STORY OF A BERM TYPE REVETMENT DESIGN
ORDU GİRESUN AIRPORT, THE FIRST SEA FILL AIRPORT OF TURKEY

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Ordu Giresun Airport is the first airport of Turkey that is completely built on a sea fill area situated at the Black sea coast of Turkey and at equal distances to Ordu and Giresun cities. The reclamation covers 1.6 million m^2 area that is surrounded with a total of 8.6 km revetment. The longest part of the revetment which is in parallel with the shoreline and at the offshore side of the reclamation area, is planned as a berm type revetment. In this sense, the preliminary cross section provided at the tender stage is checked, modifications are performed considering several criteria such as economics, performance, availability of rocks, etc. In addition to the design stages, several cross sections together with the suggested modifications are checked with laboratory tests. This paper covers the design stages where this criteria is taken into account, laboratory tests and the performance of the cross section during construction stages.

Keywords: berm type revetment; sea fill; wave overtopping

INTRODUCTION

Ordu Giresun Airport is the first airport that is built on reclamation coastal area. The project site is located at the Black Sea coast of Turkey (Figure 1). A closer look at the site with an emphasis on general layout of the reclamation area is provided in Figure 2. It should be noted that the reclamation stages were not finished when the satellite image wass taken. Thus, it looks as if some ponds were left unfilled in the general layout. As a result, in order to have an idea about the final look of the airport, Figure 3 is provided.

The need to build an airport is an outcome of the high demand from residents of Ordu and Giresun cities in order to reduce their travel time to the nearest airports, which is Samsun Çarşamba Airport for residents of Ordu and Trabzon Airport for residents of Giresun. Another reason is to reduce the high number of passengers for the existing nearby airports that is especially observed during summer time.

Figure 1. Location of Ordu Giresun Airport.

As a result of the above given needs and reasons, Directorate General of Infrastructure Investments under the Ministry of Transport, Maritime Affairs and Communication went out to tender. The first phase of the tender consisted of the design and construction of:

- 1,600,000 m2 sea reclamation area,
- 3.1 km runway,
- 8.6 km revetment

At tender stage, Directorate General of Infrastructure Investments provided the tenderers with the preliminary design of the reclamation area, berm type revetment and other relevant preliminary designs.

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Cengiz İnşaat A.Ş. was awarded the contract after the conclusion of the tender stages and Yüksel Proje Uluslararası A.Ş. was awarded as the designer by Cengiz İnşaat A.Ş.

Figure 2. General Layout of Ordu Giresun Airport.

Figure 3. Final Layout of Ordu Giresun Airport.

BERM TYPE REVETMENT DESIGN

Introduction

Berm type revetment that was designed to protect the sea reclamation area is one of the few experiences of its kind in Turkey and there was little information to put into design beforehand. Thus, before initiation of design stages, a thorough literature survey were completed about berm type revetment design and construction. After collecting the necessary information, the design stages were initiated by studies on wind and wave statistics to obtain the extreme wave estimations. In this stage, the influence of several wind sources and spatial wind data on extreme waves were examined in detail.

The following stage was to confirm if the preliminary design was performing as required and if there was any need to make modifications under the determined extreme waves. The results indicated that the preliminary design was conservative. Thus, several suggestions to the cross section of the berm type revetment were suggested to obtain a similarly safe solution but an economical one.

Starting with the preliminary cross section provided at the tender stage and the suggested cross section, several cross sections were physically tested under various wave conditions in the facilities of Directorate General of Infrastructure Investments. This part was in the care of Directorate General of

Infrastructure Investments and the results were shared with the designer. The suggested cross section was slightly modified considering the results of physical model tests and approved by the ministry officials.

Extreme Wave Estimation Studies

In order to obtain the extreme wave data, ECMWF wind data for 9 coordinates and in-situ wind measurements of two nearby coastal meteorological stations were considered (Figure 4). The data of each point and source was used to understand the influence of the data sources and the impact of spatial wind data sets on design wave estimation studies. This study eventually provided the design team with a final and clear idea about applicability of in-situ wind measurements of two nearby coastal meteorological stations as well as the influence of boundary conditions on ECMWF wind data for the site. It should be noted that, the wind measurements of two nearby coastal meteorological stations were carried to the sea with a land-sea conversion approach (Hsu, 1981) to obtain the wind data at 10 m elevation above MSL (mean sea level). It was assumed that the wind direction does not change in such a land-sea conversion.

