NATIONAL UNIVERSITY OF SINGAPORE
SCHOOL OF DESIGN AND ENVIRONMENT
DEPARTMENT OF BUILDING

BU1462 (BR1105)
CONSTRUCTION TECHNOLOGY II

DISCUSSION ON THE CONSTRUCTION OF DEEP FOUNDATION - BOX CAISSON WITH CASE STUDIES

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BOX CAISSON - CAISSON CONSTRUCTION AND SINKING METHODS

▪ CAISSON FOUNDATION
▪ CONSTRUCTION SITE
▪ TOWING OF CAISSON TO THE SINKING SITE

CASE STUDY

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Outline

This paper will look at the construction of Box Caisson. It will attempt to give a overview of the principle of caissons (types, design and uses), construction, preparation and its installation method.

A case study of box caisson used in the construction of “Container Terminal at Pasir Panjang Phase I & Phase II” is discussed herein to give the reader a better understanding of box caisson. The construction method used by two different construction company on these two project is outline for the reader to have an in depth understanding.

The Principles of Caissons

Like all other foundation, the function of caisson foundations is to enable structural loads to be taken down through deep layers of weak soil on to a firmer stratum which will give adequate support in end bearing and resistance to lateral loads.

Caisson are used in situations where it is not feasible to use other methods, say, due to boulders in the soil, or where it would not be economical to do so because the foundation is small in plan area in relation to the depth of water. In such cases, one or the other variation of caisson is likely to be suitable.

Caisson foundations fulfil a similar if not same function to piled foundation. In laymen’s term, it is a heavy structural member acting as a massive strut, which the foundation structure is built above ground level and sunk to the required founding level as a single unit. Piled foundations however, are constructed in-situ in a deep excavation and are essentially a pad foundation and buried column. This definition distinguishes the pier foundation from a caisson or monolith in which the foundation structure is built above ground level and sunk to the required founding level as a single unit.

The following definition of caisson is given:

Caisson : a structure which is sunk through ground or water for the purpose of excavating and placing the foundation at the prescribed depth and which subsequently becomes an integral part of the permanent work.
Some example of caisson are given below:

Caisson, Box: a caisson which is closed at the bottom but open to the atmosphere at the top.

![Caisson Box Diagram](Fig. 6.1 Caisson box.)

Caisson, Open: a caisson open both at the top and the bottom.

![Open Caisson Diagram](Fig. 6.2 Open caisson.)

Caisson, pneumatic: a caisson with a working chamber in which the air is maintained above atmospheric pressure to prevent the entry of water into the excavation.

![Pneumatic Caisson Diagram](Fig. 6.3 Pneumatic caisson.)
Monolith: an open caisson of heavy mass concrete or masonry construction, containing one or more wells for excavation.

Box Caisson - Caisson Construction and Sinking Methods

Caisson Foundation

As already mentioned, box caisson are structures with a closed bottom designed to be sunk on to prepared foundations below water level. Box caisson are unsuitable for sites where erosion can undermine the foundations, but they are eminently suitable for founding on a compact inerodible gravel rock which can be trimmed by dredging (Fig. 1a).

Caisson can be founded on an irregular rock surface if all mud or loose material is dredged away and replaced by a sound crushed rock (Fig. 1b).

Where the depth of soft material is too deep for dredging they can be founded on a piled raft (Fig. 1c). One method of piled raft in open sea is by the Strong Sand Pile technique.

Construction site

Depending on circumstances, i.e. site constraint, box caisson can be constructed either on land or on sea on a floating dock.

The practice of caisson construction on land requires the caisson to be slide or lower into the water for floating out to the actual final location (Fig. 2). Likewise if the caisson is constructed on a dry dock, the dock is subsequently flooded to float out the caisson.
Fig. 1 Methods of founding box caisson. (a) On dredged gravel or rock formation. (b) On crushed-rock blanket over rock surface. (c) On piled raft.

Fig. 2 Methods of constructing caisson shoe on shore. (a) On gently sloping river bank. (b) On steeply sloping river bank.
Towing of Caisson to the Sinking Site

The operation of towing a caisson from the construction site to its final location must be carefully planned. The route taken must be checked for adequate water depth. The essential requisite of the launching, towing and sinking operation is to ensure stability of the caisson during these operations.

Smaller units were generally partly built in the dry on slipways. Larger units were generally built in the wet docks which had been dammed and then dewater, the dock is then refilled when the units is completed.

Towing is generally by means of a towing bridle of wire cable with spring shock absorbers. Considerations of the hull stresses when floating has to be given during towing operations.

