CHAPTER 125

Practical Study on Larger-Scale Cylindrical Caisson Breakwater in Port of Kaohsiung

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ABSTRACT:

Using cylindrical caisson for a large-scale breakwater is not popular so far in the world. Never-the-less with the completion of Port of Kaohsiung's 2nd Harbor Entrance Project, the engineers in Taiwan has encouraged by the successful experience in this field due to its simple construction method and low cost consideration.

1. INTRODUCTION

Taiwan is an island, most of the economic activities with foreign countries rely on seaport's operation. Therefore, at least 4 international seaports were built successively in last 3 decades. Among them, Port of Kaohsiung is the most important one in terms of cargo handling and foreign trade as a result of the construction of 2nd harbor entrance as shown in Fig. 1.

Althrough there are many types of breakwaters can be selected for harbor entrance construction project, rectangular caisson breakwater is one of the most popular types in Taiwan, R.O.C. For Kaohsiung 2nd harbor entrance project due to tight schedule, limitative budget and shortage of material,the Harbor Bureau bravely and cautiously used cylindrical caissons as main structure of break-water to replace the traditional rectangular shape to meet the development of heavy industrial zone surrounding the harbor area. This not only encouraged the engineers in Taiwan, but also set a record in R.O.C.'s harbor engineering.

Perhaps, cylindrical caisson used for breakwater in Kaohsiung was not the first one, but, I think it would be the largest one in the world so far. Kaohsiung's 2nd harbor entrance, navigable by ships up to 125,000 D.W.T. is protected by 2189-meter southern breakwater and 1322-meter northern breakwater, to keep the main channel to a min. depth of 16 meters as shown in Fig. 2. This project, took 8 years to complete from 1967-1975, totally used 136 units of cylindrical caissons including 37 units of $\phi 17^m$ *and 99 units of* $\phi 24^m$ *at a cost of about US$35 millions at that time.*

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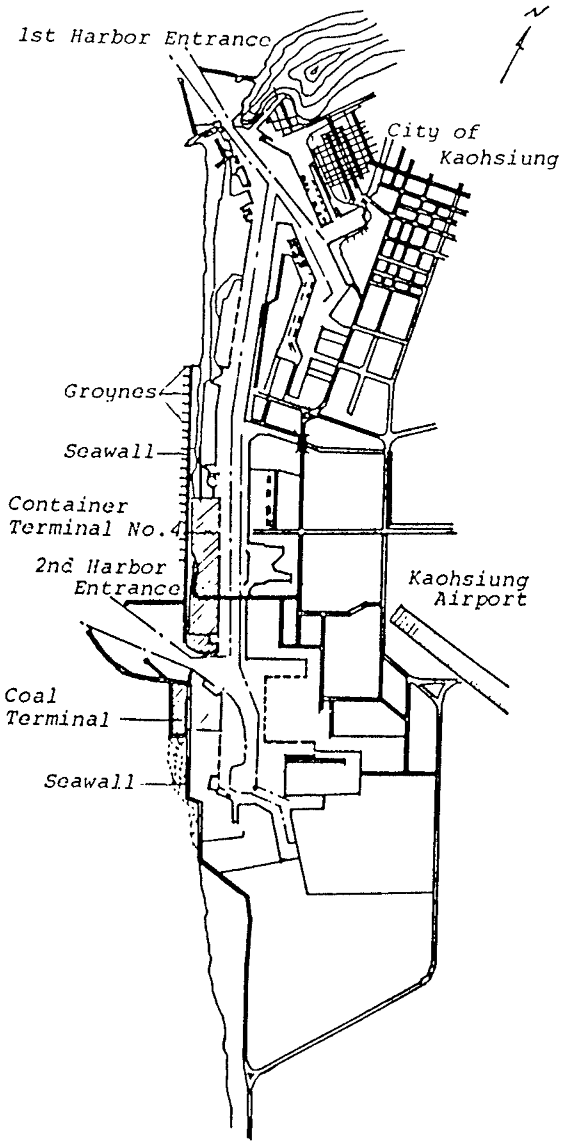