Figure 4. Coordinate and locations of two coastal meteorological stations and ECMWF data points.

In order to understand the difference between wind data sets and their applicability in the wave estimation studies, wind roses are initially drawn as in Figure 5. Since the wind roses for each ECMWF coordinate were almost similar, only wind rose obtained for 45.10°N-38.20°E was given in Figure 5. The related figure indicates that the wind speeds measured at two nearby coastal meteorological stations are lower than that obtained from ECMWF point and the wind directions were different for all of the wind data sources. Even though it was clearly deduced that ECMWF should be used as wind data source for the wave estimation studies, all of the data sources were considered in extreme wave estimation studies to have an additional comparison.

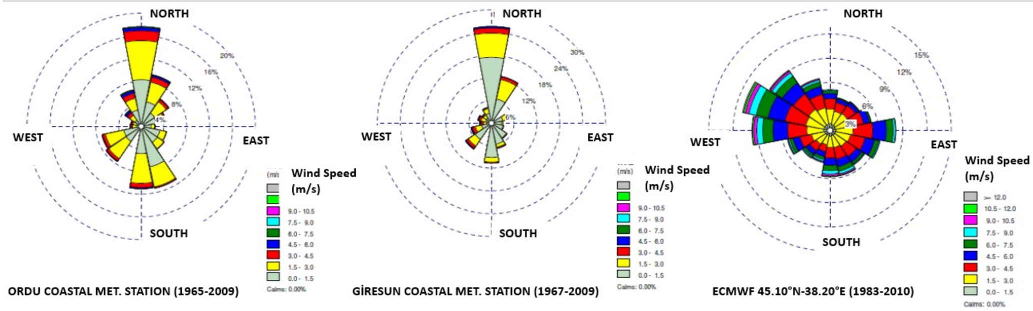
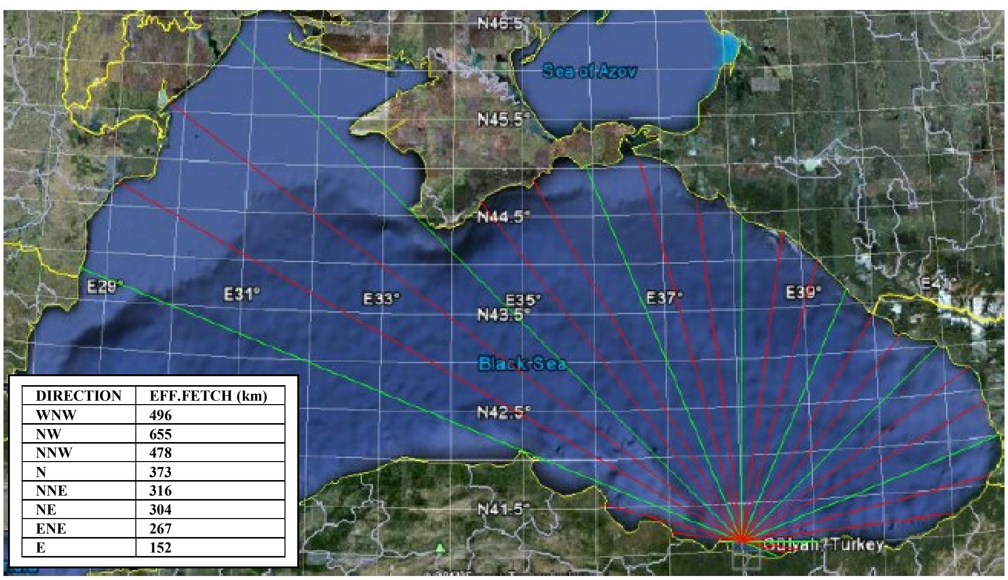


Figure 5. Wind roses for two nearby coastal meteorological stations and one ECMWF coordinate.

