CONCRETE CAISSON BREAKWATERS: AN OVERVIEW ON DESIGN AND CONSTRUCTION

Kabir Sadeghi[1], Maram Almuhisen[2]

[1]Professor, Civil Engineering Department, Near East University, Nicosia;
[2]Ph.D. Candidate, Civil Engineering Department, Near East University, Nicosia, TURKEY.

[1]kabir.sadeghi@neu.edu.tr, [2]maram.almuhisen@gmail.com

ABSTRACT

Caisson breakwaters are among the commonly constructed breakwaters, especially in Japan. Reducing the transmitted waves into ports and harbors is an essential process in order to dock the ships arriving at them. Concrete caisson breakwaters are widely used and have a large impact on the economy and industrial advancement of countries. A general guide for the construction of caisson breakwaters is presented in this paper. The main purpose that this paper serves is presenting an overall guide for the processes of planning, designing, constructing, loading-out, transportation and installation of the concrete caisson breakwaters.

Keywords: Planning, design, construction, load-out, transportation, installation, caisson breakwater

INTRODUCTION

The use of different types of offshore structures has become essential in order to cope with the ongoing development and growing fierce competition in the world today (Sadeghi, 2007a). In the process of designing the offshore structures, all external factors should be taken into consideration as the natural disasters and breaking waves cannot be escaped from in the rough seas. Additionally, a well-studied design will ensure the structure more stability against the soft seabed (Port and Harbour Research Institute, 1991). An increase in risk noted by Oumeraci, (1994) might occur unintendedly because the dynamic amplification of caisson foundation loads was not considered. The year of 1932 marked the beginning of caisson construction, reaching a number of 131 caissons in 1971 with an average construction rate of 20 units a year. As the construction of caissons keeps developing, the deepest caisson extends 60 meters down and is currently being constructed in Kamaishi Port Japan. Caisson breakwaters have many benefits other than controlling the breaking waves, these include establishing a harbor naturally and in addition to that, they do not interfere with the water flow. On the other hand, building it might be expensive, it does not absorb all the energy, and that is because of the gaps between the breakwaters.

Storm surge barriers can be replaced by caissons as they perform the same task. Following the misfortunate events of Isewan Typhoon in 1959, a line of 8.25km protection breakwater was constructed along the Nagoya Port. The soft nature of the seabed sand in that area required further treatment to the sand in order to normalize it.

Historical Background of Caisson Breakwaters

Since the Japanese have many experiences in the design and construction of caisson breakwaters, in this paper a summary of their background in this regard is submitted as follows:

It was not long until caisson breakwaters dominated other remedies on less stable seas, leaving a fingerprint to other breakwaters and transferring some features of its design to them. The number of caissons reached up to 1500 fully constructed and operational units.

The idea of the use of caisson as breakwaters spread to include all the nearby ports, not only Onahama. It was a natural result of the development of Japan as a country to influence the development of caisson industry; an example was set by Tanimoto and Takahashi (1994). At 38 meters wide, located on a southwestern island, the Hedono Port caisson is considered the widest so far. The longest caisson with a unit length of 100 meters and a height of 13.5 meters utilized as a breakwater at the port of Kochi. A major purpose of the caisson was to join concrete walls and reinforcing steel. The construction of the caisson was completed on the dock, and then loaded to a ship to be transported 370km offshore to its desired location.

The calculations and analysis of the wave strength are estimated by means of finding the average strength per unit due to the extended length of the caisson, as conditions vary after a considerable change of location. The process of constructing the deepest caisson in the world is currently being executed in Kamaishi Port in Japan, reaching a depth of 60 meters. When the design phase was done, it was kept in mind by the designers the need for a shape that will provide the highest stabilization level possible. It was concluded that the bottom should be of a flat nature (rectangular/trapezoidal). The main function of this caisson is to dissipate waves as it has double slit walls at its top. This substantial function allowed it to rapidly spread throughout the coasts of Japan over the past 50 years (Tanimoto and Takahashi, 1994).

Caisson Breakwaters' Design

The factor of safety to the offshore structures has to be calculated with respect to the lifetime of the structure itself. The lifetime of each type of structure varies, as they perform different tasks and are subject to different environmental loading and seabed soil conditions. However, the longest is 75 years being for harbor structures and a relatively short lifetime of 25 years was assigned to petroleum platforms. (Sadeghi, 2008) and (Sadeghi, 2013). The development of Japan introduced new developed types of caissons that were based on the original designs. Good examples to those are the multi-circular and the curved slit caissons (Okada et al., 1990), a semi-circular and a dual cylindrical caisson breakwater (Takahashi, 1988), and many others. The previously mentioned caissons are still in the design phase. They will only be constructed after sufficient studies and analysis have been performed on them.

