A CASE STUDY ON THE MAJOR DAMAGE AT A PORT: DAMAGE ASSESSMENT AND UPGRADE OF THE BREAKWATER

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INTRODUCTION

In this study, the major damage at a commercial port located in the Southwestern Black Sea Region due to a severe storm on January 18-19, 2018 is investigated, and the experimental campaign carried out to test the performance of the upgraded breakwaters is summarized. First, the observations during the field survey that was conducted one week after the event are presented. Next, numerical wave modeling studies carried out to estimate the wave characteristics that caused the damage are described. After that, the potential reasons for the damage are discussed based on the observations from the field survey and the numerical modeling studies. Finally, the experiments focusing on the upgrade of both the trunk and head sections of the main breakwater of the port are summarized.

FIELD SURVEY

The port (Fig. 1) is located on the Turkish coastline of the Southwestern Black Sea Region and is mainly used for coal transportation for thermal power plants. Both breakwaters were originally designed and constructed using tetrapod units.

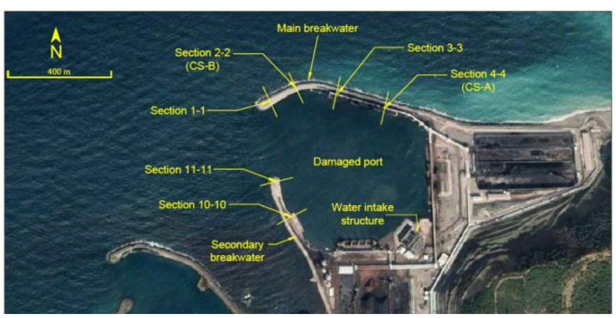

Figure 1 - Layout of the port (Google Earth, 2023).

The breakwaters were severely damaged during a storm at the Black Sea. The port was visited to observe and record the damage, collect available data, and interview the eyewitnesses. This field survey showed that Sections 2-2 and 10-10 of the breakwaters (Fig. 1) close to the entrance, failed during the storm. The crown-walls at Section 2-2 overturned towards the harbour direction (see Fig. 2) before the crown-walls at Section 10-10 overturned towards the seaward direction. The seaside and the rear side armour layers of the non-failed sections of these breakwaters also suffered excessive damage. It is also important to note that the seaside armour regions at the crest levels of both breakwaters were filled with 4-6 tons of quarry rocks to repair the damage after a previous storm that damaged the tetrapod units initially available there.

Figure 2 - Failure of the main breakwater at Section 2-2.

STORM CONDITIONS AND DAMAGE MECHANISM

A wave modeling study was carried out to estimate the wave characteristics at the deep-sea, nearshore, and inside the port using the wind data provided by NCEP CFSv2. Storm characteristics in deep water were simulated by applying a SWAN (SWAN, 2019) model nested in a WAVEWATCH III (WW3DG, 2019) grid, and obtained results were validated against altimeter measurements. Then, the waves were transformed to the port location by using three additional sub-regional and nearshore SWAN grids. Finally, SWASH (SWASH Team, 2019) was used to estimate wave characteristics inside the port to understand the differences in the wave characteristics during the different phases of the event and to investigate differences in the damage patterns.

The wave modeling studies showed that the significant wave height (H_s) close to the breakwater region reached up to 7.8 m during the peak of the storm with a peak period (T_p) of 12.4 s, approaching from the Northwest direction. On the other hand, H_s is estimated as 4.5 m at the entrance of the port (between the breakwaters), supported by the visual observations by the port staff.

The main reasons for the damage at both breakwaters are considered to be the insufficient tetrapod unit size at the armour layer and the use of rock as armour close to the crest level of these breakwaters. The storm waves broke the tetrapod units and dragged a significant portion of the tetrapod units and the rocks at the armour layer. Therefore, the underlayers and eventually the core became open to wave action. Furthermore, the excessive wave overtopping along the main breakwater dragged the rear-side armour rock, reducing the supporting forces to the crown-walls, especially at Section 2-2. It also removed the protection over the underlayers and core at the rear side. The crown-walls at Section 2-2 overturned towards the port area. On the other hand, as the support beneath the crown-walls at Section 10-10 was removed when underlayer and core rock was dragged at this section, the crown-walls overturned towards the seaside.