The studies were continued with extreme wave estimations. In this part of the design, the impact of distance between wind data coordinates and land was analyzed by taking into account different ECMWF points. Moreover as mentioned above, in-situ wind measurements of two nearby coastal meteorological stations were also considered for further discussion. For wave estimation studies, W61 Numerical Model, a Visual Fortran based model that was developed in Ocean Engineering Research Center, Civil Engineering Department, Middle Technical University was used. Wind data set for one coordinate and effective fetch distances of each directions separated with 22.5° are the main inputs of W61. The effective fetch distances are given in Figure 6. W61 produces individual and cumulative storm data summaries, yearly wave data sets for long term studies and maximum wave data set for extreme wave studies as outputs. From these data sets, wave steepness data was determined (Table 1) and this is followed by extreme wave statistics. The results of the extreme wave studies are given in Table 2. Wave heights are provided with 90% confidence intervals and extreme wave data only for 50 and 100 year return periods are given in Table 2. Based on the results, it was decided to use ECMWF wind data for 41.25°N-38.20°E coordinates for the following design stages.



DIRECTION	EFF.FETCH (km)
WNW	496
NW	655
NNW	478
N	373
NNE	316
NE	304
ENE	267
E	152

Figure 6. Effective fetch directions and distances.

Table 1. Wave steepness that are obtained for different data sources and coordinates.

SOURCE	Coordinates	Duration	Ave. Wave Steepness
Ordu Met. Sta.	40.59°N-37.54°E	1965-2009	0.0371
Giresun Met. Sta.	40.55°N-38.23°E	1967-2009	0.0419
ECMWF	41.00°N-38.10°E	1983-2010	0.0410
ECMWF	41.20°N-38.10°E	1983-2010	0.0377
ECMWF	41.30°N-38.10°E	1983-2010	0.0450
ECMWF	41.50°N-38.10°E	1983-2010	0.0444
ECMWF	41.30°N-38.20°E	1983-2010	0.0393
ECMWF	41.40°N-38.20°E	1983-2010	0.0409
ECMWF	41.50°N-38.20°E	1983-2010	0.0405
ECMWF	41.20°N-38.30°E	1983-2010	0.0437
ECMWF	41.30°N-38.30°E	1983-2010	0.0427

Table 2. Results of extreme wave statistics.

SOURCE	Deep water significant wave height, H_{s0} (m) Deep water significant wave period, T_s (s)	
	R_p = 50 years	R_p = 100 years
Ordu Met. Sta.	2.86 ± 0.30 7.03	3.06 ± 0.35 7.27
Giresun Met. Sta.	3.41 ± 0.58 7.22	3.79 ± 0.67 7.62
ECMWF 41.00°N-38.10°E	4.31 ± 1.08 8.20	4.87 ± 1.26 8.73
ECMWF 41.20°N-38.10°E	6.56 ± 0.96 10.56	7.07 ± 1.11 10.96
ECMWF 41.30°N-38.10°E	6.59 ± 0.91 9.69	7.07 ± 1.06 10.04
ECMWF 41.50°N-38.10°E	6.84 ± 0.88 9.94	7.30 ± 1.03 10.27
ECMWF 41.30°N-38.20°E	6.52 ± 0.87 10.31	6.98 ± 1.02 10.67
ECMWF 41.40°N-38.20°E	6.76 ± 0.96 10.30	7.24 ± 1.05 10.65
ECMWF 41.50°N-38.20°E	6.90 ± 0.90 10.45	7.37 ± 1.05 10.80
ECMWF 41.20°N-38.30°E	6.63 ± 0.97 9.86	7.14 ± 1.13 10.24
ECMWF 41.30°N-38.30°E	6.34 ± 0.97 9.75	6.76 ± 0.94 10.08

Wave Transformation Studies

Extreme deep water waves for ECMWF 41.25°N-38.20°E coordinates were transported to nearshore by SWAN and the nearshore design wave data in front of the revetment for different water depths were determined. The wave transformation studies were performed considering different water levels, in which effects of climate change were taken into account together with several different parameters such as wind setup, barometric effects, etc. Upper and lower confidence limits for 100 year return period extreme waves were also used as input for wave transformation studies. The results are summarized in Table 3 and several plotted outputs were given in Figure 7. Since water depth along the revetment varies, the most critical wave heights were found at relevant water depths. In wave transformation studies, it was considered to use "North (N)" as wave approach direction since it would create the most critical wave conditions, especially for the revetment section which is at the offshore side of the layout and in parallel with the shoreline. The results indicate that the waves approach almost vertical to the revetment at the offshore side of the layout which is in parallel with the estimation provided in the previous sentence.