Related Website:-


http://www.tritonsa.gr/caissons.htm


http://www.gerwick.com/default.asp?
CASE STUDY
CONTAINER TERMINAL AT PASIR PANJANG (PHASE I & II)

Project Overview

The case study discussed in this report is undertaken by Hyundai Engineering & Construction Corporation Ltd and Penta-Ocean Construction Corporation Ltd which are each responsible for Phase I and Phase II subsequently.

The site of the project is located off West Coast Road. The project “Container Terminal at Pasir Panjang Phase II.

Box Caisson is used for this project as a foundation replacing the normal open-deck construction of wharf by spun piles. Box caisson is used for this project as it was a cheaper alternative compared to that of conventional open-deck system of spun pile foundation. Firstly, the soil strata encountered at the site make box caisson attractive as depths of suitable soil does not vary greatly. The Box Caisson acts as a retaining wall preventing sand used for reclamation from being washed out to the open sea.

The caisson constructed for this project has a typical dimension of 19.15m height X 29.9rn length X 16m width. The weight of a typical caisson is about 5200 tons when empty.

Box Caisson is fabricated through several steps on lined-up works. In Phase I of the project, caisson fabrication is constructed on a floating dock which is subsequently sunk to allow the caisson to be towed and finally installed at its location. In Phase II of the project, a specialized heavy lift and transfer system helps move the caisson from a purpose-built casting yard which fabricates the caisson by “Sliding Form” to the floating dock to be launched.

In each Phases of the project, while the caissons are being fabricated in the yard, the caisson foundation is being prepared simultaneously. On completion, the box caisson is positioned at its predetermined location and sunk to its final “resting” place.
Caisson Foundation

Soil Investigation and Cavity Probing

The actual base level and dredging profile of the trench are determined from soil investigation and cavity probing results.

Limestone is present at the site and there are possibilities of fissures and cavity within the limestone. Thus, seismic survey was carried out to determine the location and extend of cavities within the top level of limestone layers. This was following by boreholes probing to confirm and the grouting of cavities.

To determine the location and extent of cavities and fissures in limestone present at site. A minimum of one to a maximum of three soil boreholes per caisson location is carried out before caisson installation. The objective of this soil investigation is to locate the top level of the limestone layers and detect the presence and size of the fissures or cavities within the limestone layer. All the boreholes were extended to a minimum of 6m below the founding level of the caisson rock base.

Trenching for Caisson Foundation

The dredging was carried out by grab bucket to the minimum undrained stress strength of 200kN/m². Shear vane test is carried out on the undisturbed samples to determine and confirm the strength of the foundation soil layer.

Sandfilling to the trench was executed immediately after completion of dredging in order to minimise possible sediment and softening of the dredging surface. Densification of the existing seabed level with the densification limit of 70% relative density. The densifications are measured using Cone Penetration Tests (CPT). The sandkey is trimmed by grab dredger to the existing seabed level.

Rock Base Placing and Compaction

Rock carried by flat top barges is moor alongside the dredger equipped with an orange peel grab to place rocks for the rock base. Transducer for echo sounder fixed to a mobile boggie on the bow of the stone placing barge to monitor the rock thickness placed is not more than two meter. The rock is then compacted with a steam hammer capable of striking energy of 12 ton-m/m² and transferring the energy generated by the steam hammer from the top of the extension to the footprint of 2m by 2m at the bottom.

The purpose of the compaction is to densify the rock of size 75-300mm and to achieve settlement of less than 30mm under the striking energy. Rock placing and compaction sequences are proceed in layers up to the proposed level.
Screed Layer

A final screed layer of stone size 20-50mm and thickness of 500mm is laid on the rock base to allow the caisson to sit evenly on the foundation. The specially designed screed platform could place accurately the screed material. Its main feature is the hydraulic extendible legs and mobile chute to fill the screed box with hopper capacity of 19m³.
TYPICAL CONSTRUCTION SEQUENCE FOR CAISSON WORK – SANDKEY FOUNDATION

STEP 1
- DREDGE TRENCH FOR SANDKEY
- FILLING TRENCH
- DESIFICATION OF SANDKEY

STEP 2
- ROCK BASE PLACING & COMPACTION
- INSTALL CAISSON
- INFILL CAISSON

STEP 3
- FILL BEHIND CAISSON
- PRELOADING OF CAISSON

STEP 4
- DECK CONSTRUCTION
Caisson Foundation Works

For the project of “Container Terminal at Pasir Panjang Phase I & II”, several methods of founding for the box caisson was used. Depending on the suitability of the subsoil conditions, the following founding methods for caisson were used:

1. Sandkey Foundation (Ph I & II)
2. Rock Foundation (Ph I)
3. Sand Compaction Piling Foundation (Ph I)
General Sequence of Caisson Foundation Works

