin, while erosion takes place at its downdrift side. By interrupting the sediment flow and by trapping sediment in their basins, harbours also give rise to erosion at their downdrift sides (Komar, 1985). In order to avoid these design problems, it is necessary to make field observations as well as both mathematical and physical model studies. Waves reflected from shore-parallel structures (seawalls and revetments) transport sediment from shore to offshore zones and cause erosion. Therefore, it is very important to avoid designing these structures.

4.3. Protecting shoreline by groins

Since enough sediment necessary for shoreline re-building is provided by rivers and transported by longshore currents, it may be trapped by proper trapping structures. Thus, groins should be constructed in the places of great longshore transport. In order to prevent leeside erosion of groins, in general, a groin is not enough and therefore a groin field (a series of groins) is necessary (Johnson and Eagleson, 1966). Laboratory studies have shown that, for the conditions of the studied region, there should be a relation between groin length and mutual distance, as:

$$G/L \approx 1.75 \text{ to } 2 \quad (1)$$

where L is groin length, and G is mutual distance between two groins. Depending on the magnitude of the protecting region, on the sediment regime and on the nearshore bed slope, groin length may be 30 to 100 m (Önsoy et al., 1993).

T- and L-shaped groins may be suitable where the onshore–offshore transport is dominant rather than longshore transport. Preventing the sediment to be transported to the offshore zones, these structures help sediment to keep deposited at the surf zone. In this case, the distance between two groins may be larger:

$$G/L \approx 2.25 \text{ to } 2.5 \quad (2)$$

In making the final coastal protection project for a region, taking into consideration the regional conditions (alignment, wave conditions, sediment regime, topography etc.), physical model studies should not be avoided.

5. Details of two typical areas

In order to give detailed information about these proposals, two typical areas (Nos. 7 and 14 in Fig. 6) are described here in detail.

5.1. Sürmene Marine Sciences Faculty (SMSF) Coast

General: In order to decrease the agitation in Çamburnu Fishery Harbour, its main breakwater was 150 m extended. This extension diminished the agitation, however, changing the wave climate, it caused great erosion problems in SMSF Coast, which lies just east of the fishery harbour (Fig. 7). Revetment and seawall were built to prevent the erosion, but, because of wave reflection and scour under the seawall, these structures failed and the Faculty Structures were endangered.

To solve the above problem, a study was carried out by Karadeniz Technical University (KTU) Civil Engineering Department Hydraulic Division Researchers. This chapter gives a general summary of this study.

Wind and wave climate: The wind and wave climate of the studied area (Sürmene, a town 40 km east of Trabzon) is similar to those given in sections 2.2 and 2.3. As can be seen, the dominant wave directions are N, NNW and NW and therefore, the net sediment transport direction is from west to east.

Model studies: Physical model studies were carried out to find a proper solution against the erosion problem. The studies were performed in a wave basin which has $30 \times 12 \times 1.5$ m dimensions in the Civil Engineering Department of Karadeniz Technical University (KTU). The undistorted model scale was selected as 1/50 by taking into account the dimensions of the basin and the study area. A sea bed was formed consisting of the natural sea bed material, a wave generator system generated monochromatic waves. The wave direction was NW (the dominant direction for the region), wave height and period were selected as 3.0 m and 7.0 s, respectively and the bed material was sand with $d_{50} = 0.18$ mm.

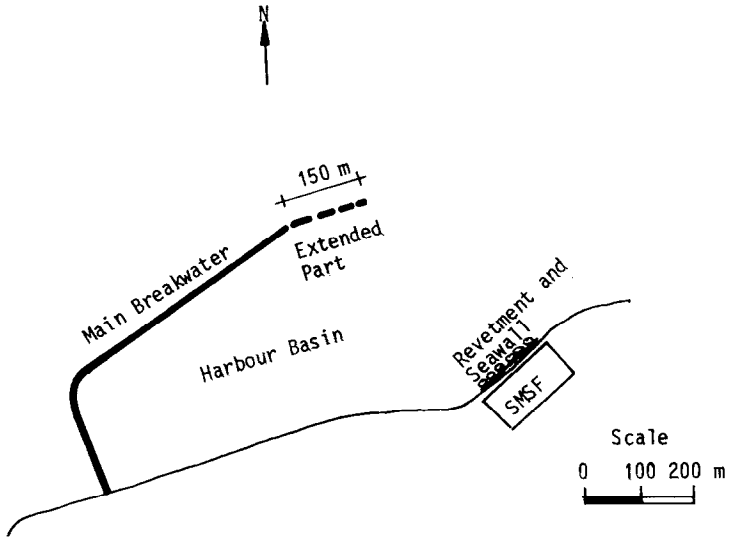


Fig. 7. General layout of SMSF coast.

