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SUBMERGED CONCRETE CAISSON BREAKWATER CONSTRUCTION

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After numerical and physical modeling, and alternate analysis, the proposed solution to mitigate wave energies entering Kahului Harbor, Maui was to construct a submerged concrete caisson breakwater, just outside the harbor that would economically improve the harbor tranquility and be environmentally friendly. One of the major challenges of this project is that construction is to be completed over a five-month period, during the summer months, when there are no swells. This requires as much prefabrication as possible, detailed planning, and precise scheduling. Construction of the individual caisson units is proposed to take place in a dry dock, cast in a single pour to avoid cold joints. On completion, it will be floated and tugged away from the dry dock and placed onto a heavy lift vessel and transported to its installation site at Kahului. Various alternate methods of transportation were studied and discarded. Also proposed is the transplantation and seeding of coral fragments on the caisson units to enhance the durability and increase the longevity of the submerged breakwater. This submerged breakwater caisson project will be the first of its kind for mitigating wave energies entering a harbor. This paper aims to present a viable construction methodology.

Keywords: Coastal engineering, Harbor protection, Wave energy mitigation, Heavy lift vessel, Scour protection units, Coral seeding.

1 BACKGROUND

Kahului Harbor is the primary commercial port for the island of Maui that experiences high amounts of traffic. This, along with the seasonal swells, makes for undesirable wave propagations inside the harbor, leading to possible safety violations and operational delays. The proposed solution: construct a submerged concrete caisson breakwater, just outside the harbor.

Being the first of its kind, this construction project will need a uniquely developed construction system. The following sections will provide insight to the strategies and construction methods.

2 SITE-SPECIFIC CONSTRUCTION CONSTRAINTS

After numerical modeling and physical verification, the proposed installation site for the breakwater is 280 m north of the existing eastern breakwater of Kahului Harbor (Figure 1). Construction and deployment of the caisson units near the installation site would be ideal. However, it was discovered that construction of this magnitude could not be undertaken on or from the island of Maui. Hence, a dry dock in Honolulu, on the neighboring island of Oahu was selected as the seat of the construction operations.

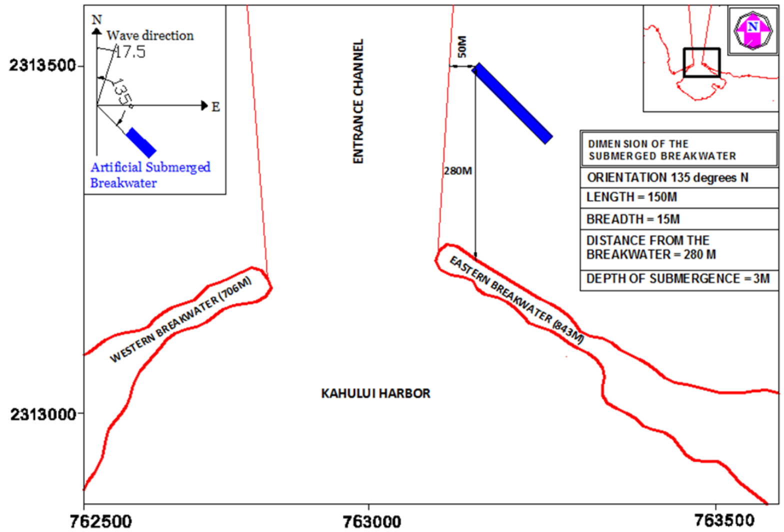

Figure 1. Final layout of the submerged caisson breakwater (Foley *et al*. 2015).

2.1 Heavy Lift Vessel Transport

Alternatives were considered in the transport of the caisson units to the construction site. However, tugging the individual caisson units is not the most secure mode of mobilization as there is a risk of capsizing and the floating dry docks cannot accommodate a caisson unit. After consulting with the marine contractor, it was recommended that a heavy lift vessel (HLV) be used in the transport of the caisson units.