- Sandkey Foundation

Work Sequence:-

1. Dredging to Design Level (200 kN/m²)
   - Dredging by layers
   - Joint inspection during final layer dredging
2. Sand Filing
   – Dumping sand with trailer or barge
   – Sandfill topping-up equivalent to settlement by compaction to be made above seabed level

3. Densification of Sandkey
   – Sand fill 2m – 3m below seabed level to be compacted by Vibroflotation

4. Levelling
   – Top surface of sandkey to be levelled to seabed level by cutter suction dredger or other means

5. Rock Placing & Compaction
   – 1st 2m layer to be placed & compacted. Sandkey 2m – 3m below rock base to be compacted with 1st rock base layer
   – Placing next layers & compact. Thickness of next layer to be decided according to compaction energy

6. Screeding & Levelling
   – Placing screed layer & levelling to the criteria

7. Caisson Installation

**Vibrofloitation of Sandkey**

On marine sandkey compaction, “Vibroflot” is deployed to carry out the vibro-compaction of sand material in the trench. Vibro-compaction by vibroflots is used with non-cohesive soils such as sand or gravel where the silt content is less than 15%. Compaction of the soil occurs by vibration of the insitu soil, which by this process is transferred into a local state of liquefaction. During this liquefaction, the sand and gravel particles move closer together until the required compaction is achieved.

The Vibroflot is suspended from a crane mounted on a barge and located above the designated compaction point. Under combination of its own weight, vibration and water jets, the Vibroflot penetrates into the ground to the required depth. When this has been reached, the lower jets are switched off and compaction is commenced.

The Vibroflot is held at this position until either the required Amp reading is obtained from the “Vibroflot Electric Motor” or for a fixed time whichever is earlier. The Amp reading / pulling time is referred to as the pulling criteria which is established in the compaction trial together with the grid spacing used.
Rock Placing & Compaction

Rock Placing and its compaction for sandkey foundation is to provide the caisson a “solid” base to be founded on.

The execution of the works is done in stages which has to be monitored carefully during the operations. Each layers of rocks to be laid and compacted is executed in stages, the scope of work for rock base is as follows:-

a. Laying of 75mm – 300mm well graded rocks on compacted sandfill in sandkeys. Compaction of this layer.
b. Laying of 20mm – 50mm screed layer 500mm thick on the compacted rock base. Compaction of this layer.
c. Laying of 2mm – 50mm stone filter layer.
d. Laying of rock size 300mm – 500mm. Compaction of this layer.
e. Laying of Armour layer 600mm – 900mm rocks. Compaction of this layer.
f. Laying of Geotextile by divers.
g. Dredging and placing dredged hard materials over the caisson foundation.

Rock Placing Barge

Rock Compaction Barge

Compaction Hammer
- for compaction of rock layers
Illustration of Rock Placing & Compaction
Screed Laying & Levelling

Upon completion of the rock base and its compaction, the screed laying works would proceed. A Screed Plant would then be positioned over the trench for the screeding works.

Screed materials are fed into the loading hopper with a backhoe on the material barge. The mobile chute under the loading hopper would then guide the screed material into the screed box below. Once the screed box is full, synchronised winches on the platform of the screed equipment would be activated to move the screed box so as to lay the screed material along the width of the rock base. This operation would continue until the required level is achieved.
- Rock Foundation

Rock foundation method is used for founding of the caisson at areas where rock are encountered. The rock placing, compaction and screeding works is carried out by a purposed built barge “Zinkoon II”. The pontoon barge is equipped with a ram soud for the compaction of the rock base and a screeding unit for the placement and levelling of rock material. The screeding unit consists of a combine feeder chute, conveyor belt, hopper pipe, fall pipe, screed pipe and screed skirt.

20mm – 50mm or 150mm – 300mm rocks are compacted at a 5.5m² grid at the prepared founding base. On completion of the rock placing and compaction, a visual inspection is carried out by divers to ensure the works is done. Once the approval of the rock mattress is given, the installation of caisson may proceed.
TYPICAL CROSS-SECTION OF ROCK MOUND AT NON-SCP AREA

SIDE VIEW OF ROCK MATTRESS LAYING PONTOON

PLAN VIEW OF ROCK MATTRESS LAYING PONTOON
- Sand Compaction Piling Foundation

In areas where soft subsoil is encountered the Sand Compaction Pile foundation method was used for the founding of caissons. The Sand Compaction Piling system a.k.a. Strong Sand Pile Technique uses a kind of compacted sand pile, which involves driving compacted sand piles into the soft subsoil.

This technique features the Vibro Flot which is located at the bottom of the casing tube and transmits energy in the circumferential direction. Since it allows direct compaction of the discharged sand, strong compacted sand piles can be continuously placed with a series of casing pipe-pulling operations.

This method can be used for both cohesive soil and sandy soil.
Sand Compaction Pile Procedure.