EXPERIMENTAL STUDIES

After the event, the breakwaters were repaired based on the initial design, placing tetrapod units along the armour layer (up to crest level properly) and reconstructing the overturned crown-walls as a temporary protection. As it was required to upgrade the initial design, a series of physical experiments were carried out at METU, focusing on both the trunk and head sections of the main breakwater using a Froude-type length scale of 1:60. The upgraded breakwaters were designed and tested utilizing a wave climate study specifically carried out for the port area (METU, 2020), where the deep-water design H_s and T_p having a return period (R_p) of 100 years were estimated as 9m and 12.1s, respectively. The main breakwater was also extended as it was easier to construct a new head than to repair a failed head. Moreover, it created a more protected area from the storms coming from the Northwest direction. Special attention was given to the transition zone between the existing and the extended head sections of the main breakwater. The main idea in the design was to minimize the removal of the existing structural units. Furthermore, Antifer units were selected to upgrade the existing structure that are relatively easy to place on top of a not-even surface consisting of (broken) tetrapod units. In all experiments, six wave series and water level combinations were considered including the waves having an exceedance probability of 10 hr/year and return periods of 50 and 100 years at high and low water levels. The number of waves in the wave series was selected assuming 6-10 hours of storm durations.

Sections 2-2 and 4-4 (see Fig. 1) were the two trunk sections tested in the experiments, which have toe depths of 32 m and 18 m, respectively. These cross-sections were upgraded using 48 tons of Antifer units placed randomly along the cross-section and regularly at the crest-level. Tested Section 2-2 is presented in Fig. 3. The stability of the armour and toe layers of the cross-sections were evaluated based on the damage number (N_{od}) and number of rocking armor units in addition to the rear side damage evaluated using damage parameter (S) based on the eroded area due to the wave action and rock diameter. Furthermore, mean wave overtopping discharges (q) over the cross-sections were measured. The results of the experiments showed that N_{od} values are acceptable considering the cumulative damage along the cross-sections after the application of six wave series. On the other hand, the measured q values are within the acceptable limits for the port operations given by the client, except for the waves having a return period of 100 years. (The port operations are recommended to be terminated for these storm conditions).

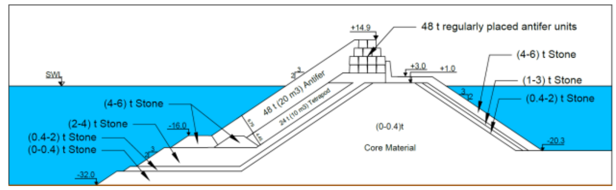

Figure 3 – Upgraded Section 2-2 (in prototype scale).

For the head section experiments, Sections 1-1 and 2-2 in addition to the extended part (Section 0-0) were constructed in the wave flume as shown in Fig. 4. The most critical transition zone between Sections 0-0 and 1-1 was placed perpendicular to the wave direction. 60 tons of Antifer units were used at Sections 0-0 and 1-1 at the beginning of the experiments. These units were irregularly placed at Section 1-1 and were regularly placed at Section 0-0 (see Fig. 4). The damage was evaluated based on N_{od} at different regions of the head section.

Figure 4 – Extended breakwater head section in the wave flume (Sections 0-0 and 1-1).

The initial experiments resulted in excessive damage, especially at the lee side of the head section. Therefore, the 60 tons of Antifer units in the highly damaged regions were replaced with 80 tons of Antifer units. The final experiments showed acceptable damage levels at all regions around the head section. In conclusion, both the trunk and (extended) head sections of the breakwater were upgraded successfully by these experiments.

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