1. **Seawalls and breakwaters**

1.1 **Breakwaters**

- A breakwater is a structure employed to reflect and dissipate the energy of water waves.
- They may be constructed to form a harbour or typhoon shelter and create sufficiently calm water, thereby providing protection for safe navigation, berthing and mooring of vessels, and other harbour activities.

There are three main types of breakwaters:
1. rubble mound breakwater
2. vertical breakwater
3. composite breakwater

1.1.1 **Rubble Mound Breakwaters**

- A rubble mound breakwater is typically constructed with a core of quarry-run stone.
- The core is protected from wave action by rock underlayers and an outer layer composed of massive rocks (1500-4000 kg/unit) or specially shaped concrete armour units.
- The breakwater is support on a prepared foundation on the seabed. (The preparation of the foundations for breakwaters and seawalls is to be discussed in the next section.)
Rubble Mound Breakwater

Concrete Armour Units

Dolos

(Source: Civil Engineering Office)
1.1.2 **Vertical Breakwaters**

- A vertical breakwater is a vertically faced structure extending directly from seabed level to resist wave attack.
- They are usually reinforced concrete caissons pre-fabricated in a dry dock.
- They are then transported to the site by flotation and sunk into the seabed foundation.
- The inside chambers of the caisson are filled with earth or rock to increase its mass.

![Caisson Type Vertical Breakwater](Source: Civil Engineering Office)

1.1.3 **Composite Breakwaters**

- A composite breakwater is a combined structure consisting of a vertical structure placed on a rubble mound that is submerged at all tidal levels.
- This type of structure may be used as a breakwater in very deep water where the volume of rock required for a rubble mound structure can be reduced, or
- when it is not practicable to design a vertical face structure to carry the design wave loading to the full depth.
1.2 Seawalls

A seawall can be used as a soil retaining structure of reclamation or as an armouring structure to protect a shoreline from erosion against wave and current actions. They may be vertical or sloping.

There are four common types of seawalls used in Hong Kong:

1. Concrete Blockwork Seawalls
2. Caisson Seawalls
3. Wave Absorption Vertical Seawalls
4. Rubble Mound Sloping Seawalls

Remarks:
Bermstones shall be \( \geq 1000 \) kg/unit.
Levelling stones shall be grade 75 rock fill material.

**Concrete Blockwork Seawall**
1.2.1 Concrete Blockwork Seawalls

Concrete blockwork seawalls are gravity structures made up of precast concrete blocks. They are commonly used in Hong Kong because have the following advantages:

1. Relatively low cost of construction.
2. Long history of satisfactory performance with negligible need for maintenance.
3. Flexibility to cope with some differential foundation settlement.
4. They can provide marine frontage for vessel berthing and cargo handling.
5. Damage from vessels in accidents is usually minor.
6. Incorporation of landings, pumphouses and drainage outfalls is relatively simple.

1.2.2 Caisson Seawalls

Similar to a caisson breakwater, a caisson seawall is usually pre-fabricated then sunk into its designated locations.
1.2.3 Wave Absorption Vertical Seawalls

- Vertical seawalls with solid face are highly reflective of wave energy. This may not be acceptable inside a harbour as wave agitation will affect vessel operation and navigation.

- Wave reflection can be reduced by introducing wave absorption units on the vertical seawalls. A vertical seawall contains a wave absorption chamber with perforated front wall that allows flow into and out of the chamber.
1.2.4 Rubble Mound Sloping Seawalls

- The slope of the seawall is generally protected by rock armour. If the wave condition renders the rock size not economically available in the market, concrete armour units can be used as an alternative to protect the slope of the seawall.

(a) Rubble Mound Seawall for Reclamation

(b) Rubble Mound Seawall for Shore Protection (Source: Civil Engineering Office)
2 Preparation of foundations for seawalls and breakwaters:

2.1 Dredging

2.1.1 Fully dredge method for preparation of the foundations of seawalls or breakwaters may involve totally removing the marine deposits and replacement with sand or rubble fill in order to provide adequate foundation stability and to prevent excessive settlement. Normally, dredging is stopped when a firm stratum has been reached.

