PROTECTING VALLETTA'S GRAND HARBOUR AGAINST ADVERSE WAVE CONDITIONS

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INTRODUCTION

Valletta's Grand Harbour is a natural shelter that has been home to a variety of activities for many centuries. Today, the area serves as a multipurpose port with terminals for cruise liners and cargo vessels and also houses marinas, local and international passenger ferries, water taxis, shipyards, fuel docks and many other activities. There are nine cities and towns within the port area which is the most densely populated and built-up region in Malta. The Grand Harbour is also of prime heritage importance as it is surrounded by the fortifications built by the Order of St John in the Three Cities, Floriana and Valletta, which was inscribed on the UNESCO's World Heritage List in 1980.

The protection of Grand Harbour against waves is mainly ensured by a system of two breakwaters at its entrance, built during the British era at the beginning of the 20th century. However, due to Malta's central position in the Mediterranean basin, the site is exposed to waves from multiple directions. The most common conditions are waves from the NW (*majjistrale*), which play a key role in the port's operating conditions. The NE (*gregale*) and E sectors, to which the harbour is more directly exposed, are less frequent, but they include the most severe storms (up to 7 - 8 m of Hs). Recent storms in February 2019 (NE sector) and February 2023 (E sector) caused significant damage in the port, highlighting the need for enhanced protection.

Infrastructure Malta therefore wishes to improve the operational and extreme wave conditions in the Grand Harbour and commissioned ARTELIA to carry out several studies to characterize the wave conditions in external approaches and inside the harbour, define a protection scenario, assess the hydraulic efficiency of the different structures and test them in ARTELIA's hydraulic laboratory.

ASSESSMENT OF BASELINE WAVE SITUATION

The first stage of the studies was to characterize the current wave climate. Offshore waves were simulated in the Mediterranean Sea from January 1992 to June 2019, using satellite wind and wave measurements. Special attention was given to the calibration and validation of the storm of 24 February 2019. As a result, the wave climate off Valletta was established and the different directional sectors were defined (Figure 1). Extreme sea states were then extrapolated for each of them.

A wave disturbance model was then built over the Grand Harbour, using the PHAROS computational software developed by Deltares. A transfer matrix based on 36 period / direction combinations, applied to the wave systems allowed the transfer by interpolation of the entire time series to eight analysis areas located at places of particular interest in the harbour. Chop waves generated by the local wind were also accounted for. This allowed the operational conditions in the baseline situation to be determined at these areas. Finally, storm conditions from the NE and E sectors were also simulated.

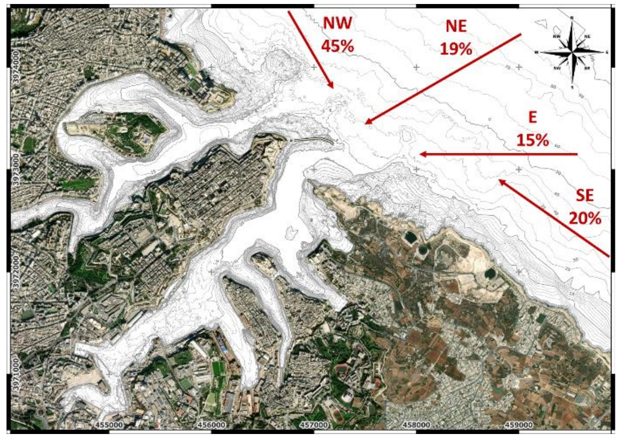

Figure 1 – The Grand Harbour and the main directional wave sectors off Valletta

DEFINITION OF A PROTECTION SCENARIO

The description of the offshore and in-harbour waves in the baseline situation made it clear that several structures were needed in order to reduce the agitation in both usual (mainly from the NW) and storm (mainly from the NE and E) conditions. In addition, the site is characterized by significant water depths (~ 20 m), steep slopes and highly reflective rocky foreshore, including cliffs. As the waves enter the harbour, they are subject to multiple reflections with little dissipation. Two approaches were therefore combined: firstly, to prevent waves from entering the port where possible; secondly, to enhance wave dissipation at the point of first reflection.

Several tests with the wave disturbance model led us to define a protection scenario (Figure 2) consisting of: (i) an outer breakwater at the tip of the Sciberras Peninsula to block the propagation of the most frequent NW waves; (ii) a detached submerged breakwater along the peninsula to dissipate, by depth-induced breaking, the energy of NE and E waves, particularly during storms; (iii) two revetments at the foot of the cliffs further inside the harbour to dissipate the energy of waves rolling along the shore, as observed during recent storms.

The wave disturbance model applied to this new layout showed a significant improvement in the wave climate in all areas analysed. Considering an operational wave criterion of 0.3 m, the downtime was generally halved. A significant reduction in storm waves is also achieved, although the efficiency of the structures decreases as the wave period increases.