Table 3. Results of wave transformation studies.

Scenarios	1	2	3	4	5	6
Wave Direction	N	N	N	N	N	N
R_p (years)	100	100	100	100	100	100
H_{s0} (m)	7.37	7.37	6.32	6.32	8.42	8.42
T_s (s)	10.80	10.80	10.00	10.00	11.54	11.54
Water Level	MSL	HWL	MSL	HWL	MSL	HWL
H_{10}	6.08	6.40	5.59	5.78	6.39	6.85
α_{10}	7.27	6.77	6.11	5.85	7.48	7.65
H_{11}	6.45	6.68	5.81	5.91	6.91	7.25
α_{11}	6.86	6.33	5.90	5.42	7.74	7.19
H_{12}	6.66	6.82	5.91	5.96	7.22	7.49
α_{12}	6.67	6.15	5.70	5.23	7.57	7.03
H_{13}	6.81	6.92	5.96	5.98	7.47	7.69
α_{13}	6.24	5.79	5.32	4.92	7.11	6.63
H_{14}	6.95	7.02	6.01	6.01	7.72	7.89
α_{14}	5.58	5.22	4.71	4.43	6.39	5.99
H_{15}	7.01	7.03	6.01	6.00	7.87	7.97
α_{15}	5.57	5.21	4.73	4.41	6.37	5.98
H_{16}	7.02	7.01	5.99	5.98	7.95	8.00
α_{16}	5.35	4.99	4.53	4.19	6.15	5.74

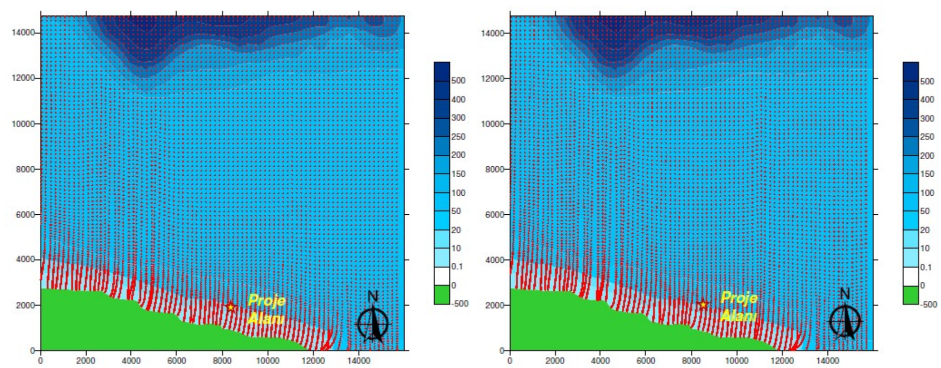


Figure 7. Sample graphs of wave transformation studies.

Modifications on the Preliminary Design

Considering the near shore design wave conditions, the preliminary cross section of the berm type revetment, given in Figure 8, was checked. Since the cross section is quite long and thus the writings are not clearly readable, it is best to define the details separately:

- The crest elevation is +6.70 m and the crest width is 12 m
- The slope between crest and the berm is 1V:3H
- The crest and the slope between crest and berm consist of 6-8 ton rocks
- The berm elevation is -1.00 m and the berm width is 15 m
- The slope between berm and the apron is 1V:3H
- The berm and the slope between berm and apron consist of 8-10 ton rocks
- The apron and toe elevation is -5.00 m
- The total width of apron and toe is 40 m
- The apron consists of 6-8 ton rocks whereas the toe is composed of 8-10 rocks
- There are different filter and under layer that are composed of various rock categories ranging from 4-6 tons to 0.2-4 tons
- The core is composed of 0-0.4 ton rocks

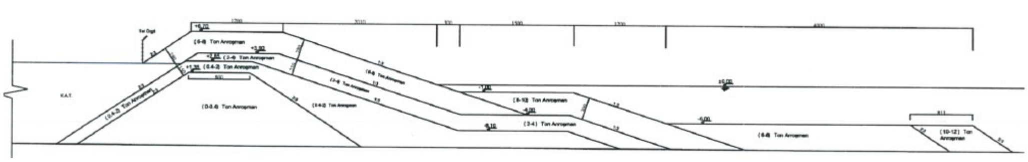


Figure 8. Cross section of berm type revetment at tender stage (Preliminary Design)

