HAIFA BREAKWATER RETROFIT DESIGN

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INTRODUCTION

Haifa Port is Israel's largest commercial port and is a vital gateway for international trade and commerce. The port handles a diverse range of cargo, including containers and bulk goods, as well as passenger liners and Navy vessels. The Israel Ports Development and Assets Company Ltd (IPC) has completed the development of a new container terminal in the Port of Haifa, which consists of several extensive marine structures, including an approximately 880 m extension to the existing main breakwater ("Main Breakwater Extension (MBE)). The Existing Main Breakwater ("EMBW") is comprised of two parts: the original breakwater that was built in the 1930s ("British MBW") and an extension that was built in the 1980s ("Carmel MBW"). As part of a campaign to improve accessibility to the Port of Haifa and to enhance the structural integrity of its marine infrastructure, IPC intends to retrofit an approximately 1,750 m long section of combined British MBW and Carmel MBW (Figure 1).

This breakwater section has deteriorated over the years and is subject to regular overtopping during storm events. In addition the stone used for the British MBW has deteriorated and neither the British MBW nor Carmel MBW were designed to resist current wave or seismic loading. Furthermore, the frequency and intensity of large storms are increasing, and therefore, and this coupled with the deterioration to date results in repairs being required on a more frequently basis. IPC retained HPA Engineers, P.C. (HPA) to carry out the planning and design of the retrofit alternatives for both breakwaters. The main objective of this study was to develop various retrofit options for 12.5-yr, 25-yr, and 50-yr design life, considering conventional rock armor and concrete armor units. The three design life alternatives were evaluated by considering six key factors: life-cycle cost, seismic resistance, effect on Navy and other harborside operations, environmental issues, sustainability, and construction schedule.

CONCEPT CROSS-SECTION DEVELOPMENT

HPA developed conceptual breakwater cross-sections for these three design life alternatives, spanning between Polynom Harbor and the MBE. Several client requirements have been accommodated throughout the development of the design, including but not limited to, re-use as much rock as possible from the Carmel MBW on the British MBW to minimize rock disposal, minimize dredging, avoid dismantling the western-most 450 m section of British MBW so as to not potentially jeopardize and/or restrict Navy operations in this region, avoid rocks larger than 3 t as they are largely unavailable in Israel, ensure there is no downtime at the quays on the lee side of the breakwater retrofit or at the Navy quays by keeping the post-dismantling top of rock levels as high as possible, don't extend new work into the navigation channel on the harbor side of the breakwaters.

The evaluation was carried out based on the results of numerical wave modeling to assess the design wave conditions along the breakwater, project-specific geotechnical investigation, and a site specific seismic investigation. The 100-year design wave heights are estimated to range from 5.7 m to 3.6 m for the future retrofit of the Carmel Breakwater and British Breakwater, with 5.7 m at the transition between the Carmel Breakwater and the MBE and decreasing towards the British Breakwater.

The client has confirmed that pedestrian/vehicular access to the western-most ca. 410 m of the British Breakwater is required; overtopping considerations consider the operational safety of pedestrians and vehicles, and the relevant allowable overtopping limits per EurOtop guidelines have been adopted (Eurotop, 2018). For the remainder of the British and Carmel Breakwaters, overtopping considerations are limited to structural damage to the crest (and rear slope of the structures) under extreme storm events only.

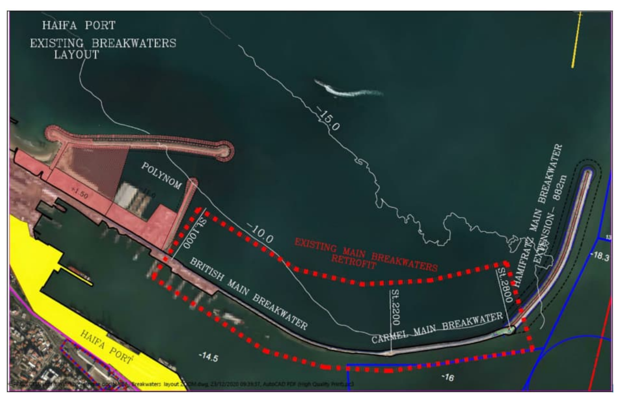

Figure 1 - Haifa Main Breakwater Project limits

Table 1 provides an overall comparison between the three design life alternatives, considering the six factors mentioned above. Based on this evaluation, the 25 yr design life solution was recommended for implementation. Antifer cubes, which have proven to work well on past projects at both Haifa and Ashdod Ports, were considered as the armor solution along the British and Carmel Breakwaters for this evaluation. The client subsequently requested that additional concrete armor units be considered to identify whether some other armor solution is more economical than the Antifer cubes. Table 2 compares the four (4) 25-year design life alternatives, similar to the one presented in Table 1 for the Antifer cube design life alternative. The results indicate that the single-layer Cubi-pod had the highest rating. Therefore, based on the single-layer Cubi-pod solution having the highest overall rating per Table 2, including being the lowest cost alternative, and having no known disadvantages, it was recommended for implementation. The new armor layer comprises different sized Cubi-pod armor units, where the size of the units was selected based on the severity of the waves reaching the structure. The sizes included 3 m^3, 4 m^3 and 5 m^3 units placed over three different sections from west to east. The retrofit design also extended to the rear (lee side) of the breakwater, where a combination of Cubi-pod and rock would protect the rear slopes. Given the history of the Haifa BW, and the cultural importance of the breakwater, two World War II vintage Fire Command Towers where required to be accommodated in the design. One of the design requirements was the prohibition of any alterations to these structures, however changes to the breakwater slopes were permitted, subject to their not blocking views of the towers from shore. Figure 2 shows a typical cross-section of the Carmel Breakwater, which includes a combination of rock armor and Cubi-pod armor units.