1. Determine the location for the piles.
2. Start to drive the casing pipe.
3. Driving the casing pipe.
4. The pulling force will help to discharge the marine clay.
5. Marine clay is fully discharged and casing pipe is ready for drive in operation.
6. Put infill sand into the casing pipe and driving the casing pipe to its predetermined depth.
7. Put infill sand.
8. Sand level check.
9. While pulling up the vibro Flo to its required depth and stop the vibro Flo.
10. Put infill sand and start the vibro Flo to compact the discharged sand and stop the vibro Flo.
11. Finish the vibro Flo.
12. Put infill sand.
13. While pulling up the vibro Flo to discharge the sand and air to the casing pipe. Put the vibro Flo to form the sand pile to its required depth. Put air.
Sand level check and start the Vibro Pile, deliver compressed air to the casing pipe.

While pulling up the Vibro Pile, deliver compressed air to the casing pipe to form the sand pile to its required depth.

Finish the discharged sand and stop the Vibro Pile. Air, Sand, and start the next Vibro Pile.
Fabrication of Caisson

Two methods of construction / fabrication of caisson was used for this project, “Container Terminal at Pasir Panjang Phase I & II”.

Method of Fabrication – Phase I

The main contractor for Phase I project, Penta-Ocean Construction Corporation Ltd, chose to fabricate their caisson on a huge floating dock where in every cycle of fabrication 4 nos. of caisson is built simultaneously. The fabricate method used for its operation uses the “jumping formwork” system, the construction of each caisson is split into 5 segment starting from the base followed by the wall of the caisson. The following is an illustration of its sequence of works (note: 4 nos. caisson is cast simultaneously, i.e. Caisson “A”, “B”, “C” and “D”):-

Step 1: Road / Building paper is laid on the deck of the floating dock to avoid the adhesion of the caisson to the floating dock.

Step 2: Base preparation and casting of caisson “A”. Base reinforcement is placed in the correct position and fixed. Steel formwork is used for the base.

Step 3: Preparation and casting of the 1st segment of caisson wall for caisson “A” and base preparation and casting of caisson “B”. A system of “jumping formwork” is used for the casting of the caisson walls.

Step 4: Preparation and casting of the 2nd segment of caisson wall for caisson “A”, 1st segment of caisson wall for caisson “B” and base preparation and casting of caisson “C”.

Step 5: Preparation and casting of the 3rd segment of caisson wall for caisson “A”, 2nd segment of caisson wall for caisson “B”, 1st segment of caisson wall for caisson “C” and base preparation and casting of caisson “D”.

Step 6: The sequence of works continue until the final 4th segment of caisson wall is completed for each caisson. Once the last segment of the caisson wall is completed the corbel of the caisson is cast. The corbel uses steel formwork.

Step 7: On completion of all the 4 nos. of caisson, preparation of the floating dock for sinking of the caisson commences.

Concrete Height of each Segment to be cast
TYPICAL CONSTRUCTION DETAILS OF CAISSON

SEQUENCE OF WORKS
FABRICATION OF CAISSON ON FLOATING DOCK
Specification

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<td>Draft (navigate)</td>
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<td>Pumping Time (out)</td>
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<td>17 Painting</td>
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<td>18 Towing / Sinking</td>
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Method of Fabrication – Phase II

The main Contractor for Phase II project, Hyundai Engineering & Construction Corporation Ltd, chose to use the “Sliding Formwork” for the fabrication of its caisson.

A casting yard is set up at the newly reclaimed land at the edge of the sea front to enable the caissons to be launched into the sea. A casting yard is built for the purpose for casting the caissons. This casting yard is purpose-built to accommodate the casting of 1 no. caisson per cycle. As a all-weather casting yard, a 24 hours operation for the yard is achieved.

To enable that the caisson move from each stages of completion to the next, a specialized heavy lifting and transfer system is employed based on the requirements of the caisson:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caisson weight (Max.)</td>
<td>5359 ton</td>
</tr>
<tr>
<td>Caisson Dimension</td>
<td>20W(Base) x 29.9L x 19.15H</td>
</tr>
<tr>
<td>Pulling Capacity (Max.)</td>
<td>80 ton</td>
</tr>
<tr>
<td>Pump Capacity</td>
<td>18,000 L / Min</td>
</tr>
</tbody>
</table>

The "AeroGo Caisson Transfer System" is used to transport the caisson base slab into the portal frame for wall casting and as well as to transport the completed caisson to a floating dock for launching.

The AeroGo consist of two transporter assemblies equipped with a total of 120 AeroCaster. When pressurized sufficiently with sea water, it is designed to carry loads of up to 5529 metric tonnes. The AeroGo is designed to be operated on a flat smooth concrete surface which is the bottom of a trough over which the caisson are built.