It was initially thought that it would be a good start to calculate the wave height on top of the apron, since apron will act as sea bottom for waves that are approaching the slope between berm and apron due to its length. For this, below given figure (Figure 9) were used. The calculations indicated that Hs=4.04 m waves are expected to be observed on the apron. This input wave height was used in the following design stages which were wave run-up, wave overtopping studies as well as determination of rock categories for apron, berm and slope between berm and apron. All of the relevant calculations were performed via Breakwat 3.3. TAW (2002) approach was considered for wave run-up calculations whereas Neural Network and TAW (2002) approaches were taken into account for wave overtopping calculations. The rock categories were determined using Van der Meer (1988) approach via Breakwat 3.3 for both apron, berm, slope between berm and apron and toe. The results showed that 10-12 rock category should be used for apron, slope between berm and apron at trunk, whereas the rock categories should be 12-15 tons at head sections. 10-12 tons turned out to be adequate for toe.

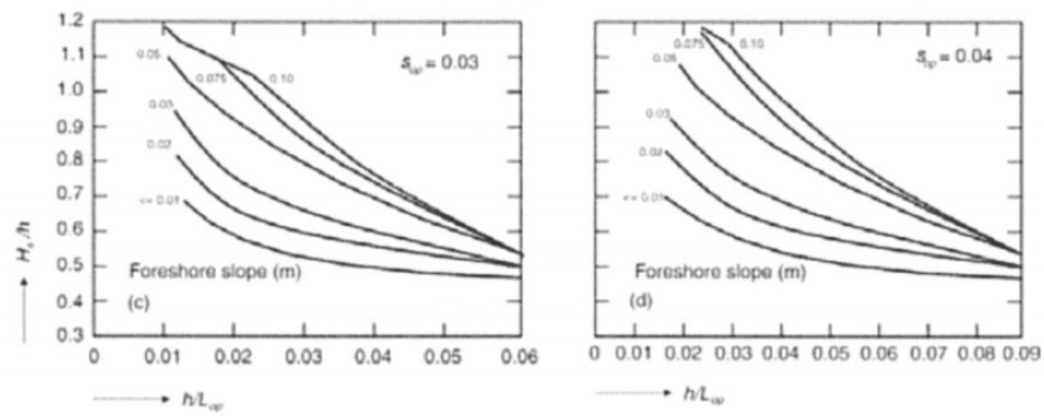


Figure 9. Figures for shallow-water significant wave heights on uniform sloping foreshore (Rock Manual, 2007)

Following the calculations, it was suggested to have the following modifications on the preliminary cross section:

- Keeping the toe width reducing the apron length about 20 m or 30 m based on physical model tests
- Raising the berm elevation to +1.00 m for allowing construction from land thus decreasing the construction time

The suggested modifications are illustrated in Figure 10. It should be noted that the filter and under layers were modified according to the armor layer rock categories but the general look in the cross section was not changed too much.

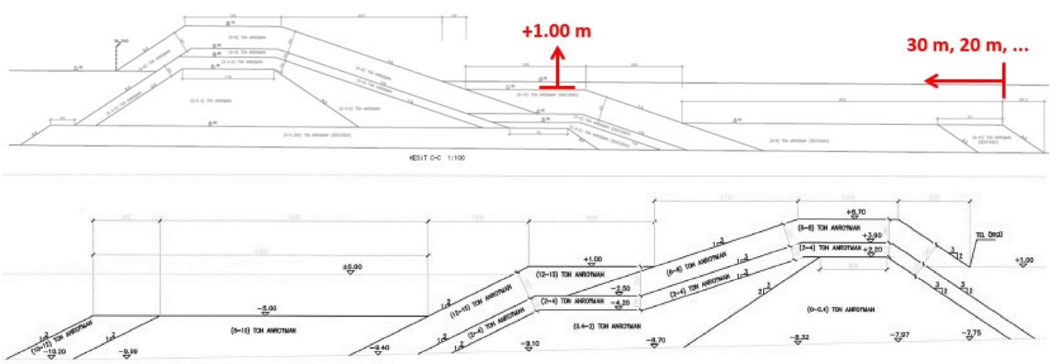


Figure 10. Suggested modifications on the Preliminary Design (on top) and the modified cross section (on bottom)

Physical Model Tests

The physical model tests were initiated with the suggested cross section. Since the physical model tests were in the care of Directorate General of Infrastructure Investments, they tested several more cross sections including the preliminary design cross section. In these physical model tests, the main focus was on the influence of berm elevation and the apron width on stability of the cross section and wave overtopping. The list of the tested cross sections, their differences and the obtained results are given in Table 4.