In 1976, the idea of the curved split caissons was introduced to the practice field after undergoing numerous analysis and experiments. With 150 meters of length and laying on the port of Funakawa, the first curved split caisson was constructed in 1984. However, the method of construction was more of a set of separate processes to create the parts. Once all the parts were done, they were then assembled together on the fixed concrete part of the caisson. The analysis concluded that cylindrical and trapezoidal caissons are more stable and have more resilience to overcome the conditions of rough sea areas (Tanimoto et al., 1987). A good example of deepwater caissons would be the one in Kamaishi Port. Although the design of deepwater caissons developed substantially, the impact they were leaving on the environment needed to be reduced. Hence, constructing deep and less rigid structures was found to serve that purpose. Therefore, the dual cylindrical caisson was introduced as a solution. The difference in the design in the latest mentioned types of caisson is that it consists of a hollow circular wall separating the inner wall from the outer permeable cylinder. Several experiments progressed since the year 1989 resulting in the construction of a 180 meters long caisson breakwater with a relatively shallow depth of 11 meters (Tanimoto and Goda, 1992). Research is currently in progress to construct an offshore caisson breakwater to reduce the erosion factors affecting the beaches, such caissons will be semicircular shallow

Leena and Luna International, Chikusei, Japan.
(株) リナアンドルナインターナショナル, 筑西市,日本
ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc. leena-luna.co.jp

water caissons. Due to their firmness and rigidity gained by the design of the top part, that provides higher resistance against waves. Surely, a major part of the undergoing research is collecting data on wave and wind effects (Sadeghi, 2007b). More detailed data to the processes of designing and constructing the caissons and the hydrodynamic loading due to the waves, currents and wind, can be found in the following references: (United States Army Corps of Engineers, 2011), (The Overseas Coastal Area Development Institute Of Japan, 2002), (Sadeghi, 1989) and (Sadeghi, 2001) and (US Army Coastal Engineering Research Center, 1980), (Nouban and Sadeghi, 2016).

CONSTRUCTION METHODS

The method of construction of a caisson breakwater can be separated into 17 phases, as outlined in the following sections:

Phase 1: Pre-Construction Surveys

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

Phase 2: Mobilization of the Dry Dock

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

Phase 3: Supply of Materials

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 and formwork, and associated tools) and (2) Supporting Port (materials: rock or concrete mattresses for foundation layer, fill material to submerge caissons, pre-cast scour blocks, and crushed-rock leveling layer).

Phase 4: Excavation of Seabed for Foundation

The seabed normally is required to be excavated about 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 seabed 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).

Phase 5: Mobilization of Plant and Manpower for Foundation

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

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.

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 padeyes) into the structure during casting, as they will be used as a 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; and 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.

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 inch to 6 inch 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.

Phase 9: **Transport of Caisson Units to the installation 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 heavy lift vessel (HLV).

Phase 10: **Unloading of Caisson Unit**

Once the HLV is in place at the construction site, the vessel will ballast itself to an appropriate draft considering the caisson's working draft. This will ensure adequate clearance for the caisson to be towed away and moved to above the foundation layer. The HLV will then navigate back to the dry dock to collect the next caisson unit.

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

The positioning and ballasting of the caisson unit are vital to the success of the project. Once the caisson is removed from the HLV and is floated 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 tugboats 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

Leena and Luna International, Chikusei, Japan.
(株) リナアンドルナインターナショナル, 筑西市,日本
ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc. leena-luna.co.jp

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). It is to use appropriate number of water pumps with appropriate discharge capacity. About 80% of all cells need to be filled for the caisson to be on the foundation layer.

Phase 12: **Pumping of Fill Material in Caisson Unit**

The 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 normally 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 the crushed Integrated Solutions for Infrastructure Development 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-inch 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.

Phase 13: **Caisson Unit Connection**

The caisson design has been incorporated into 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.

Phase 14: **Casting of Scour Protection Units**

A traditional formwork mold will be constructed and pouring will be conducted. The units can be lifted by crane and transported by barge to the supporting 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.

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 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. Considering the number of scour units per caisson section and considering the aim of installing how many units per day, the time needed to complete each section of scour protection is calculated.

ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc.leena-luna.co.jp
Leena and Luna International, Chkusei, Japan.
(株) リナアンドルナインターナショナル, 筑西市,日本

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; video graphics survey recording any damage to the structure during construction (e.g., any gaps between the caisson units or other construction abnormalities).

Phase 17: **Coral Seeding/Propagation**

An important element of this type of structure 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, 2015).

CONCLUSION

This paper gives a general guidance for the essential steps required in the planning, design and construction of concrete caisson breakwaters. The selected references and other related codes, in this paper, can be considered as reliable guides.

REFERENCES

[1] Foley, F. (2015). *Submerged breakwater modeling and coral reef ecological analysis for harbor protection*. Hawaii: University of Hawaii, College of Engineering, Civil and Environmental Engineering.

[2] Hibbs, H. (2009). *Installation of Caisson breakwater at Costa Azul*. Mexico: Thomas Telford Limited.

[3] Mann, S. (2009). *A floating factory for the Maasvlakte 2 Caisson Breakwater*. USA: TUDelf University.

[4] Nouban, F., & Sadeghi, K. (2016). Rough estimation of breakwaters' materials required for construction of harbors. *Academic Research International*, *7*(3), 56-65.

[5] Okada, O. (1990). *Recent developments of new type breakwaters in Japan*. Osaka: PIANC 27th International Congress.

[6] Oumeraci, H. (1994). Review and analysis of vertical breakwater failures-lessons learned. *Coastal Engineering, 22* (1–2), 3–29.

[7] Overseas Coastal Area Development Institute "OCDI". (2002). *Technical standards and commentaries for port and harbour facilities in Japan, Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), National Institute for Land and Infrastructure Management*. Japan: Port and Airport Research Institute.

[8] Port and Harbor Research Institute. (1991). *Technical standard forport and harbour facilities in Japan*. Tokyo: Overseas Coastal Area Development Institute of Japan.

[9] Sadeghi, K. (1989). *Design and analysis of marine structures*. Tehran: KNT University of Technology.

[10] Sadeghi, K. (2001). *Coasts, ports and offshore structures engineering*. Tehran: Power and Water University of Technology.

Leena and Luna International, Chikusei, Japan.
(株) リナアンドルナインターナショナル, 筑西市,日本
ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc. leena-luna.co.jp

[11] Sadeghi, K. (2007a). An overview of design, analysis, construction and installation of offshore petroleum platforms suitable for Cyprus oil/gas fields. *GAU Journal of Soc. & Applied Sciences*, *2*(4), 1-16.

[12] Sadeghi, K. (2007b). A numerical simulation for predicting sea waves characteristics and downtime for marine and offshore structures Installation operations. *GAU Journal of Soc. & Applied Sciences*, *3*(5), 1-12.

[13] Sadeghi, K. (2008). Significant guidance for design and construction of marine and offshore structure. *GAU Journal of Soc. & Applied Sciences*, *4*(7), 67-92.

[14] Sadeghi, K. (2013). *An overview on design, construction and installation of offshore template platforms suitable for Persian Gulf oil/gas fields*. Kyrenia: First International Symposium on Engineering, Artificial Intelligence and Applications.

[15] Takahashi, S. (1988). *Hydrodynamic characteristics of wave-power extracting caisson breakwater*. New York: ASCE.

[16] Tanimoto, K. (1987). *Structures and hydraulic characteristics of breakwaters – The state of the art of breakwater design in Japan*. Hong Kong: Port Harbour Res.

[17] Tanimoto, K., & Goda, Y. (1992). *Coastal structures and breakwaters.* London: Thomas Telford.

[18] Tanimoto, K., & Takahashi, S. (1994). Design and construction of caisson breakwaters, the Japanese experience. *Journal of coastal engineering*, 57-77.

[19] Tsinker, G. (2014). *Handbook of port and harbor engineering: Geotechnical and structural aspects*. New York: Springer Publishing.

[20] US Army Coastal Engineering Research Center. (1980). *Shore protection manual*. Washington: U.S. Government Printing Office

[21] US Army Corps of Engineers. (2011). *Coastal engineering manual (CEM)*. Washington: U.S. Government Printing Office.

ISSN: 2186-8476, ISSN: 2186-8468 Print
www.ajsc.leena-luna.co.jp
Leena and Luna International, Chkusei, Japan.
(株) リナアンドルナインターナショナル, 筑西市,日本