Once the caisson is lifted up, a winch system will then pull and pushes the caisson onto the next stage of construction.

The “Sliding Formwork”, also known as “Slip Formwork” is a system of formwork that slides continuously up the face of the wall being cast by climbing up and being supported by a series of hydraulic jacks operating on jacking rods. The whole wall is thus cast as a monolithic and pointless structure.

This formwork system is a continuous operation. Good site planning and organization is very essential. Round-the-clock working that involves shift working, careful control of concrete supply to ensure continuous operation and on-site supervision is the essences for this system to be effectively utilized.

The actual architectural and structural design of a box caisson is most suitable for the application of a slipform system. Generally, the main requirements whereby slipform is viable for use in construction is a wall of uniform thickness with a minimum number of openings and a height of at least 20m. This will
ensure that the cost of equipment, labour and planning justifies the proposition of using slipform system.

The slipform used for this project are constructed of mainly steel with certain part constructed of timber.
SLIDING FORMWORK
SETTING UP OF THE CAISSON CASTINY YARD

1. Erection of Gantry Tower Pairs (To +15120)
2. Temporary Wire Bracing of Towers
3. Erection of Jack Rods (To +574)
4. Installation of Jacks
5. Erection of Slabform Trusses

1. Lifting of Trusses (Approx 30°)
2. Erection of Slabform Deck
3. Timber Decking During the Progress of Erection
4. Installation of Upper Deck
5. Preparation of Hanging Scaffold

4. Lifting of the Rig to Top of Jack Rods
5. Extension of Tower to -2854
6. Temporary Wire Bracing
7. Extension of Jack Rods to -2144
8. Lifting of Rig to Top of jack rods
9. Wire Bracing (Permanent)
10. Extension of Towers to Top (+2500)
11. Extension of Jack Rods to +2794
12. Completion of Gantry Trusses Roof
13. Helper Installation

7. Transferring of Foundation
8. Lowering of the Rig
As mentioned, the fabrication of the caisson is by means of the continuous casting method and it is made possible by using the movable formwork known here as - "Slipform".

A fixed steel portal frame casting yard is built above the ground on the reclaimed land. The span of the casting yard is approximately 24m across the gantry and the length is approximately 36.50m and the free height above bottom of foundation is approximately 28m, thus the whole structure covers the dimension of one caisson. The portal frame has a metal roof on top. This will permit casting to be in progress even in bad weather.

Reinforcement steel, concrete and formwork for the concrete brackets will be delivered and distributed by overhead travelling telfers which suspended at the gantry roof. The concrete are delivered by the telfers which are emptied into 18 nos. of 0.5m3 hoppers on the upper deck. A suspended platform below the main deck allows the workers for access to the completed concrete surface for touching up the finished work.

A concrete casting bed is laid through the gantry (portal frame) and reaching the temporary wharf. This permits the transferring of the caisson base slab as well as the completed caisson for launching.

The fabrication, transfer and launching of caisson is executed in the following sequence: -

- **Step 1**  Fabrication of base slab - Special soffit formwork system for the base slab to be used. - Upon completion, base slab shall be moved to the next step using "AerGo" lifting and transfer system.

- **Step 2**  Fabrication of Caisson wall - Slip formwork system to be used. Stationary portal frames erected sustain the slipform system and provides weather protection for all weather operation.

- **Step 3**  Application of Dry-Treat - Ensure proper curing of the concrete.

- **Step 4**  Loading of Caisson onto the Floating Dock.

- **Step 5**  Launching of Caisson.

The caisson base slab is prepared and cast just behind the portal frame. The base slab sits on two shallow troughs, which have two sets of base steelforms. These steelforms are operated by the “AeroGo” Transfer System which moves the caisson from each stage to the next.

There are two bar bending / cutting areas. One is for the caisson fabrication during the continuous casting process. The other bar bending / cutting area is beside the caisson base slab casting area, this bending yard prepares the necessary bars for the casting of the base slab.
Caisson Fabrication Procedure:

Stage 1: Fabrication of Base Slab

The reinforcement cage is first formed. The rebars cutting and bending yard are located just beside the casting yard for the base slab. The rebars are lifted into the central part of the reinforcement cage by means of a mobile crane. Those rebars required at the base sides or sidewalls are carried manually.

The process of fixing the base slab reinforcement can be done in 3 or 7 days. Meanwhile prior to fixing the reinforcement, the steel forms are erected and installed to hunch the base sides. A check sheet is used to record the inspection. It is to ensure that the dimension is correct, rebars are fixed accordingly, the steel cage for base slab is cleaned, and the steelforms are oiled.