This method, though relatively simple, requires the disposal of dredged sediments, in particular when the quantity is large. In addition, removal of soil is generally discouraged unless there is strong justification.

2.1.2 Partial dredge method – Partial removal of marine deposits, leaving the stiffer or stronger deposits in place, reduces the dredging and fill quantities compared to the full-dredge method. Partial dredging may be carried out in conjunction with installation of vertical drains and staged construction.

The main purpose of vertical drains is to accelerate the consolidation of the remaining soil so that the target settlement due to primary consolidation can be achieved within shorter period (to be discussed in the next section).

Staged construction allows sufficient time for the marine deposits to consolidate and gain strength between stages of construction. Partial dredging normally requires longer construction period for consolidation to take place.
2.2 Deep Cement Mixing

- The principle of deep cement mixing (DCM) is based on chemical reactions between clay and chemical agents.
- Lime and Portland cement are the two most commonly used admixture stabilizers.
- The purpose of mixing chemical additives with the soil is to improve the stability, strength and stress-strain properties of the soil.
- DCM is implemented in the field by machines with rotation blades that supply chemical agent into the soil for in-situ mechanical mixing to form DCM piles.

2.3 Stone Column

- Stone columns are columns of densely packed gravel installed in the soil.
- Their diameter generally ranges from 0.6 m to 1.0 m and the size of gravel normally ranges from about 75 mm to 100 mm.
- The technique utilizes the vibroflot equipment for forming cylindrical holes in the soil to the desired depth.
• Then gravel is poured into the hole in layer of about 300 mm each.
• For each layer, the vibroflot is used to compact and displace the gravel outwards.
• Compaction is continued until the lateral resistance to the displacement of the soil by the gravel is fully developed. (Alternatively, the gravel is pumped through a supply duct to the bottom of vibroflot progressively.)
• The maximum practical length of stone columns is about 30 m.
By constructing stone columns in a square, rectangular or triangular grid pattern, the ground is transformed into a composite mass of vertical, compacted granular cylinders with intervening soil.

This method provides the advantages of increasing the average shear strength and decreasing the compressibility of the treated soil.

Since gravel is a good drainage material, installation of stone columns in clayey soil also accelerates the dissipation of excess pore water pressure and hence the consolidation.

Vibroflot with delivery tube

Layout of Stone Column Foundation
3. Reclamation

3.1 Purpose of Reclamation

Reclamation may generally be carried out:

- To provide land for essential major transport infrastructure.
- To provide land for housing, community facilities and public open spaces.
- To provide land for port and industrial uses.
- To eliminate areas of badly polluted water and improve hydraulic conditions by rearranging the coastline.

3.2 Reclamation Method

3.2.1 Drained Method

The drained method leaves the soft marine deposit in place, and the consolidation is usually accelerated by the use of vertical drains and sometimes with surcharge preloading. Drained reclamation is usually carried out in the following sequence:

**Sequence of Drained Reclamation**
a. **Laying of geotextile on the seabed**

Geotextile may be laid on the seabed to separate the fill from the underlying soft marine deposits, preventing migration of fines. It also enhances the stability of the underlying marine deposits in supporting the loading of the reclamation fill.

b. **Deposition of blanket layer**

This blanket should consist of free draining granular material of about 2 m thick. This granular layer works with the vertical drains to enable drainage from the clayey deposits. It also acts as a capping layer to spread the load from the fill during the filling operation.

c. **Installation of vertical drains** (also known as wick drain or band drain)

The vertical drain was band-shaped with a plastic core enclosed by a non-woven geotextile filter jacket. It functioned as a passage for water flow, to accelerate the dissipation of pore water pressure during the consolidation of the marine deposit layer. The band drains were installed in a triangular grid pattern with 1.5 m c/c spacing.