2.2 Optimal Construction Window

Construction times will be limited due to the seasonal wave heights at the site. There are no specific guidelines for the maximum wave height at which caisson installation can take place. After simulations, Esteban *et al*. (2009) found wave height could be up to 1.5 m without causing risk or damage during installation to the caisson, or health and safety regulations. Thus, the only practical time period for construction of the caisson units would be in the summer season (May to September), when the waves are small.

3 PROPOSED CONSTRUCTION METHOD

The proposed method can be separated into 17 phases, as outlined in the following sections.

3.1 Phase 1: Pre-Construction Surveys

Prior to construction, specific surveys will be conducted that include a bathymetric survey, sea bed dive survey, and marking the site with high-visibility navigation buoys.

3.2 Phase 2: Mobilization of the Dry Dock

The mobilization of the dry dock will take a year of planning and permitting. The elements to be mobilized for casting in the dry dock are two long-reach cranes for loading/unloading all equipment and formwork, two concrete pumps, tool/maintenance workshop, rebar stockpile, site office/cabin, slip formwork, and base layer formwork.

3.3 Phase 3: Supply of Material

The materials required for this project will be delivered to the two main delivery sites: (1) the dry dock (materials: ready-mix concrete, reinforcing steel, slipform and formwork, and associated tools) and (2) Kahului Port (materials: rock or concrete mattresses for foundation layer, fill material to submerge caissons, pre-cast scour blocks, and crushed-rock leveling layer).

3.4 Phase 4: Excavation of Seabed for Foundation

The sea bed is required to be excavated 0.5 m across the footprint of the structure. The method for efficient and effective excavation would be with the use of a cutter suction dredger. On completion, the sea bed will be inspected and compacted samples will be collected. There might be a requirement to compact the excavated bed by an underwater dive team and a manually operated grader to achieve the required ground consistency (Mann 1999).

3.5 Phase 5: Mobilization of Plant and Manpower for Foundation

The required resources for the installation of the foundation are as follows: split hopper barge; tug boat, if barge is not self-propelled; commercial dive team; 30 metric ton crane barge; manual underwater grader; and remote operated grader.

3.6 Phase 6: Placement of Pre-Cast Foundation Units

Pre-cast concrete mattresses will be used as a foundation layer as it would dramatically decrease installation time and be less labor intensive. A fine layer of rubble is recommended to be deposited prior to the installation of a foundation unit. These operations will use a barge mounted crane and be overseen by a dive team.

The suggested length of each mattress is 10 m, derived from recommendations of the United States Army Corps of Engineers (USACE). The USACE guideline for mattress height/thickness is 60 cm, and in order to achieve the required 1.3 m height, two layers of mattresses will be required. The foundation layer must support an area of 126 m in length by 27.75 m wide; the total area that the caisson structure and scour protection blocks will occupy. Therefore, the total number of mattresses required would be 466.

3.7 Phase 7: Concrete Pouring of Caissons

Two main elements make up the caisson unit: (1) the bottom slab, and (2) the outer and inner walls. As the bottom slab is designed with an outer toe wider than the outer caisson walls, two techniques of concrete casting are required. A traditional formwork will be constructed for the bottom slab and the rebar will be placed per the design requirements. As soon as the pour for the bottom slab has been completed, a slipform for the outer and inner walls will be used, and concrete will be poured immediately to ensure no cold joints (Hibbs *et al*. 2009). The caisson is designed to be completely submerged and will have to be made watertight.

Another critical aspect is the installation of 12 anchor points (using pad eyes) into the structure during casting, as they will be used as point of connection for towing and positioning. The 12 points are located as follows: one for each corner at the top of the structure; one for each corner in the bottom of the structure; one on top of the caisson in the center of each length. Once the concrete is cured, the calculated water line (the buoyancy of the caisson) will need to be marked on the structure at each corner as a guide to assess the stability and keel of the caisson when floating in the dry dock and during ballasting.