HYDRAULIC PERFORMANCE OF THE DETACHED BREAKWATER

A key point of the scenario is the dissipation of wave energy at the detached submerged breakwater by depth-induced breaking. In order to estimate the new reflection coefficient of the "breakwater - foreshore" system, to be used in the wave disturbance model, a numerical wave flume based on the IH2-VOF computational code, developed by IH Cantabria, was set up.

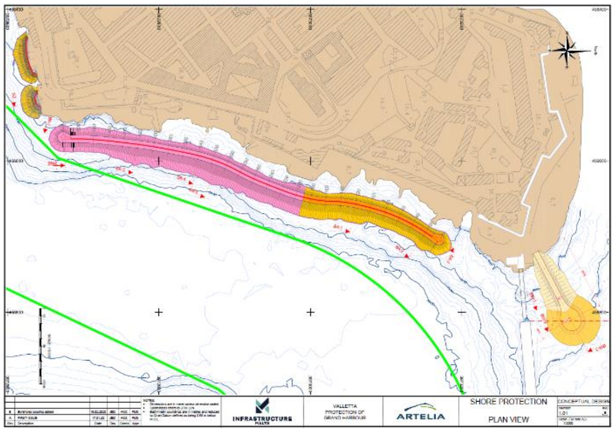

Figure 2 - Protection scenario for Grand Harbour

Irregular waves for different peak periods were propagated along local bathymetric profiles without and with the berm, whose cross-shore position also varied (Figure 3). The simulations showed that a reduction of 50% of the reflection coefficient of the natural foreshore could be expected.

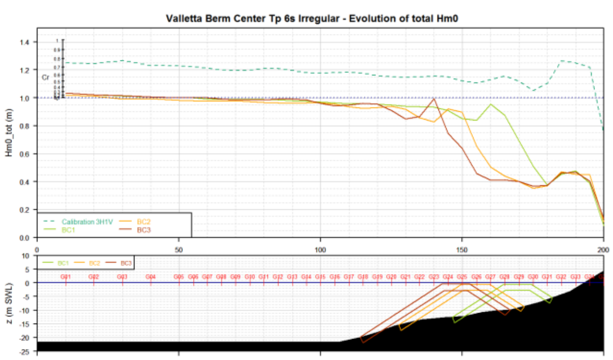

Figure 3 - Assessment of the reduction of reflection induced by the detached breakwater in a numerical flume

PHYSICAL MODELLING

The detached submerged breakwater was tested in the wave flume of the ARTELIA hydraulic laboratory in order to (i) verify the stability of its ACCROPODE™ II 6 m^3 armour and (ii) refine the characterisation of the reflection coefficient of the "breakwater - foreshore" system (Figure 4).

The tests showed a very large reduction in reflection coefficient, ranging from -23% to -74%, highest for large peak periods and high freeboards.

The outer breakwater was tested in a wave basin (Figure 5). This breakwater, with armour of ACCROPODE™ II 8 and 12 m^3, is the most sensitive area as is within the context of the surrounding historical structures: the Valletta's fortifications and the historical detached St-Elmo's breakwater.

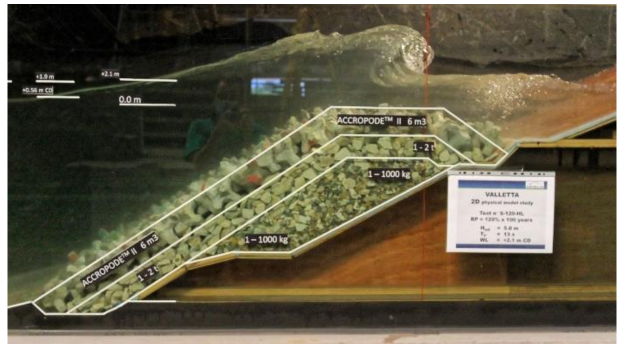

Figure 4 - 2D physical modelling of the detached submerged breakwater

The new breakwater will protect the historical one from NW waves. In addition to stability assessment, the model allowed estimating to what extent the new breakwater could protect the existing St'Elmo bridge, currently very much exposed to NE storms, with waves running up the abutment and hitting the deck from below.

Figure 5 - 3D physical modelling of the outer breakwater

The tests demonstrated the stability of the breakwater for the proposed design and provided useful recommendations for its crest level, which should be kept as low as possible for visual integration within its historical context, while maintaining hydraulic efficiency.

CONCLUSIONS

The protection of the Grand Harbour is made difficult by its peculiarities: a natural, deep, steep shelter surrounded by highly reflective rocky foreshores; exposed to three different directional sectors, all of which have to be taken into account; home to many and varied activities and as such considered a key asset of the Maltese economy; and last but not least, a place of great historical and cultural importance.

Infrastructure Malta and ARTELIA have adopted a global approach to consider the Grand Harbour as a whole and propose a protection scenario with the best possible visual integration. The role assigned to wave dissipation by a submerged detached breakwater illustrates the innovative and atypical solutions required by the specifics of the site. This project is currently being evaluated by the public authorities for future implementation.