Fig. 1 Port of Kaohsiung

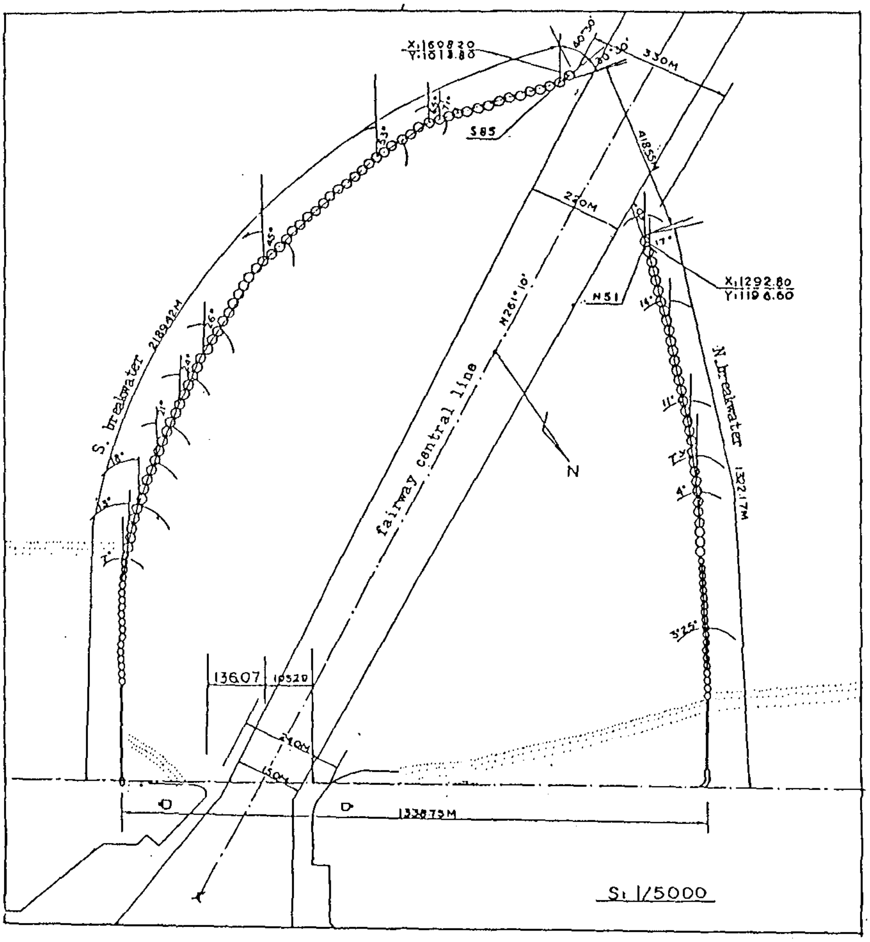


Fig. 2. Layout of Kaohsiung 2nd Harbor Entrance Breakwater (by using cylindricl caisson)

2. PRACTICAL EVALUATION

In view of practical evaluation of cylindrical caisson breakwater, it will be compared its project cost, construction period, construction method, technical problem, damage rehabilitation during construction and maintenance after operation etc. with those of the rectangular type in Taiwan's conditions.

2.1. Initial cost

As conservative evaluation, the construction cost of the cylindrical caisson breakwater could save about 15-20% than that of the rectangular one due to simple construction method and short construction period etc.,

For diver demand, from beginning to the end, divers needed for placing cylindrical caissons in Port of Kaohsiung were only 2-3 teams in comparison with about 50 teams which needed for rectangular types of the same size in doing foundation works and so on in Taiwan's experience. This implied that the cost could reduce in a large amount for cylindrical caisson breakwater.

For rock requirement, due to foundation free, the volumes of rock need for cylindrical caisson breakwater was only half as much as rectangular type. This meant it could save much more money and time in comparing cylindrical caisson breakwater with rectangular one.

For others, it could save about 20% of the budget for equipments and other kinds of material in cylindrical caisson breakwater.