Inspection is always conducted a day before the concrete pouring. The sequence of concrete pouring works is:

i.) For the sides of the base slab, the concrete is poured directly from the concrete mixed trucks.

ii.) The central part of the reinforcement cage will receive concrete either by concrete pump truck or a concrete hopper lifted by a mobile crane. Starter bars for the wall of 1 meter is left for the next stage of fabrication. The whole casting operation will take about 10 to 20 hours to complete.

iii.) The side formwork is only allowed after 24 hours of curing. On passing the cube compressive strength test result > 10.29 N/mm², a set of concrete cubes will be sent to the site concrete laboratory to be crushed and verified for the compressive strength.

iv.) The result of the compressive strength result also determines whether the base slab should be transferred into the slip-form portal frame.

v.) Total concrete volume of the base slab is about 485 m³.

Stage 2: Casting of Caisson Wall

The base slab is then transported into the portal frame and the slipform is lowered to meet at the base slab. Care is taken to ensure that the one-meter high vertical starter bars from the base slab are guided into the slipform.

With the weather protection roof installed on top of the gantry, it protects caisson fabrication against heavy rain and heat on a sunny day. Hence, it is possible to carry on works regardless of the all weather conditions.
The concrete is brought by means of concrete trucks from the batching plant located at the shade of the yard. The concrete is then poured into the hoppers, which are lifted up to the upper deck slipform by means of overhead ‘travelling telfers. These overhead telfers are then guided to empty the concrete into the concrete hoppers. These overhead telfers are used to lift fresh concrete as well as to lift debars and other materials up to the working decks.

The concrete hoppers are equipped with shut-off lids and are manually controlled by workers on the upper deck. The concrete hopper deliver fresh concrete via the concrete distribution funnels and concrete is directed into caisson walls. These funnels are approximately 0.5m³ and have a 150mm hose attached to them.

The workers on the main deck will guide the hose to where concrete is required. Each pour of concrete is about 25 cm per layer and the concrete are distributed evenly and vibrated thoroughly.

A total number of 18 electric vibrators with a shaft of 19mm are used for compaction of the fresh concrete. Spare-vibrators stored on the upper deck for replacement in case of any breakdown.

Rebars are lifted and stored on the upper deck and are subsequently delivered down to the main deck by passing through the openings on the upper deck. The supplies of debars are kept constant by lifting them from the bar bending yard to the upper deck by the travelling telfers.

Each unit of typical caisson has seven R.C corbels. These corbels are concreted using separate steel forms that will be attached to the slip-form in the later stages of casting. The rebars cage of the corbels will be fixed inside the steel forms before lifting them up to the slip-form rig.

The weight of each corbel is about 2.6 tons. Total volume of a completed caisson including the base slab is about 2050m³.

Step 3: Caisson Holding Area

After the wall of the caisson is completed, the caisson is moved out of the portal frame to the next stage of temporary holding area and prepared to be transferred to the floating dock.

While waiting to be transferred, the following works are carried out: -

- Dismantling of the steelform for the corbel.
- Chemical dry-treat is sprayed on the caisson walls to protect it from the corrosive sea water.
- Final check on the verticality of the caisson wall.
- Any touching up and remedy works.
Step 4: Loading of Caisson onto the floating dock

To transport the caisson, the AeroGo Transfer System is used to transfer the caisson onto the floating docks.

Sea water is pumped into the AeroGo system, this causes the "Aerocasters" to raise up the caisson to a level of 30 to 50mm above the ground. The transporter sliding upon a thin film of water, sliding on a near fictionless surface, with the help of the winch system then pushes the caisson onto the floating dock.

Once the caisson is in position on the floating dock, the operation is ceased.

Step 5: Launching of the Caisson

During high tide, the floating dock will be towed to deeper sea by tug boats. Water is ballast into the caisson's internal cells until it begins to tilt. The caisson is then allowed to slide at an angle of about 12 to 15 degrees into the open sea.

Once the caisson slides out of the floating dock, the tug boats then pulls the caisson onto the designated temporary holding area until the caisson foundation is ready for its placement.

Caisson Fabrication Schedule

Base on a weekly casting cycle of 24 hours operation, the casting yard is able to fabricate one complete caisson and one caisson base.