At first, for checking the validity of the model, sand movement at the coast was tested and it was determined that as a result of diffracted waves by the extended part of Çamburnu Fishery Harbour, a westerly (from east to west) sediment transport was generated and it caused severe erosion in front of the SMSF structures. Since this situation is just like observed in the prototype, it was decided that the model represented the prototype very well. After this test, the best solution was tried to be found to decrease the erosion. Since there was enough sediment to feed the coast, groins were considered to solve the erosion problem.

14 various groin alternatives were tested in the laboratory. The tested groin parameters of these alternatives are given in Fig. 8. At the end of the 14 tests, it was observed that, some erosion occurred at all alternatives, except the 11th one. No erosion was observed in case of the 11th alternative, which consists of two-L shaped groins; therefore it was considered to be the best solution.

Because of the shoaling within the basin of the fishery harbour, there was a great amount of sediment just westside the groins. After construction of the groins, the waves which

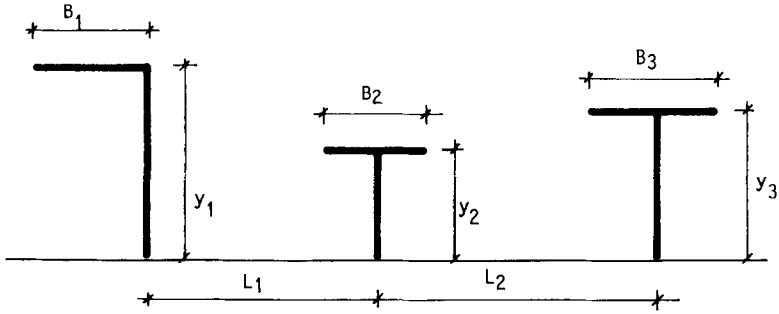


Fig. 8. Groin alternatives tested in the laboratory.

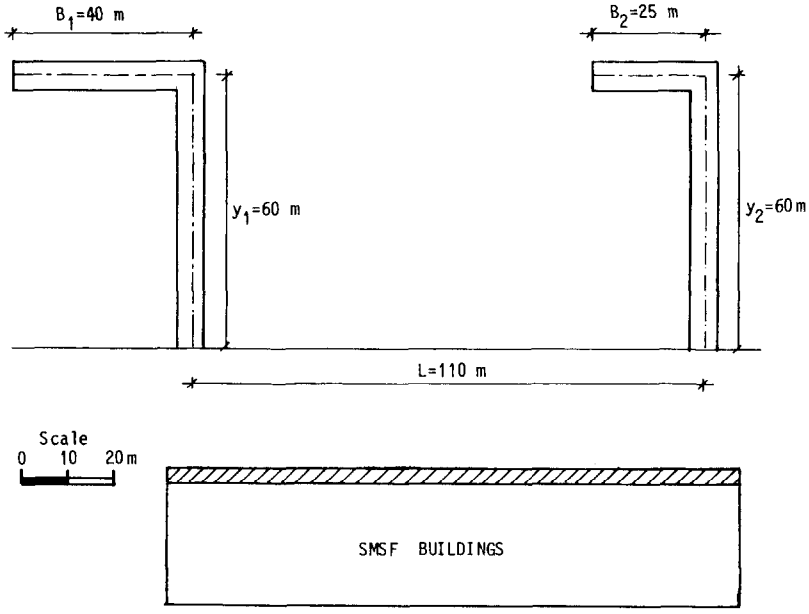


Fig. 9. Schematic layout of 11st alternative.

diffracted from groin tips generated easterly currents which led to an easterly sediment transport and caused the sediment to be deposited at the westside of the groins (especially of the west groin). A schematic plan view and a photograph taken one year after construction of the groins are given in Figs. 9 and 10. The sedimentation can be seen in Fig. 10. No important erosion was observed after the construction of the groins. It is obvious, however, that the best solution is artifical nourishment near and between the groins.

5.2. *Karadeniz Technical University (KTU) Coast*

The KTU Coast with 1200 m length lies east of Değirmendere River. Annual sediment volume transported by this river was estimated at 90 000 to 100 000 tons (Yüksek, 1992). But because of incorrect site selection and erroneous building of various coastal structures, severe erosion occurred at this coast. In addition, sand and gravel mining by people and municipalities aggravated erosion problems. A general layout and coastline changes observed in 10 months (from 21 December 1993 to 27 October 1994) and proposed measured are given in Fig. 11. The groins and seawall were not built at the same time, but nearly 5 to 8 years ago.