Table 4. Summary of parameters that were changed in the physical model tests and the obtained results for each test.

Section	No	Crest elevation	Armor layer	Apron (elevation / armor layer category / armor slope)	Berm (width / armor layer category)	Toe	Damage at berm armor layer	Damage at apron armor layer	Wave overtopping
Suggested Section	Model 1	+6.7 m	6-8 tons	+1 / 10-12 tons / 1V:2H	40 m / 8-10 tons	10-12 tons	0.00 %	9.00 %	5.05 l/s/m
Alt-1	Model 6	+6.7 m	6-8 tons	+1 / 10-12 tons / 1V:2H	30 m / 4-6 tons	10-12 tons	0.00 %	9.43 %	5.95 l/s/m
Alt-2	Model 7	+6.7 m	6-8 tons	+1 / 10-12 tons / 1V:2H	20 m / 4-6 tons	10-12 tons	0.20 %	15.40 %	6.54 l/s/m
Alt-3	Model 8	+6.7 m	6-8 tons	+1 / 10-12 tons / 1V:2H	none	none	1.17 %	17.50 %	12.83 l/s/m
Alt-4	Trial 1	+7.5 m	8-10 tons	+1 / 10-12 tons / 1V:2H	none	none	0.50 %	10.50 %	4.23 l/s/m
Alt-5	Trial 2	+7.5 m	8-10 tons	+3 / 10-12 tons / 1V:3H	none	none	0.10 %	3.17 %	1.43 l/s/m
Alt-6	Trial 3	+7.5 m	8-10 tons	+5 / 10-12 tons / 1V:3H	none	none	0.00 %	2.23 %	0.44 l/s/m

Based on the physical model tests, the final design was decided as in Figure 11 which corresponds to Alt-5 in Table 4. The apron was completely omitted and a simple sloping structure with a berm located at +3.00 m was adapted in the final design. This increase of berm elevation was due to much easier and faster construction as well as its impact on wave run-up and overtopping values. The omitting of the apron was due to its less impact on wave run-up and overtopping. Better wave overtopping results were obtained by simply increasing the berm elevation to +3.00 m.

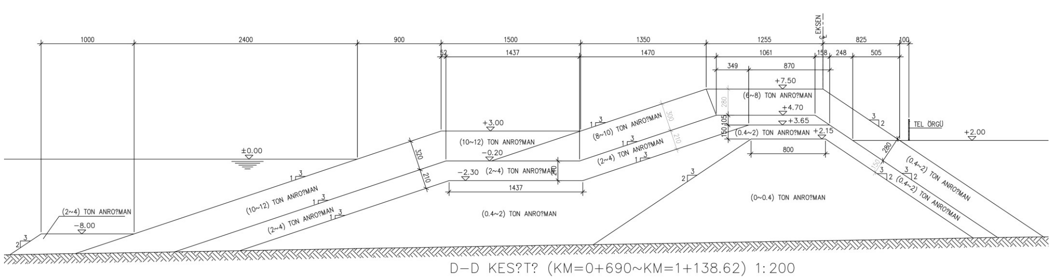


Figure 11. Final Cross Section

CONSTRUCTION STAGES

The construction started at January 2012 with the western side revetment, and then first continued to north and then to east till the completion of the connection at the eastern side by the end of 2013. When the construction of the berm type revetment reached a certain stage, the sea fill works were initiated six months after the initiation of the revetment construction and first under the runway then on the other locations. The sea fill works were finalized at the second half of 2015.

During construction stages of the revetment which lasted around 3 years, several storms, approximately corresponding to almost 10 year return period design waves, were observed. Even though the observed wave conditions were smaller than the design wave conditions, changes in the cross sections were regularly documented after the relevant storm conditions.

Storms observed during construction of the revetment were statistically analyzed and their impact on the integrity of the structure was determined. During construction period of the revetment between

2012 and 2014, the highest observed storm was determined as H_s=5.00 m, T_s=8.80 s. This study was performed using ECMWF wind data of 2012-2014 for 41.2°N 38.20°E coordinates. The total stormy hours are plotted against their corresponding Hs and Ts values as in Figure 12 for better visualization.