![Installation of vertical drains](image1.png)

To commence the acceleration of consolidation earlier, the band drains are usually installed over water using special marine plant just after laying of the sand blanket. The vertical drains can also be installed after reclamation using land plant.
d. **Controlled thin-layer placement**

Controlled even placement of thin layers of fill on the reclamation site is necessary to avoid shear failure of the underlying marine deposits and the formation of mud waves. An initial thickness of no more than one meter of fill is usually required with subsequent layers increased as appropriate. Placement can be by bottom-dump barges, hydraulic filling, grabbing or end tipping.
3.2.2 Fully Dredged Method

In fully dredged method, all marine and alluvial clays or silts are removed by dredging and replaced with fill.

Pros:
- The method is relatively simple.
- Settlement of the reclamation fill is more quickly and more predictable.

Cons:
- Can be expensive where thick layers of soft deposits exist.
- Causing mud waves during dredging
- Disposal of dredged sediments, particularly for contaminated mud may be problematic.

This method is generally discouraged unless there is strong justification.

3.2.3 Partial Dredged Method

- The partial dredged method involves partial removal of marine or alluvial deposits, leaving the lower, stiffer or stronger deposits in place.
- The remaining marine deposits shall be treated as that in the drained method.
- In fact it is the combination of the drained method and fully dredged method, so it combines and neutralizes both the pros and cons of the two methods.
3.3 Fill Materials

Fill materials for reclamation includes public fill, marine sand fill and crushed rock, but public fill and marine sand fill are the most commonly used types of fill in local conditions.

3.3.1 Public Fill

- Public fill is the inert portion of construction and demolition material from private and public developments and demolition sites.
- Because of the shortage of areas to accommodate the public fill generated by the construction industry, priority should be given to its use.
- It is also the government policy to maximize the use of public fill in reclamation projects.

3.3.2 Marine Sand Fill

- Sophisticate dredgers are use to obtain the sand from a marine borrow area.
- Since the mobilization costs are high, the size of the project must be large enough to justify the use of sophisticated dredgers.
- Plant such as trailing suction hopper dredgers may dredge marine sand fill very fast and at relatively low costs, particularly when the borrow area is close to the reclaimed site.
- These dredgers can deposit marine sand in the reclamation by bottom dumping or by hydraulic pumping.
- The rate of formation of reclamation can be very rapid compared to the use of other types of fill.
3.3.3 Rock Fill

- Crushed rock from local land sources should not normally be used for reclamation. It should be used as foundation materials or processed to produce aggregate products, as far as possible.
- In case a works project involving large quantities of rock excavation and removal, the surplus rock material can be used for reclamation.
- Where crushed rock over 250 mm is used, it should be placed in areas where no building development will take place, to avoid impeding piling or excavation works in the future.

3.4 Fill Treatment

- Fill treatment processes are to speed up the consolidation of the reclaimed area in order to reduce the long term settlement.
- It shall be noted that the settlement is contributed from both the existing marine deposits and the newly reclaimed materials.

3.4.1 Surcharge Preloading

- Surcharge preloading can be used to accelerate settlement of fill that would otherwise occur more slowly.
- Monitoring of the consolidation of the fill will be carried out periodically.
- The surcharge should only be removed when the required settlement or increase in strength has been achieved.
3.4.2 Dynamic Compaction

- Dynamic compaction involves repeated dropping of heavy weights onto the ground surface.
- Large amounts of energy are transferred to the soil in the form of impact force and waves, particularly shear waves.
- This results in a densely packed particle arrangement.
- Dynamic compaction is suitable for use in most soils except cohesive soil below the water table.
- The pounders used for dynamic compaction may be concrete blocks, steel plates, or thick steel shells filled with concrete or sand, and may range from one or two up to 200 tons in weight. Drop heights up to 40 m have been used.
- Dynamic compaction can also be carried out underwater.

(Source: R. Chudley)

NB Final ground level after compaction treatment and final levelling could be up to 1:500 lower than original ground level.