3.8 Phase 8: Pre-Cast Concrete Caps

Pre-cast caps will be installed at the last phase of construction and will be used as a platform for the casting of top slab. The pre-cast concrete caps need to be constructed with a 4” to 6” flexible pipe inserted into it and should match the same point on the top slab. There will be two pipes installed for each cell: one as an inlet port and the second with a geotextile membrane for the output, allowing water to be expelled during the sand filling stage. *Bauer* connections, or similar, are recommended so they are easy to operate by a diver.

3.9 Phase 9: Transport of Caisson Units to Kahului Site

Once the first caisson unit has been completed, the dry dock will be prepared for flooding, during which the caisson will be monitored to assess there is an even keel. In the instance that the keel is uneven, sand ballasting in the correct cells will take place until it is at the acceptable level. The caissons will be connected to tugs via the anchor points and then towed to the HLV.

3.10 Phase 10: Unloading of Caisson Unit

Once the HLV is in place at the construction site, the vessel will ballast itself to approximately 40 ft; the caisson’s working draft is 29 ft. This will ensure adequate clearance for the caisson to be towed away and moved to above the foundation layer. The heavy lift vessel will then navigate back to the dry dock to collect the next caisson unit.

3.11 Phase 11: Positioning and Ballasting of Caisson Unit onto Foundation

The positioning and ballasting of the caisson unit is vital to the success of the project. Once the caisson is removed from the HLV and is floating on its own buoyancy, the next stage of installation is to move the caisson into position over the prepared foundation. The installation of the first caisson unit is vital to the alignment of the other caisson units.

In order to move the caisson unit in the most controlled approach, a minimum number of four heavy tug boats will be used. Two tugs will be positioned at the front of the caisson and one at the back, pushing slowly when required. A fourth tug will be on standby for any adjustments on either side of the caisson. Outside the perimeter of the foundation, a four point anchoring system will be used, to guide the caisson into place with marine grade rope and pulleys to allow for finer control, until the position is satisfactory and checked with GPS (Hibbs *et al*. 2009).

During the ballasting stage, movement of the caisson may occur due to wave/wind forces or uneven ballasting to the caisson. In this situation, the tugs and mooring lines will have to readjust the caisson and check with the RTK (real-time kinetic) GPS, having an accuracy to 2 cm, enabling informed operational control. To prevent any heavy loading on the caisson cells as well as any roll of the unit during ballasting, the cells should be loaded uniformly (Tsinker 2014). The proposed approach is to use a total of eight water pumps with a discharge of 50 m^3 per hour. Each cell is 99 m^3 and 80% of all cells need to be filled for the caisson to be on the foundation layer.

3.12 Phase 12: Pumping of Fill Material in Caisson Unit

Filling should be carried out as soon as the caisson is correctly positioned and seaward compartments should always be completely filled for stability under wave loading (BS3649-7:1991). Directly after the caisson unit has been ballasted and on the foundation layer, the filling activities can take place. This will involve the use of four hydraulic pumps and the same stage-wise approach for filling. The dive team will connect the outlet hose to the inlet port on top of the caisson. The hydraulic pumps will be placed into a barge containing 1,000 m^3 of crushed rock/sand fill material. Water will be pumped into the barge and a slurry mix will be created. The hydraulic pumps will be mounted from an *A-Frame/Davit Arm* and lowered into the slurry and pump the slurry from the barge into the caisson cells via the 4" delivery hose. During the filling process, constant checks with RTK GPS will be made and the tugs may have to re-align the caisson. If it is noticed that the caisson is out of position, water can be pumped out of cells allowing it to float and for the tugs/guidance system to reposition the unit.

3.13 Phase 13: Caisson Unit Connection

The caisson design has been incorporated with an interlocking arrangement between each Caisson unit. This will assist with acting as a guide and allow accurate confirmation that the caisson unit is in the correct X- and Y-axis positions in relation to the previous unit.