Table 1 Evaluation Matrix for Breakwater Retrofit Alternatives

Factor	Weighting	12.5-Year Design Life Antifer Cube Armor		25-Year Design Life Antifer Cube Armor		50-Year Design Life Antifer Cube Armor	
		Rating	Score	Rating	Score	Rating	Score
Life Cycle Cost	10	10	100	7.5	75	6.3	63
Seismic Resistance	9	0	0	10.0	90	10.0	90
Effect on Harborside Operations During Construction	9	10	90	8.0	72	6.0	54
Effect on Harborside Operations Due to Overtopping After Completion	9	7	63	9.0	81	10.0	90
Environmental Issues (Suspension of Solids, Rock Quantities, Noise, Damage to Ecological Assets, Construction Waste, Contamination)	8	10	80	9.5	76	9.4	75
Sustainability (Resistance to Extreme Storm Events)	8	6	48	8.0	64	10.0	80
Construction Schedule	8	10	80	8.5	68	7.3	58
TOTAL			**461**		**526**		**510**

Table 2 Comparison of the Four 25-yr Design Alternatives

Factor	Weighting	Antifer Cubes		Accropode™		Cubi-pod (Double Layer)		Cubi-pod (Single Layer)	
		Rating	Score	Rating	Score	Rating	Score	Rating	Score
Life Cycle Cost	10	8.0	80	8.8	88	9.2	92	10	100
Seismic	9	10	90	10	90	10	90	10	90
Effect on Harborside Operations Due to Overtopping	9	10	90	8	90	10	90	10	90
Environmental Issues (Suspension of Solids, Rock Quantities, Noise, Damage to Ecological Assets, Construction Waste, Contamination)	8	8	64	10	80	9	72	10	80
Sustainability (Resistance to Extreme Storm Events)	8	10	80	10	80	10	80	10	80
Construction Schedule	8	9.4	75	9.4	75	8.9	71	10	80
TOTAL			**479**		**503**		**495**		**520**

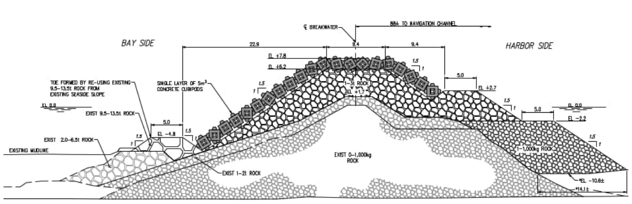

Figure 1 - Carmel BW Retrofit 5 m^3 single-layer Cubi-Pod armor at trunk.

PHYSICAL MODEL TESTS

2D and, subsequently, 3D, physical model tests were carried out to verify the recommended retrofit design. The objective of the physical model studies was to evaluate the performance and behavior of the key marine components forming part of this project. To achieve the objective, the retrofit design options had to be replicated in a physical model environment and subjected to a range of wave conditions at different water levels. The 3D physical model study was conducted at a scale of 1:36.5, and all tests were carried out inside a large wave basin with an area measuring approximately 60 m by 30 m. These included moderate-intensity events and extreme overload conditions. One of the principal outcomes of the 3D testing was that the retrofit design include a double-layer of armor in front of the two heritage sites. In contrast, a single-layer armor layer was sufficient for the remainder of the design. The armor unit sizes selected for the different areas should were sufficient for the retrofit design. The details of both the 2D and 3D physical model testing will be presented in the full paper.

PRELIMINARY RETROFIT DESIGN

The preliminary design was developed by using the figures developed for the Concept Design for the single-layer Cubi-pod and adapting them to incorporate the results of the 2D and 3D physical stability model testing, as well as developing additional cross sections at typically 50 m spacing, accounting for the seabed elevations and slopes as well as the existing profile at each cross-section. Factors influencing the development of the various cross sections included the environmental conditions, i.e., design wave height, existing mudline, presence of historic structures, specifically the East and West Fire Command Towers, existing transitions between various segments of the breakwaters, and the presence of the Navy base. All breakwater existing, dismantling, and retrofit drawings are provided in the Final Preliminary Design Drawings.

BIODIVERSITY ON THE BREAKWATER

A wide range of practical solutions to enhance the biodiversity of the breakwater structure was investigated. These include ECONcrete, Reef Cubes, Ecopod, Artificial Abrasion platforms, and Rock pool Habitats.

In the sub-tidal zone, from -0.5 to -5 m below sea level, enhancing the biodiversity of the Haifa Breakwater Retrofit project depends on improvement of structural complexity and constructing heterogenic niches, crevices,
tunnels, and other structural irregularities that may mimic a natural rocky ecosystem. This will be achieved by drilling or chiseling in rocks, using precast units, or intentional positioning of boulders or other construction units to maximize free spaces between the armor units. This will eventually encourage the colonization of invasive and opportunist organisms that might reduce biodiversity and ecosystem sustainability. It is recommended to install pits and pools anywhere on the external side of the breakwater, where there are rocks at sea level.

REFERENCES

EurOtop, (2018). Manual on wave overtopping of sea defences and related structures. An overtopping manual largely based on European research, but for worldwide application. 304p.