As can be seen in Fig. 11, the coast may be divided into 6 subregions. The coastal changes observed in 10 months and possible measures of these subregions can be summarized as follows:

1st subregion: As a result of sediment transported by Değirmendere River, this subregion is generally sandy and gravelly. 3 to 5 m deposition was observed during the observance period (in 10 months). No structure is necessary.

2nd subregion: In this area, which lies between two short groins, severe erosion occurred as a result of sand mining. But, in the recent months, this mining was prevented and it was

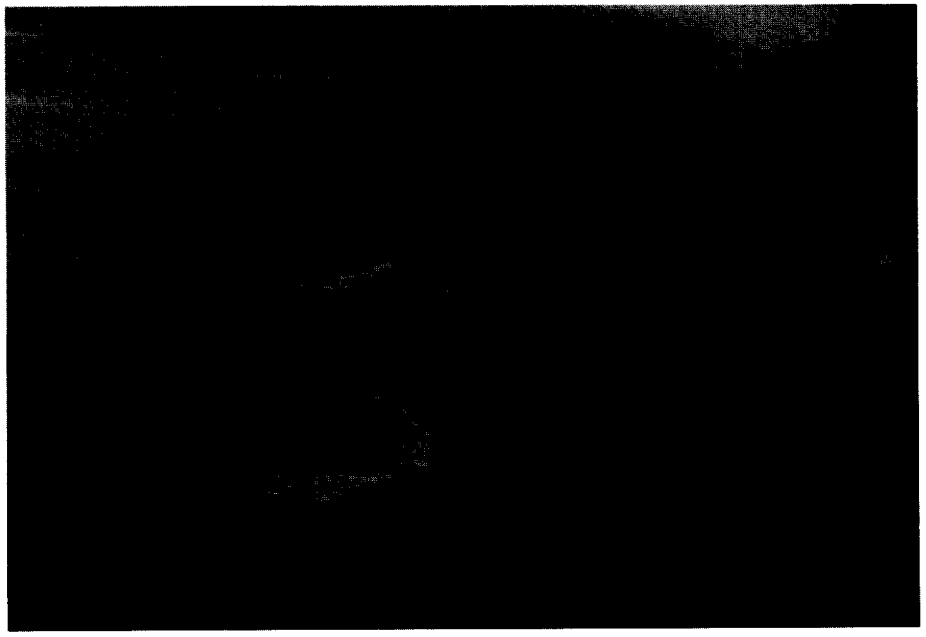


Fig. 10. Photograph of L groins one year after their construction.

expected that the coast will rebuild itself by sediment transport from Değirmendere River. No structure is necessary.

3rd subregion: Although little erosion was observed, its amount is negligible and no measure is necessary.

4th subregion: Because of wave transformation by the groin, erosion took place at the east side of the groin. Deposition was observed at the west of the short groin (at the east of the region). It is evident that, there is easterly longshore transport in this region. Therefore, two groins (30 m in length) may be useful in trapping sediment and rebuilding the coast. In order to rebuild the coast, however, sand mining should be checked.

5th subregion: A seawall was built to prevent erosion at the west side of the region, but, because of wave reflection, great amounts of erosion at the coast and scour under the seawall are threatening its stability. A rocky zone is exist in the sea at the center of this subregion. Acting as a detached breakwater, these rocks trapped the sediment and caused deposition. If the present two groins are extended to 50 m, an additional groin with 50 m length is built and artificial sand nourishment is applied from upcoasts to the front of the seawall, the erosion is expected to be decreased.

6th subregion: No urgent measure is necessary at this region, where little deposition was observed.

The above considerations may be used in pre-designing of the coastal structures; the final design is only possible after further field and laboratory studies.

6. Conclusions and recommendations

The conclusions obtained from this study are as follows:

1. An introduction to wind, wave and sediment regime of the Eastern Black Sea Region of Turkey is given. The dominant wind directions are SSW and SW; effective wave direc-

