MONITORING DAMAGE EVOLUTION OF CONSTRUCTED RUBBLE MOUND STRUCTURES

Christina N. Tsaimou, National Technical University of Athens, ctsaimou@central.ntua.gr
Michalis K. Chondros, National Technical University of Athens, michondros@mail.ntua.gr
Vasiliki K. Tsoukala, National Technical University of Athens, tsoukala@mail.ntua.gr

BACKGROUND AND OBJECTIVES

Port and coastal rubble mound structures are constructed to minimize the effects of wave action on beaches and harbors. Their structural degradation and, consequently, their damage are usually linked to the instability of the armor layer, expressed as rocking, units' displacements, blanket sliding, or settlement (Campos et al. 2020a). Within the context of retaining the functionality of in-service rubble mound structures, monitoring instability issues allows for understanding damage evolution and optimizing repair actions to confront failures.

Monitoring damage progression of constructed rubble mound structures is a rather demanding task that is mainly approached by executing field measurements or conducting physical experiments (Campos et al. 2020b). Although physical modeling is quite popular, it encloses limitations associated with the principles of conducting small-scale experimental tests to simulate real conditions such as wave conditions, structure's geometry, etc. On the other hand, field approaches require continuous monitoring that should enclose state-of-the-art techniques to achieve accuracy and precision during data collection. In an attempt to contribute to the existing body of knowledge regarding monitoring damage of in-service rubble mound structures, the present paper is focused on investigating armor layer stability by processing Structural Health Monitoring (SHM) metadata.

Dating back to the 30s with the leading-edge studies of de Castro (1933) and Iribarren (1938), several researchers have been occupied with building stability formulas for the armor layer of rubble mound structures (e.g., Melby and Kobayashi, 1998). These studies were built upon experimental data and aimed to predict damage evolution of rubble mound structures during initial design. For the cases of in-service rubble mound structures, challenges such as i) the lack or insufficiency of inventory design data (e.g., inner armor geometry, porosity, permeability, etc.), ii) the potential applied treatments for maintenance and repair during their lifetime that may change the initially constructed cross-section, iii) the differences between design and as-built cross-sections, and iv) the variations along the same structure due to construction defects or occurred failures affect the accuracy of damage prediction models. Combining the concept of short-scale or full-scale damage monitoring with modeling structural response up to the destruction level can be beneficial for estimating failure (Campos et al. 2020b).

Regarding the full-scale real-time survey, Remote Sensing techniques including Unmanned Aerial Vehicles (UAVs) have been proposed for field monitoring of damage (Gonçalves et al. 2022). The application of UAV-based SHM of constructed rubble mound structures indicated that aerial imagery data analysis with Geographic Information System (GIS) tools enables building both the longitudinal and transverse profiles of the structures, thus providing data for monitoring instability issues (Tsaimou et al. 2022). Moreover, the periodical application of the SHM program assisted in comparing profiles from the different time periods of the inspections.

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Profile extraction for in-service rubble mound structures is achieved by analyzing the Digital Elevation Model (DEM) that is generated by UAV-data photogrammetry analysis. Once GIS analyses are completed, elevation data is inserted into Computer-Aided Design (CAD) software for estimating both the sea-side armor slope and the eroded area if occurred between the time intervals of the UAV inspections. The estimated output along with information derived by a GIS-based processing of orthophoto metadata (e.g., the diameter of armor units of the external layer) and wave data acquired by open-source databases assist in exploring damage evolution.

The monitoring approach was applied at the rubble mound structure of the domestic-ferry domain of Lavrio port located at the southeastern tip of Attica, Greece. Further details regarding the application of the SHM program, data collection with four UAV-based inspections, and relevant analysis with photogrammetry software and GIS tools can be accessed through relevant work conducted by Tsaimou et al. (2022). As shown in Figure 1, both the 3-D reconstruction model of the structure and the plan view of the orthophoto indicate significant variations in the geometry (i.e., elevation and width) along the structure. Moreover, the central part of the structure seemed to be the most vulnerable to prevailing conditions and forces since its width was considerably limited.