2.2. Construction period:

Using very simple and mass-produced methods for fabricating cylindrical caissons and for the sake of no necessity placing rock base, foundation screed and other sophisticated under-water-works for caissons etc., the construction progress of cylindrical caisson breakwater was much faster than that of the rectangular type. Normally, under the same manpower to complete a same size breakwater, the construction period taken by cylindrical caissons was only half as long as the rectangular one. Taking Port of Kaohsiung's 2nd harbor entrance breakwater into account, placing about 24 units of cylindrical caissons a year were a very high through-put regardless of bad weather in the region lasting for more than 5 months annually.

2.3. Construction method:

Taking average, 2-dozen of cylindrical caissons were needed per year in Port of Kaohsiung's 2nd harbor entrance breakwater construction project. Hence, many possible approaches were used in fabricating works simultaneously to meet the annual demand. At the same time, some other construction methods were also simplified to cope with the actural requirements which were quite different from the rectangular type.

For fabricating works, cylindrical caissons were built either on shore bank, quay side or inside the dock simultaneously to catch the schedule.

2.3.1 Fabricated on shore bank:

Some caissons of 17-meter in diameter were built to complete on the shore bank. After completion, they were launched and floated by cutter dredger, and then, grounded before towing & sinking to prevent them from hitting each other in typhoon season as shown in Fig. 3. Some 20 units of $\phi 24^m$ cylindrical caissons were done in the same way before fabricating dock was available. Simplification and low cost were the advantages, but they needed a lot of land areas and coastal fronts for using.

Fig. 3. Cylindrical Caissons fabricated on shore area.

2.3.2 Fabricated inside the dock:

A total of 81 units of $\phi 24^m$ cylindrical caissons were fabricated inside the dock to the height of 4-meter (draught 3.7^m, freeboard 0.3^m) as shown in Fig. 4, and then, built continuously outside the dock, also in water, till completion and grounded for temporarily setting. This case cost more and took a long time to complete with no other better solution.

Fig. 4. Cylindrical caisson fabricated inside the dock.

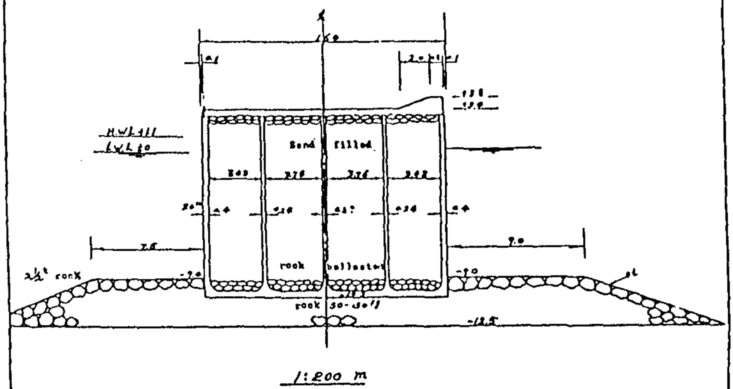
2.3.3 Fabricated on quay side:

Some caissons of 17-meter in diameter were constructed to the height of 1.57 meters (draught 0.86^{m}, free board 0.71^{m}) on the apron of quay side, and then, hoisted by 200-ton capacity floating crane down to the water to continue the rest part as shown in Fig.5. Being completed, they were grounded temporarily as well. Quay was the requisition for this case.

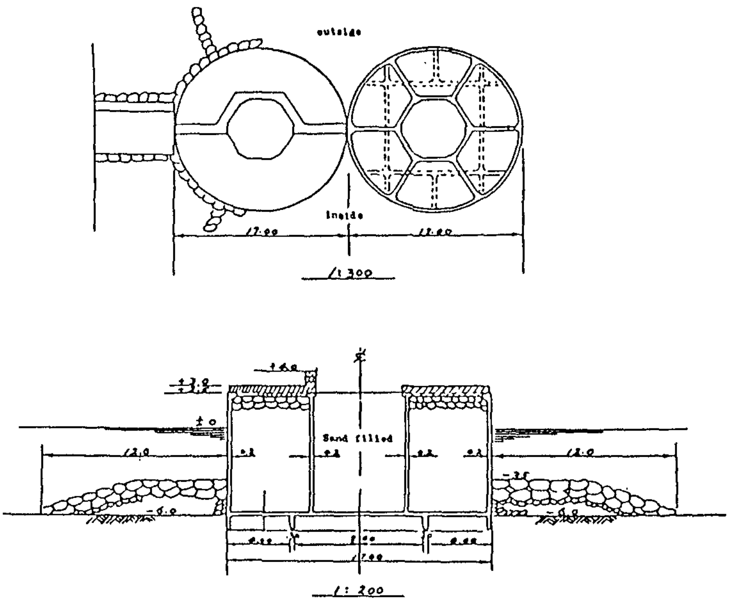
Fig. 5. Cylindrical caisson fabricated on quay apron.