(Free Fall Hammer)

(source: CYCAL/HKD)

Craters Formed by Free Fall Hammer

(Free Fall Hammer)

(source: CYCAL/HKD)
3.4.3 Vibro-compaction

- The vibro-compaction method is used to compact a thick layer of fill, particularly in reclamation.
- It is used for granular soils, in particular sand.
- This method is very similar to the stone column method except that no additional granular material will be used to fill the borehole; instead the original fill material is pushed back into the borehole.
- The vibroflot is penetrated into the fill and retracted in a controlled motion such that a dense column of fill is formed.
- The compaction is carried out in a triangular grid pattern of 2.5 m to 4 m c/c spacing.
- Effective compaction depth can be up to 35 m.
- Vibro-compaction is only applicable to granular materials of certain grading properties.
- Vibro-compaction cannot effectively compact the surface few metres of fill and therefore separate compaction of the surface layer will be required.
3. Submarine Pipeline and Outfall

Submarine pipelines are pipelines laid under the sea for carrying public services and utilities such as water, electricity, communication, oil, etc.. An outfall is a large diameter submarine pipeline discharging wastewater directly into the sea. An outfall may be laid on the seabed or bored under the seabed at some depth, or a combination of both.

3.1 Pipeline Materials

The diameters of the pipeline range from less than 0.1 m to above 4 m. The materials that are used for submarine pipelines fall into five main categories:

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>Weldable carbon steel</td>
</tr>
<tr>
<td></td>
<td>Grey or Ductile Iron</td>
</tr>
<tr>
<td>Concrete</td>
<td>Reinforced concrete</td>
</tr>
<tr>
<td></td>
<td>Concrete surrounded steel pipe</td>
</tr>
<tr>
<td>Plastic</td>
<td>Glass Reinforced Plastic (GRP)</td>
</tr>
<tr>
<td></td>
<td>High Density Polyethylene (HDPE)</td>
</tr>
<tr>
<td></td>
<td>Medium Density Polyethylene (MDPE)</td>
</tr>
<tr>
<td></td>
<td>Polyvinyl Chloride (PVC)</td>
</tr>
<tr>
<td></td>
<td>Unplasticised Polyvinyl Chloride (UPVC)</td>
</tr>
<tr>
<td>Flexible Armoured Pipe</td>
<td>e.g. spiral wound steel armouring with UPVC lining and rubber or plastic outer sheath</td>
</tr>
<tr>
<td>Proprietary Materials</td>
<td>e.g. Corrugated HDPE</td>
</tr>
</tbody>
</table>
3.2 Construction Methods

There are several methods by which outfalls can be constructed, but are basically variation of the following, which can be combined if appropriate:


b. Bottom pull method.

c. Float and lower method

d. Immersed tube method.

e. Lay barge / Reel barge method.

f. Boring method

The choice of the above methods depends on the diameter, length and depth of the pipeline being laid. Long sea outfalls have been constructed with diameters up to 4m, and lengths extending offshore to as far as 10 km and water depths approaching 100m.

3.2.1 Foreshore crossing

For crossing foreshore, temporary works may be required, which may comprise:

a. Sheet pile cofferdams and open cut excavation to take the pipe. The seawall is rebuilt following outfall installation.

b. A tunnel or thrust bore under a seawall with a sleeve pipe inserted to take the main pipe.

c. Horizontal directional-drilled hole to install the pipe beneath the seawall.

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Horizontal Directional Drilling

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3.2.2 **Pipe-by-pipe method**

Pipes for this method of construction are usually precast in a factory, but in some cases can be manufactured at a site specifically created for the purpose near to the outfall location.

The pipes are lowered into their required position on the seabed or into a pre-dredged trench from a crane or gantry mounted on a floating barge. Joints usually consist of spigot and sockets with ‘O’ rings, although in some cases bolted flange connections or proprietary mechanical systems can be employed. For large diameter pipes an alignment frame with hydraulic rams is usually necessary to enable the pipes to be pulled together and supported while backfill material is placed as foundation.