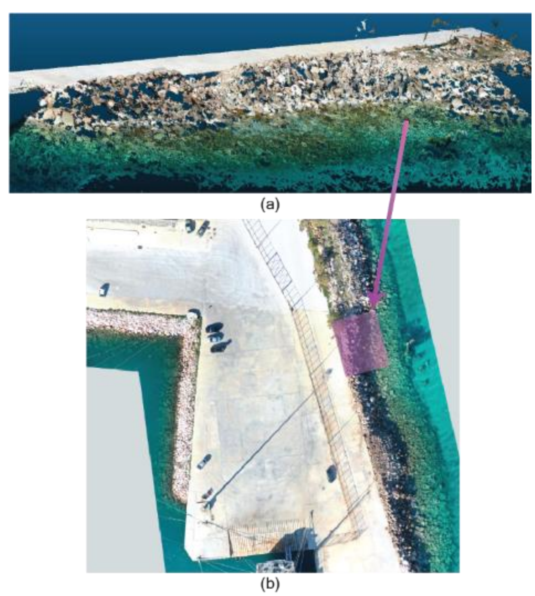
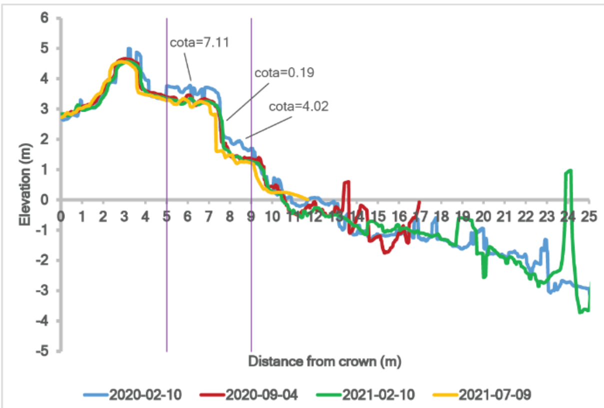
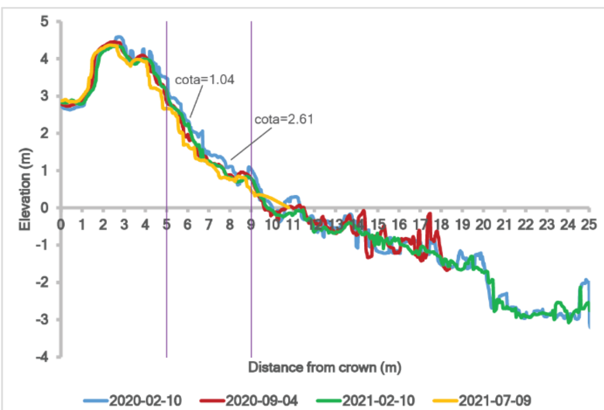


Figure 1 – Rubble mound structure of Lavrio Port, Greece: (a) 3D illustration and (b) orthophoto.

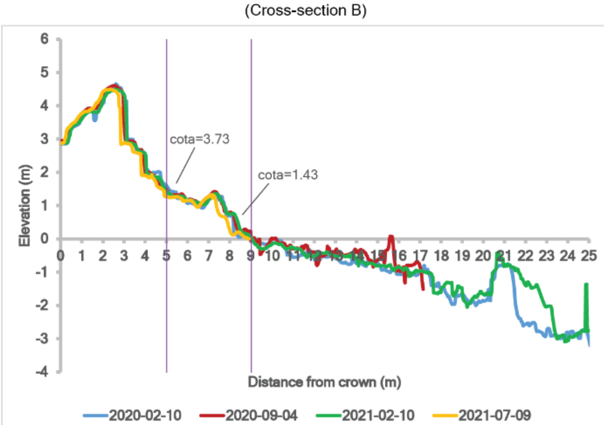
Working on the profiles (Figure 2) of three successive cross-sections denoted as cross-sections A, B, and C, defined at the beginning of the reduction of the structure's width and enclosed within the purple box in Figure 1, the sea-side armor slope and the eroded area were estimated and compared (Figure 3) for the part between distances 5 m and 9 m from the crown (Figure 2).



(Cross-section A)



(Cross-section B)



(Cross-section C)

Figure 2 - Profiles of cross-sections A, B, and C of the rubble mound structure.

Although the maximum significant wave heights are approximately the same during the time intervals of the in-situ inspections, the estimated eroded area is higher between the first and the second inspections for the cross-sections A and B, while for the cross-section C, armor units' displacement is higher between the last two inspections (Figure 3). Moreover, during the interval of the second and the third inspection the lowest eroded area was registered. Further investigation regarding the number of high wave heights is also required to examine the structure's response against wave forces and find the cause of the damage evolution.

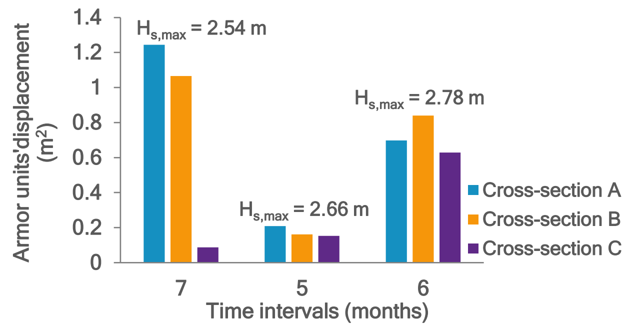


Figure 3 - Estimated eroded area.

CONCLUSIONS

Exploring damage evolution of in-service rubble mound structures is quite challenging. Nevertheless, ongoing SHM programs allow for acquiring data such as eroded area and slope that in combination with wave information can assist in gaining insight into the behavior of the structure and identifying potential causes of failure. Further research can involve the implementation of a long-term monitoring program to develop damage progression curves for constructed rubble mound structures.

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