For foundation built-up, due to caissons being put directly on sea bed of slope ranging from 1:100-1:50 or so, natural sea bed was just the foundation of cylindrical caissons to make the cutting wall to cut through it. Placing rocks or armour units for this kind breakwater aimed at giving appropriate protection to the toes of cylindrical caissons rather than to the foundation, as shown in Fig. 6.

As to the towing & sinking of cylindrical caissons, It's a key point for breakwater construction. The temporarily grounded caissons were refloated before towing. Towing & sinking was done in a continuous process to put the caisson in the right position. Then, the following works, such as sandfill, rock-placing and capping etc. followed up till the caisson come to the absolutely stable condition.



Typical cross section of rectangular caisson breakwater



Typical cross section of cylindrical caisson breakwater

$\phi 17^m$ cylindrical caisson

Using for depth $-3.0^m \sim -6.0^m$ Sections

Fig. 6. Different Foundation Methods between cylindrical caisson and rectangular shape breakwaters

2.4. Technical problem:

Some technical problems which play a very important role reffering to the cylindrical caisson breakwater were cutting wall installation, gap control, design criteria and so on.

2.4.1 Cutting wall installation:

Cutting wall's design was a very important breakthrough to the cylindrical caisson breakwater. It's installed along the bottom wall with a height of 1.25-1.50 meters as shown in Fig. 7. When cylindrical caissons placed directly on the sea bed, it cut into the sand layer by its self-weight and weight of sand-fill etc. to increase the horizontal resistance forces against sliding. At the same time, it could protect the sand under the caisson from scouring during constructing in monsoon season (wave height under 2 meters). The later was more important than the former due to caisson being placed in monsoon season rather than in typhoon season.

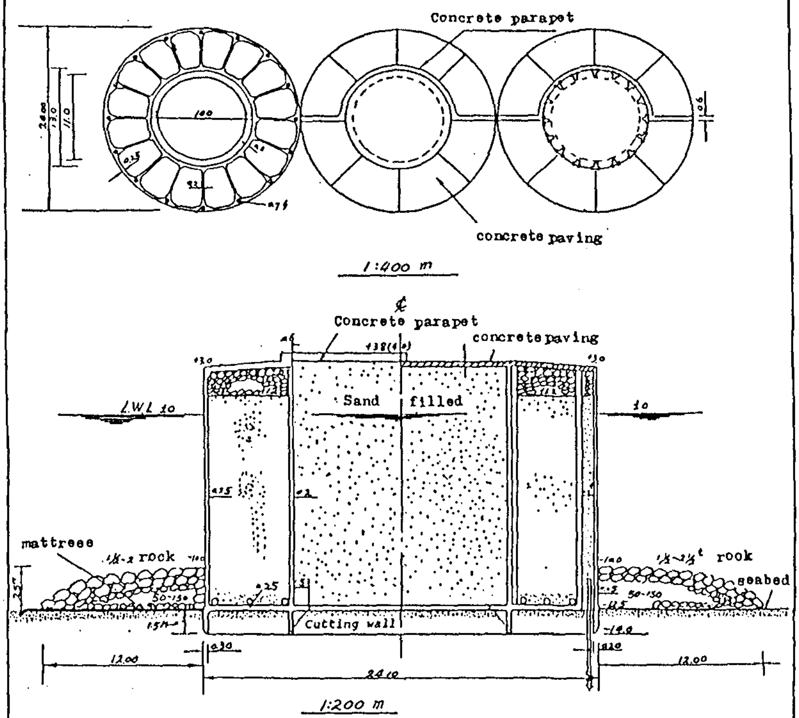


Fig. 7. Typical cross section of cylindrical caisson breakwater
$\phi 24^m$ cylindrical caisson
Using for depth – 6^m ~ – 12.5^m sections