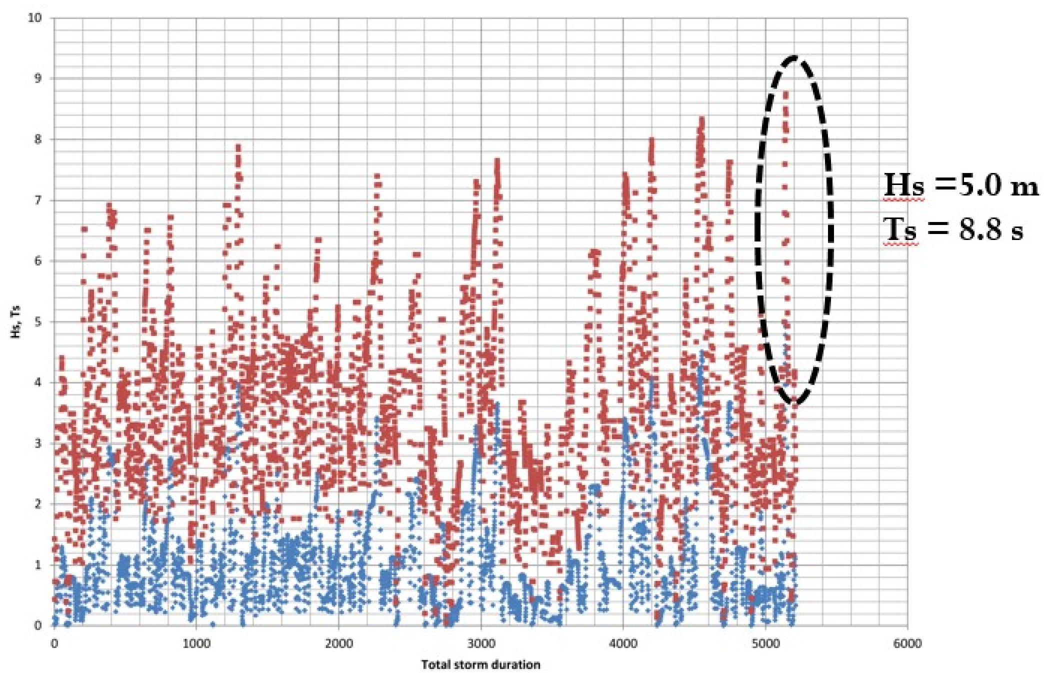


Figure 12. Total storm duration vs H_s, T_s

After these storms, measurements were performed to determine if any profile changes occurred and if there was any need for repair and maintenance along the revetment. The results showed that apart from minor changes, almost no profile changes were observed (Figure 13). This is a good indication for overall performance of berm type revetment for the future.

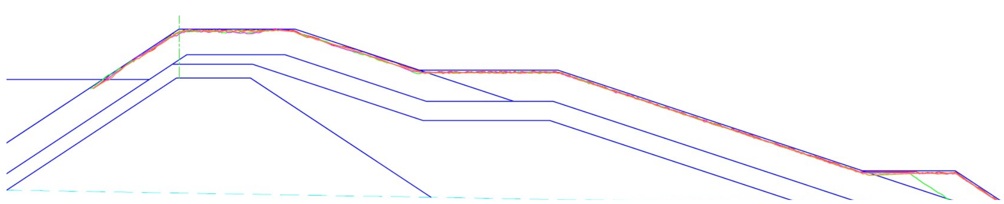


Figure 13. Armor layer profiles for the berm type revetment before and after the storms (dark blue line: the initial position of the armor layer; red line: the measured position of the armor layer after the storms)

DISCUSSION

In this paper, the design stages of berm type revetment of Ordu Giresun Airport is discussed with specific emphasis on the influence of wind data sets and wind data coordinates on determination of design wave data and the impact of berm elevation, apron width and elevation on the structure stability and wave overtopping. The cross section was tested with the storms observed during the construction stages and the results indicate no damage conditions under 10 year return period storm conditions.

It is planned to continue documenting the cross sectional damages after each significant storm and if possible to review the design under recently published relevant literature studies.

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