SPATIAL ASSESSMENT OF THE FAILURE PROBABILITY OF RUBBLE-MOUND BREAKWATERS

Rosaria Ester Musumeci, University of Catania, rosaria.musumeci@unict.it
Martina Stagnitti, University of Catania, martina.stagnitti@unict.it
Enrico Foti, University of Catania, enrico.foti@unict.it

INTRODUCTION

Nowadays, many aging harbor defense structures need to be urgently upgraded, also considering the climate change-induced forcing variability (Foti et al., 2020). In particular, adaptation solutions should be designed taking into account the intrinsic uncertainty of climate projections (Morim et al., 2018), as well as the impossibility to apply the traditional design assumption of stationary forcing (Davies et al., 2017). The above-mentioned climate uncertainties, together with the non-conventional nature and the lack of geometry and material uniformity of historical or adapted structures can be properly considered only through approximated or fully probabilistic (i.e. level II and level III, respectively) design methods (Burcharth, 1987, 1993).

While the theoretical basis of the probabilistic design dates back to the 80's-90's, only recently it has started to be included into some recommendations and guidelines (e.g. Japanese and Spanish technical recommendations). Several studies on the probabilistic design of new harbor breakwaters have been performed, in some cases including the effects of climate change though in a simplistic way (Takagi et al. 2011; Kim and Suh, 2014; Galiatsatou et al. 2018). However, to the authors knowledge, only Stagnitti et al. (2022) presented the application of a probabilistic design method to existing damaged and upgraded structures under the effects of climate change, even if without investigating the performance variability along the structure. A further effort is needed to increase the ease of applicability of probabilistic design methods, and to make the probabilistic results immediately usable for decision-making processes.

In this context, the present work proposes the application of a probabilistic design framework based on the Monte Carlo simulation technique to existing harbor rubble-mound breakwaters and their possible upgrading solutions, considering the lack of structural and forcing uniformity along the structure. The assessment of the structure performances is carried out by iteratively calculating easy-to-use indexes for different cross-sections of the breakwater, which are representative of its uneven geometry and composition, as well as of the variable wave forcing. Then, performance spatial maps are constructed to provide a concise view of the obtained results, which can guide both the design and the decision-making processes. Here, the proposed methodology is applied to the case study of the Catania harbor breakwater (Italy).

METHODS AND MATERIALS

The probabilistic methodology proposed by Stagnitti et al. (2023) is adapted for the assessment of the performances of different cross-sections of rubble-mound harbor breakwaters. In particular, after selecting the limit state to be investigated, the corresponding reliability function is defined, which express the difference between the resistance and the solicitation terms. Failure occurs when the reliability function assumes negative values. Both state-of-the-art and site-specific experimental or numerical formulas are employed, in order to consider the peculiar geometry and composition of each part of the breakwater. Then, the failure probability of each studied cross-section is calculated through the Monte Carlo simulation technique, as the ratio between the number of life cycle with at least one failure and the total number of realizations. The failure probabilities are employed to calculate performances indexes, such as the ratio between the calculated and the maximum acceptable failure probability during lifetime (r), and the rate of the growth of the failure probability during lifetime (s). Finally, the obtained results are summarized in spatial maps to provide a graphical quantitative representation of the breakwater performances.

The proposed methodology is applied to the existing cube-armored breakwater of the Port of Catania and to its future upgraded configuration (see Figure 1), considering two failure mechanisms due to the collapse of the outer armor layer and to excessive mean overtopping discharge. Information about the response of the considered unconventional structures to wave attack is derived from the extensive experimental and numerical dataset provided by Stagnitti et al. (2023a, b). For the present climate, the reanalysis wave dataset provided by Korres et al. (2019) and the sea level dataset provided by Hersbach et al. (2019) are employed, whereas for the future climate the projected dataset of the Copernicus Climate Change Service (Caires and Yan, 2020; Yan et al., 2020) are adopted.

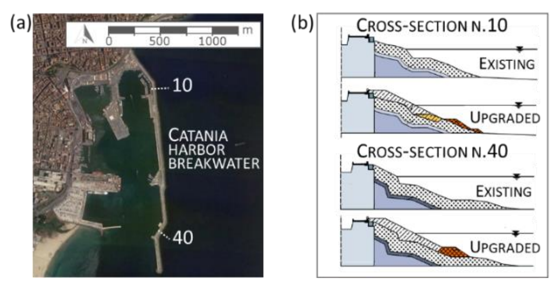

Figure 1 - (a) Satellite image of the Port of Catania (Google Earth, 2020) and (b) sketches of the existing and upgraded configurations of its harbor rubble-mound breakwater (inspired by project works provided by the local port authority).

RESULTS

The structural conditions of the existing breakwater are preliminary assessed through the analysis of the georeferenced point cloud of the emerged structure specifically acquired in 2020, the orthophotos provided by the Sicilian Regional Territorial Information System for the years 2000, 2007 and 2012 and the project works made available by the local port authority. In particular, modifications of the emerged armor layer are investigated for 40 representative cross-sections spaced of about 50 m (see Figure 2a). The analysis of the displacement of the emerged armor blocks during the period 2000-2020 reveals that each cross-section was differently modified by the action of sea storms, in terms of both magnitude and direction of the displacement of the contact line between the sea and the armor layer (see Figure 2b). For instance, Figure 1b shows the different shape of the damaged existing armor layer of cross-sections no. 10 and no. 40. The lack of geometrical uniformity along the structure makes necessary the spatial analysis of its performances.

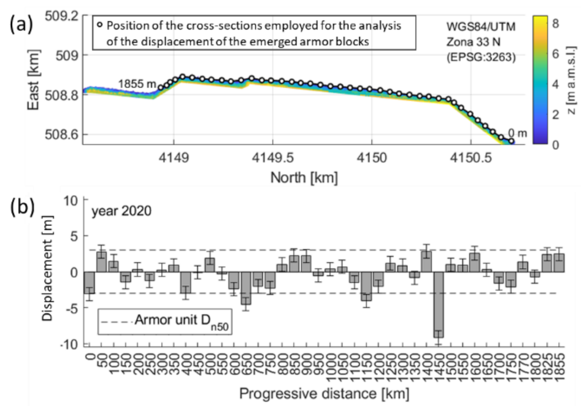

Figure 2 - (a) Mesh of the emerged breakwater recovered from the UAV point cloud acquired in 2020; (b) displacement of the contact line between the sea and the armor layer during the period 2000-2020.

Therefore, the calculation of the failure probability and of the performance indexes is carried out for 10 representative cross-sections spaced of about 200 m. For each climate scenario and for each failure mode, Monte Carlo simulations with 2.25×10^4 realizations are performed, considering the breakwater useful life equal to 50 years. First, state-of-the-art reliability functions are employed for all the tested cross-sections, in order to quantify the effects of wave climate variability on the structure performances. Then, site-specific reliability functions specifically calibrated for groups of similar cross-sections are employed to take into account also the effects of the uneven geometry.

The comparison between the present and future performance indexes reveals that the structure response to the wave action is not expected to worsen in the future. Moreover, the investigation on the spatial variability of the structure performances highlights that the shape of the existing armor layer mainly influences the stability of the additional blocks. A deeper discussion of the results will be provided at the conference.

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