Physical Modeling Supporting Design and Construction of Low Crested Breakwater for the Ayia Napa Marina, Cyprus

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Abstract

A new marina and land development at Ayia Napa, Cyprus, was designed by SmithGroupJJR. The marina features a 600-slip harbour framed by a large shoreline protection scheme comprised of wave absorbing block wall, revetments, breakwaters and pocket beaches, as well as significant upland development including two towers and residential villas, some of which are in close proximity of the sheltering breakwater. A one kilometer long low crested breakwater with tetrapod armour was selected as the most technically, economically and environmentally feasible solution. A key design feature was maintaining a crest height low enough to provide the villa owners and marina users with un-obstructed views of the ocean. Therefore, a key element in the design was limiting the amount of wave overtopping that could pass over the low crested structure and threaten the villas, yachts, cars and people on the lee side of the breakwater. In particular the maximum overtopping flowrate rather than the mean time-averaged flowrate was identified as a critical design criteria, since it is more closely linked to the risk to people and property.

The original design of the breakwater was verified and optimized through an extensive physical model testing program. Flume physical model tests at scale 1:45.1 were carried out in March 2015 to define the breakwater cross section, were a 20 ton tetrapod armor unit was selected on a cross section with a 4 Tetrapod berm width of 10.2m and crown wall up to an elevation of 7.8 meters was designed to obtain a desired overtopping rate. However, as the site plan evolved, it became apparent that the height of the crown wall, at 7.8 meters above the low water tide level, created an obstruction to the view shed from inside the Marina basin and the Villa which prompted SmithgroupJJR to consider alternative designs.

Therefore, a redesign of the breakwater cross section to lower the breakwater height for the purpose of improving the views from the residential villas and the Marina basin was done. Several schemes to reduce the crown height were considered, and a wide low crested breakwater concept was selected. A second physical model study was commissioned in order to verify the performance of alternative design and guide their optimization with respect to wave overtopping, stability and constructability. The tested cross section was designed using the Neural Network Overtopping tool from TU Delft to develop the structure geometry and the guidance of Van Gent (2013) to determine the size of the berm stones. The proposed section consisted of two layers of tetrapod armour units placed on a structured grid, set to a front slope of 1:1.33 to a crest elevation of +4.6m above the waterline, and a 20 meter berm width backed by a crown wall at the same elevation (Figure 1). Also, the feasibility of removing the need for an excavated trench, on the shallow water portion of the breakwater, to secure the toe of the structure required verification in the physical model.

The efficient physical model study of the revised design was carried out at the National Research Council of Canada (NRC). A two-dimensional physical model of an idealized foreshore at the project site was constructed at a geometric scale of 1:42.2 in a 63m long by 1.22m wide wave flume. Scaled models of two breakwater cross-sections (one in shallow water, the other in deeper water) were constructed and exposed to scaled reproductions of the design wave conditions forecast for the site. The physical model provided a good simulation of the important hydrodynamic processes influencing the tetrapod armour layer stability and overtopping, including nearshore wave transformation, wave breaking, wave run-up, and interstitial flows through the armour and filter layers.

The performance of the two cross-sections was assessed by observing the stability of the armour units and amount of overtopping during exposure to a series of irregular wave conditions and elevated water levels representing design storms. The effects of different widths of the top “berm” on the stability and overtopping rates was explored using a double berm width-tray system to optimize the laboratory time use. Each test series generated much information with respect to the interaction of the extreme design waves with the foreshore and the breakwater (wave breaking, run-up, and overtopping), and the response of the breakwater to this forcing (stability of the armour and the resulting overtopping discharges). The physical model was crucial to refining and confirming the design refinements developed to accommodate the site conditions encountered during the construction, and the efficiency of the model study led to reduced downtime in the field while these design sections were verified and optimized.

The Ayia Napa Breakwater is currently under construction, where 50% completion has been achieved and is expected to be completed in April 2019. The construction of the breakwater has been closely supervised, assuring that the breakwater meets the design conditions as observed in the physical model. Even though difficulties have been encountered the different parts of the breakwater have been successfully achieved, including the toe trench to secure the Tetrapods from sliding, the Tetrapod innovative placement pattern, and the top berm width.

During construction several large storms have been encountered, which have allowed for checking the design parameters as observed in the physical model tests. For this purposes a wave gauge has been installed at the location of the wave paddle of the test flume section. Overtopping rates have been measured, the behaviour of the trenched Tetrapods documented and thus far the observed performance of the portions of the breakwater built are in agreement with the physical model results and design expectations. The innovative design and design approach of the Ayia Napa Marina Breakwater provides a good example on how to achieve a harmonic breakwater with the landscape and environment, as well as highlighting the value of integrating a physical model to deal with potential design changes that arise during construction.