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<tr>
<th>Works Description</th>
<th>Mon</th>
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<td>Fix base slab formwork</td>
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<td>Concreting of base slab (465m³)</td>
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<td>Caisson &quot;B&quot;</td>
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<td>Fix 1m high starter bars</td>
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<tr>
<td>Transfer caisson base slab to slipform</td>
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<td>Concreting of caisson wall (1600m³)</td>
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<td>5½</td>
<td>Caisson &quot;A&quot;</td>
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<tr>
<td>General maintenance and house-keeping</td>
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Remark: Works Description Mon Tue Wed Thur Fri Sat Sun Days Caisson
Caisson - Casting Yard
"AerGo" Lifting and Transfer System
"AerGo" Lifting and Transfer System
"AerGo" Lifting and Transfer System
"AerGo" Lifting and Transfer System
Caisson - Base Preparation & Casting
Caisson Body Preparation & Casting
Caisson Body Preparation & Casting
Caisson Body Preparation & Casting
Caisson Body Preparation & Casting
Caisson Body Preparation & Casting
Caisson Body Preparation & Casting
Caisson - Corbel Preparation & Casting
Towing, Sinking & Temporary Mooring Procedures of Caisson

PHASE I

At the end of each casting cycle, the caissons in the floating dock is prepared for launching into the open sea. The phase 1 project for caisson construction under taken by Penta Ocean Construction Co. Ltd. completes 4 nos. of caisson per cycle. As mentioned, the casting of these caisson is done on a floating dock measuring 55.0 m length x 40.0 m wide. The typical layout for each cycle is shown on the above diagram.

The overview of work procedure for towing, sinking and temporary mooring is illustrated in the following flow chart.

WORK FLOW CHART FOR TOWING, SINKING & TEMPORARY MOORING OF CAISSON

Step 1  Securing of Caisson mooring rope

Step 2  Submerging of floating dock

Step 3  Pumping ballast water into Caisson

Step 4  Floating of Caisson

Step 5  Towing Caisson out of floating dock

Step 6  Towing Caisson to mooring area

Step 7  Pumping preparation

Step 8  Pumping water into Caisson

Step 9  Caisson sitting on seabed
Step 1: Securing of Caisson Mooring Rope

Prior to submerging the floating dock, all 4 caissons in the floating dock is secured to the dock tower pits by means of ropes and shackles. (sketch 1-1)

On the caisson, the ropes are secured to anchors that are cast into the caisson.

![PLAN OF FLOATING DOCK](sketch1-1)

Step 2: Submerging of Floating Dock

The submerging speed of the floating dock is 4m/hr. During the process of submerging, great attention is observe to ensure that the floating dock does not “heel over”. The position of the floating dock is monitored every 15 minutes at 2 location by Total Station to ensure that the floating dock sinks at the designated –19.9m ACD area.

At the same time during the submerging of the floating dock, the pumping of ballast water into the 4 nos. caisson is started concurrently. When 7m of all the caisson is submerged, submerging of the floating dock is stopped temporary to confirm and ensure that the ballast water of all the caisson is completely pumped to the correct required level. Having made the assurance, the submerging of the floating dock then continues. The caisson will float with a draft of 11.7m.
Step 3: Pumping Ballast Water into the Caisson

As the floating dock is submerged, ballast water is pumped into the caisson concurrently.

On each caisson, a set of 6 nos. submergible pumps, 1 generator and purpose made control panel is utilised for ballasting the caisson.  

Ballasting of the caisson is sequenced such that the weight is uniformly distributed throughout. The height of ballast water is pre-determined for each different type of caisson type I, Ia and II (sketch 3-2a, 3-2b and 3-2c) to ensure that the caisson does not tip to the heavy side of the caisson (the side of the corbels).

Once the caisson are properly ballast, the pumps are removed to prepare for towing operation.
Step 4: Floating of Caisson

As the floating dock and the caisson is submerging, the floating dock which is secured by mooring rope to the land is tighten to ensure the dock stays in place.

Ropes to the caisson secured to the floating dock are also tighten.

Step 5: Towing of Caisson out of the Floating Dock

After the floating dock and caissons are floated, the caissons are towed out of the floating dock to a temporary mooring area.

The pilot of the towing operation oversees the whole operation from the top of each caisson to be towed. Caissons are towed out of the floating dock with the assistance of one no. 2600 horsepower tugboat which will lead the tow infront of the caisson with and two nos. 250 horsepower tugboats pushing from behind.

Once out in the open sea, a safe distance from the floating dock, the lead tugboat releases its towing ropes and the caisson is towed by the two smaller tugboats to the temporary mooring area.
Step 6: Towing of Caisson to Mooring Area

The towing of caisson is carried out at a period where the current is below 0.8 knot.

The caissons are towed to a designated mooring area via a designated route. Great care has to be taken to ensure that the towing speed is below the allowable and there is no excessive tilting of the caisson.

Step 7: Pumping Preparation

The caisson is towed to a demarcated temporary mooring area. On reaching the mooring area, a crane barge equipped with water pumps is positioned alongside the caisson to prepare the caisson to be sunk to the seabed of the temporary resting area.
Step 8 & 9: Pumping Water into the Caisson

After all 6 nos. pumps are positioned, water is pumped into the caisson simultaneously. Care is taken to ensure that the caisson is kept upright at all times.