The pipe-by-pipe method is generally considered suitable for short lengths of outfall in shallow water sheltered coastal locations.
3.2.3 Bottom pull method

A construction site is formed adjacent to and in line with the route of the outfall, and individual pipes are joined to make the pipeline string. The string is placed on rollers which are arranged to support the pipeline from the site to the waters edge. The first string is pulled forward until the rear end is at the tie-in position, using a winch mounted on a barge anchored offshore. The next string is then moved across to the rollers and joined to the first string. The pulling operation is re-commenced and the procedure repeated until all the strings have been joined and pulled into position.

3.2.4 Float and lower method

A construction site on land adjacent to sea is formed and individual pipes are joined to make one or more pipeline string. Careful weight and buoyancy control of the strings is essential as small variations can lead to difficulties during the floating and lowering operation.

The completed strings are moved into the water and secured under supporting
pontoons at suitable spacing to suit the strength and buoyancy requirements of the pipe. For large diameter outfalls, there may be sufficient buoyancy to enable the strings to float without pontoons. The strings are then towed and maneuvered to the right location. The lowering operation is achieved by means of winches mounted on the pontoons, by flooding the string with water or by a combination of the two.

**Float and lower method**

### 3.2.5 Immersed tube method

The immersed tube method has been developed for the construction of large rectangular or circular culverts which are normally associated with road tunnels and cooling water intakes.

A construction site is required where individual pipes can be manufactured and joined into lengths that are suitable for the type and size of floating plant that will be used.

Individual pipes are joined into lengths of up to 50 m long. The lengths are fitted with watertight bulkheads so that they can be floated to the location of the outfall. The lengths are then positioned in a controlled manner by a combination of flooding and lowering under floating plant, into a pre-dredged trench. Weight control is critical in order to ensure that the pipe lengths can be safely handled, placed and joined to the previously positioned pipe length.
Stage 1
The post-tensioned units are launched, floated into position alongside the barge and flooded. Winches on the barge control the lowering of the unit complete with alignment frame.

Stage 2
The alignment frame is used to joint the unit to the previously laid unit. The other end of the unit is temporarily supported on sand bags.

Stage 3
The pipe is underspoiled by a hopper to ensure a firm foundation. Permanent protection in the form of armour stone is placed around the pipes.
3.2.6 Lay Barge / Reel barge method

Lay barges and reel barges are sophisticated vessels that usually associate with long pipelines for deep-water offshore projects related with the oil and gas industry.

The lay barge or reel barge would be positioned on the line of the pipeline as near to the shore as the operating conditions and draft of the vessel allow. Pipe would then be pulled (using the bottom pull method) from the barge through the surf zone to the high water level. The lay barge or reel barge would then maneuver away from the shore by means of its own mooring anchors, whilst at the same time paying-off pipe on the seabed.

3.2.7 Boring method

Please refer to notes of Tunneling.
4. Construction of jetties, piers and dolphins

4.1 Jetties

Jetties jut out into the sea, usually at right angles to the shore line, although T-shape and L-shaped jetties are not uncommon. They are open structures, usually of steel tubular or precast prestressed tubular piling with a heavy concrete deck. The jetty structure must be designed to withstand impact loads and ‘bollard pulls’ from berthing ships: this is usually accommodated by raking pile construction and fendering, the later to avoid holing the ship.

(Source: Roy Holmes)

Foundation of a Jetty

A Jetty

Fenders
If sea bed is a rock formation the piling construction will not be economically produced by normal driving methods; boreholes of about 600 mm diameter may be bored into the sea bed to form bored piles.

(Source: John W. Gaythwaite)

**Typical Dolphins**

**Construction of Bored Piles Over Water**

4.2 Dolphins

Dolphins are individual mooring points to which vessels may be tied while waiting to enter a wharf or dock. They are also used as a guide to ships entering narrow harbours. Their construction is similar to that of jetties.
References:


- http://civcal.media.hku.hk/