2.4.2 Gap control:

Gaps between each two caissons should be controlled in a proper limit, designed for 40cm in Kaohsiung's case, to avoid wave transmission packing sand from outside the breakwater to silt the channel. Furthermore, the unsuitable arrangement of the gaps could induce wave momentum to wash away the rock or armour units placed in between the gaps. In Kaohsiung's case, we should do routine maintenance by placing about US$300,000 equivalent armour units (Used 15-20 ton modified tetrapods) annually due to bad control of gaps.

2.4.3 Design criteria

Besides the sand-fill and the weight of caisson itself, the stability design of cylindrical caisson for bearing, sliding and overturning was also controlled by constructing caisson as a hollow type with 1.25-1.5m cutting wall to cut through the sand layer. For the 6 meters designed wave height, the factor of safety of $\phi 24^m$ *cylindrical caisson were:*

$$F_b = 2.25$$

$$F_s = 1.84$$

$$F_o = 5.40$$

Which were all larger than the standard value 1.2 set for the design criteria.

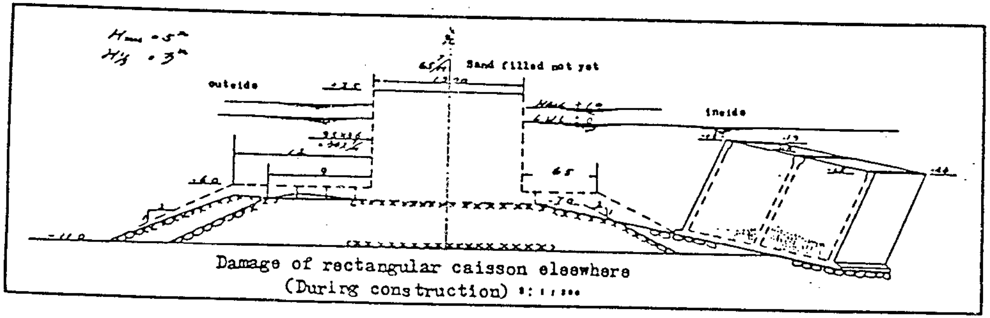
2.5. Damage rehabilitation during construction

During construction, already placed cylindrical caissons would be declined to about 9 degree or sunk down to the sand bed some 1.5 meters deep, but wouldn't be moved out of the position as hit by big wave forces in case that protection works had not yet completed. If so, the repair and rehabilitation works could be done by mounting precast concrete frame on the top of caisson to the design elevation. This procedure was quite different to the rectangular type which would be damaged in a different way-slide away from its position as shown in Fig. 8. Other damages, such as wall fracture, also could be repaired in a easy way.

2.6. Maintenance after operation:

Although there were many advantages using cylindrical caisson for breakwater, maintenance was the big problem to be solved in comparison with the rectangular one.

For regular maintenance, placing 7.5-20 ton of armour units should be made annually to protect the toes of cylindrical caissons from scouring before typhoon season.