Water is pumped to the required level in order that the caisson remain sited on the seabed level without tilting to one side (sketch 8-1a, 8-1b and 8-1c).

During the pumping operation, the tug boat helps to hold the caisson in position. Once the caisson sits on the seabed, the tug boats return to the holding area for the next operation.
Phase II

On completion of caisson fabrication, the “Aergo” lifting system moves the caisson into the floating dock along-side the wharf. The floating dock is then towed to deeper sea by tugboats for launching of the caisson.

Water is ballast into the caisson’s internal cells until it begins to tilt. The caisson is allowed to slide at an angle of about 12 to 15 degrees into the open sea.

Ballasting Scheme for Towing of Caisson

PPTD PH II
Caisson Installation

Installation of caisson is carried out by a winch pontoon equipped with several numbers of winches and a crane pontoon.

After completion of screed levelling of the rock base, caisson is towed from the holding area to the final installation location by tugboats. As with the procedures used in the holding area for temporary storage of caisson, the same method is used to install the caisson onto its final location. Once the caisson sits on the rock base, the position and elevation of the caisson is checked to confirm its location and to ensure its required level is correct.
Compaction of Sandfill in Caisson

After the caisson is positioned in its final location, the caisson’s cells are hydraulically filled up with sand. Vibrocompaction is carried out to compact the infilled sand to the required density (95% of maximum dry density).

In this deep compaction method, a vibro-hammer serves as the driving mechanism that is clamped to a probe that is vibrated down into the sand. The hammer is suspended from a crane and the vibrations generated are in the vertical direction.

The vibro probe is driven down by the vibro-hammer to the depth where vibrocompaction is to commenced (-14.5m ACD or about 17m below +2.65m ACD). The shaft is pulled out slowly as the sand is vibrated.

For every cell of the caisson, 4 nos. of compaction point is compacted.
Caisson Joints

The works to follow after caissons are installed at its location is as below:-

1. Waterstop installation of joints behind the caisson.
2. Armour stone and filter stone laying at the toe and heel of caisson respectively and geofabric laying behind caissons.
3. Sand infilling of caisson cells, vibrocompaction of the infilled sand & density checking by CPT.
4. Sand backfilling behind caissons.
5. Preloading with sand surcharge / concrete blocka and removal of surcharge after sufficient subsoil consolidation / settlement has taken place.
6. Sand infilling (packed into geofabric tubes) of the smaller octagonal voids (inner and outer) form by 2 caissons next to each other.

The final stage for the connection of each individual caisson is the jointing between each caisson. After the works following the caisson installation the next step is to connect caissons to each other.

The works of connecting / jointing between each caisson is referred to as the caisson joints.

Underwater concrete infilling by tremie method is carried out from –16.5m ACD to –1.0m ACD in the elongated and the octagonal void (only the middle of the three) form by 2 caissons (ref. Fig 1 & 2).

After the concrete has achieved the designated compressive strength of 30 Mpa (usually of the third day after concreting), the voids from –1.0m ACD to +2.65m ACD is infilled with rocks. The elongated void is filled with graded rocks of 75mm to 150mm and the octagonal voids are filled with 20mm to 50mm graded stones.

With this arrangement for the jointing of caisson joints, a passage for water to flow between the open sea and the newly reclaimed land behind the caissons is left opened. This allows water pressure on the newly reclaimed land to be in check.
FIG. 1 PORTION OF CAISSON JOINT TO BE INFILLED WITH TRXHLE CONCRETE

FIG. 3 CONCRETE INFILLING OF CAISSON JOINT BY THE TRENHE METHOD

worker to check on the level of concrete in the hopper to ensure that it is fully-charged at all times
Tremie Concrete to Caisson Joints

Rock infill to voids from –1.0m ACD to +2.65m ACD
Caisson joints

- Infilling of octagonal voids with 1m diameter geofabric tube filled with sand.
Waterstops

The installation of waterstops is fixed to the joints between adjacent caissons. The purpose of this water stop is to provide an adequate barrier to the rear of the joint against infiltration of the backfill sand.

The waterstop assembly is fixed to the entire length of each caisson joint.
Reference  “Construction Technology for Tall Buildings” (2nd Edition)
            Michael Chew Yit Lin, Singapore University Press

            “An Introduction to Deep Foundations and Sheet-Piling”
            Donovan H. Lee, London Concrete Publications Limited

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Slipform & Heavy lift System “Aergo”:-

http://www.bygging-uddemann.se/

Sand Compaction Piles:-

http://www.eekeum.co.kr/method_04.htm

http://www.eng.nus.edu.sg/EResnews/May95/fhlee.html

http://www.nipponkaiko.co.jp/english/index2.htm