Prior to installation of the remaining three caisson units, the four point anchor system will need to be moved with the crane mounted on the barge. Additionally, the connections on Caisson 1 will be used to pull and position the Caisson 2 into place. When the male connection of Caisson 1 smoothly fits with the female connection of Caisson 2, the ballasting will take place. The dive team and support boat will need to monitor to make sure that the connection whilst ballasting is flush between Caissons 1 and 2. If a gap is noticed one of the support tugs will have to push against Caisson 2 to remove any gap. With the possibility of horizontal movement, the tugs will again be used to readjust any difference and caissons secured with guidelines to prevent further movement.

3.14 Phase 14: Casting of Scour Protection Units

A traditional formwork mold will be constructed and pouring will be conducted on Oahu. As the unit's weight will be 19.2 tons, they can be lifted by crane and transported by barge to Kahului Port for loading. Once at the port, they will be loaded onto the crane barge used to assist with the caisson installation. The caissons will be lowered into place using the crane with guidance from the dive team and the use of the RTK GPS system for accuracy.

3.15 Phase 15: Installation of Scour Protection Units

Placement of the scour protection blocks will take place immediately after a caisson unit has been set. Scour protection (Figure 2) on the seaward side should be placed and completed as soon as possible after positioning of the caisson (BS 6349-7: 1991). During the time the heavy lift vessel returns, the scour protection units for the first section needs to be completed. There are a total of 162 scour units per caisson section and with the aim of installing 15 units per day; it would take approximately 10.8 days to complete each section of scour protection.

3.16 Phase 16: Post Construction Surveys

On completion of the construction project, final surveys will be conducted along with as-built drawings. The surveys will include: RTK GPS survey to assess final structures position and crest height; bathymetric survey; videographic survey recording any damage to the structure during construction (e.g., any gaps between the caisson units or other construction abnormalities).

3.17 Phase 17: Coral Seeding/Propagation

An important element of this project is to conduct coral seeding and coral propagation activities to enhance the local ecology, contribute to the local environment, rather than destroying it, and to increase the durability of the caisson units. The seeding is done on the caisson units at the dry dock, after concrete pouring has been completed and the formwork removed. Studies indicate that coral seeding is feasible and that coral are indifferent to basalt, limestone, or recycled concrete (Foley *et al.* 2015).

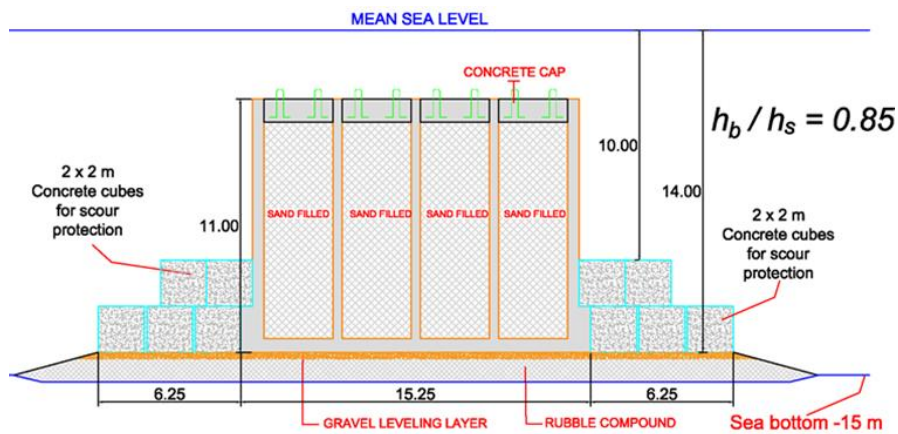

Figure 2. Elevation view of caisson breakwater showing scour protection units (Alvarez *et al.* 2015).

4 CONCLUSION

The construction of this submerged concrete caisson breakwater is feasible with the addressing of the construction constraints and implementation of the proposed construction method.

Acknowledgments

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