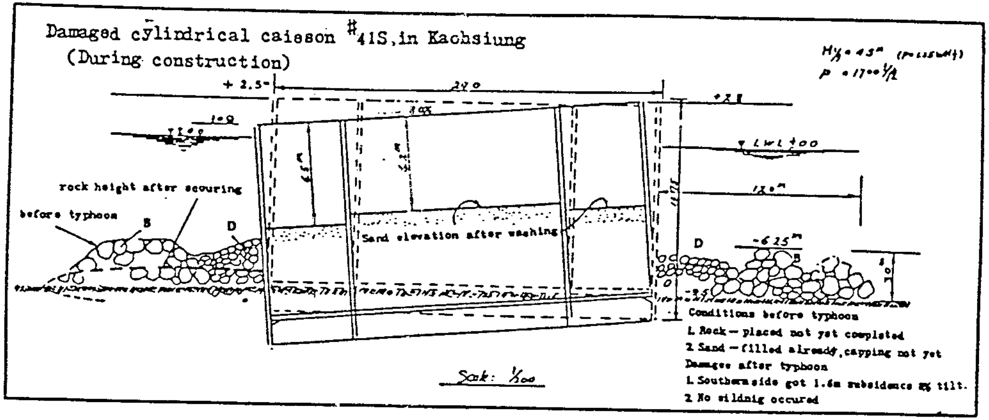


Fig. 8 Different damages for cylindrical and rectangular caissons during construction.

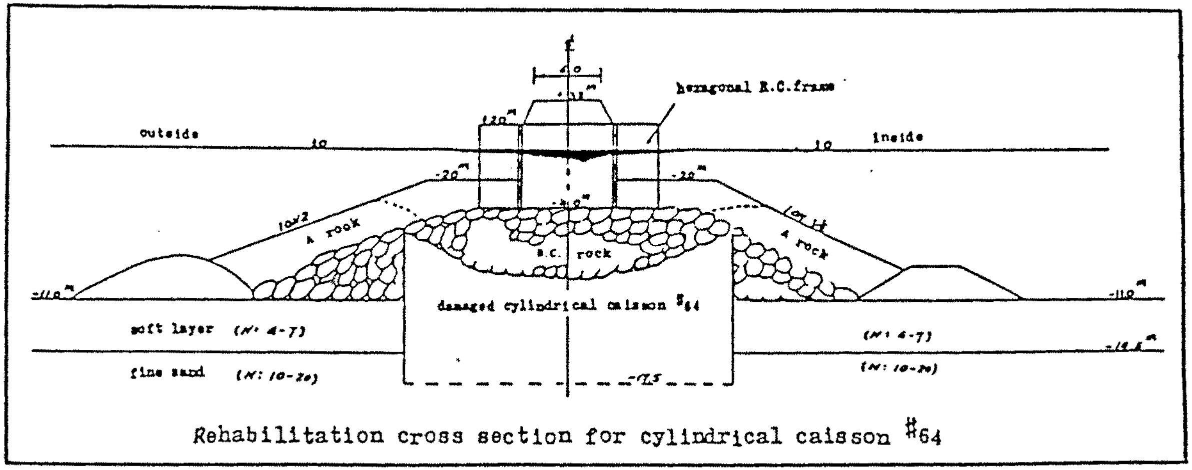


Fig. 9. Repair method for serious damaged cylindrical caisson breakwater

For emergent disposal, repair works should be carried out as soon as typhoon passed in case of serious damages occured as shown in Fig. 9.

3. CONCLUSIONS:

(1) Using cylindrical caisson for a large-scale breakwater is encouraged as Port of Kaohsiung's 2nd harbor entrance breakwater has successfully experienced in many typhoon attack (the peak wind speed reached 63 m/sec or 227 km/hour) since it was completed in 1975.

(2) Cutting wall was a key point in cylindrical caisson breakwater design, from which a very good horizontal resistance force against sliding could be given to reduce the damage to the least during/after construction.

(3) Gap design of cylindrical caisson breakwater gave a very close relation with maintenance, Therefore, laboratory model test and mathematics model analysis should be done to find the suitable armor units for long-term stability consideration.

(4) No matter what disadvantages during/after construction are, using cylindrical caisson for the large-scale breakwater project is worthwhile to recommend as it could shorten construction period, simplify construction method and reduce construction cost under the consideration of security and safety. Especially, it will provide a valuable experience for developing countries which run short of funds and need seaport urgently.

4. REFERENCES:

(1) Gong, C.I. et al (1976). Report on improvement study of Kaohsiung 1st Harbor Entrance.
(2) Report on study of construction plan of Kaohsiung 2nd Harbor Entrance (1968)Kaohsiung 2nd Harbor Entrance Construction Department, Kaohsiung Harbor Bureau.
(3) Report on Kaohsiung 2nd Harbour Entrance Construction Project (1976).