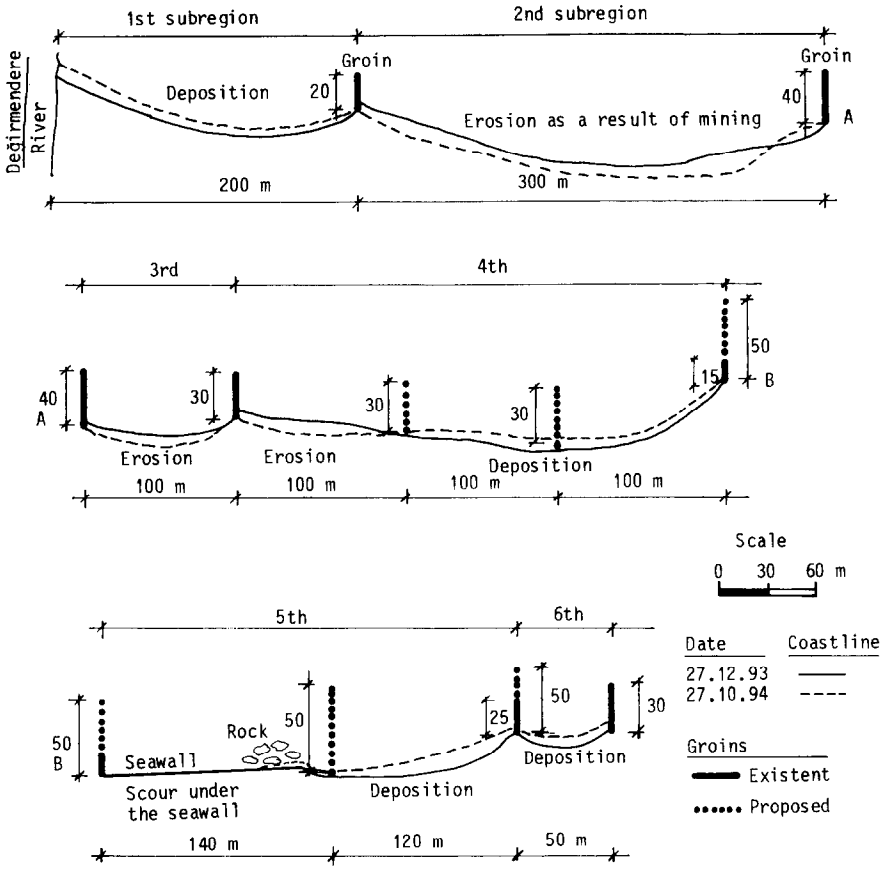


Fig. 11. Summary of the KTU coast.

tions are N, NNW and NW; thus, net sediment transport is from west to east. The rivers transport a large amount of sediment which largely consist of coarse sand and fine gravel.

2. The erosion zones are studied and classified according to their priority and some measures to diminish the erosion are given.

3. Detailed knowledge about field and laboratory studies carried out in two typical areas of the region is presented.

4. Some project criteria of possible coastal structures to be designed for diminishing the erosion are presented.

This study is the first one to deal with the erosion problems of the studied region as a whole in which detailed field, desk and laboratory studies are carried out. In the region, further studies should be carried out. The following topics are recommended from this study:

1. Mining sand and gravel both from rivers and coasts should be strictly checked.

2. The negative effects of coastal structures on the near coasts should be considered; it is necessary to be careful in site selection and designing of these structures.

3. It should be avoided to construct shore-parallel structures such as seawalls and revetments.

4. In designing the groins to protect and improve the coasts, Eqs. 1 and 2 may give only an idea about their length and mutual distances. Model studies are necessary for final design.

5. A wave gauging system should be established in the region as soon as possible.

References

Çam, T., 1986. Wave Estimation and Determination of Design Wave Characteristics in Eastern Black Sea Region. M.Sc. Thesis, Karadeniz Technical Univ., Trabzon, Turkey, 67 pp. (in Turkish).

Johnson, J.W. and Eagleson, P.S., 1966. Sediment Problems at Coastal Structures. In: A.D. Ippen (Editor), Estuary and Coastline Hydrodynamics. McGraw-Hill, Ch. 9.6, pp. 462–488.

Komar, P.D., 1985. Coastal erosion in response to the construction of jetties and breakwaters. In: Handbook of Coastal Processes and Erosion, Chapter 9, pp. 191–204.

Önsoy, H. and Yüksek, Ö., 1993. Protection Against Coastal Erosion and Study of Groins for Beach Improvement in Eastern Black Sea Region. Research Report, Karadeniz Technical Univ. Civil Eng. Dept. Hydraulic Lab., Trabzon, Turkey, 117 pp. (in Turkish).

Önsoy, H., Özölçer, İ.H., Birben, A.R. and Yüksek, Ö., 1993. A Study on the Effects of Groins and Offshore Harbours in Coastal Protection and Beach Improvement in Eastern Black Sea Region. Research Report, Karadeniz Technical Univ. Civil Eng. Dept. Hydraulic Lab., Trabzon, Turkey, 41 pp. (in Turkish).

Yüksek, Ö., 1992. A Study on the Sedimentation Processes at Fishery Harbours and Development of Proper Design Criteria. Ph.D. Thesis, Karadeniz Technical Univ., Trabzon, Turkey, 136 pp. (in Turkish).