ENGINEERING AND CONSTRUCTION STANDARD

FOR

ONSHORE FACILITIES

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1. SCOPE

This Standard gives guidance and recommendations on general criteria relevant to the planning, design and construction of structures set in the maritime environment, as may be encountered in various civil engineering projects in the field of Petroleum Industries.

The structures to which this Standard is applicable are those that are located at, or are close to the shore. It includes different aspects of planning, design and construction of breakwaters, berthing and mooring facilities, and shore protections. Offshore structures are not covered by this Standard, although certain aspects may be found to be common in both fields.

For offshore facilities refer to IPS-G-CE-480.

This Standard is written in general terms and its application to any particular project may be subject to special requirements of the work under consideration.

2. REFERENCES

In this Standard the following standards and publications are referred to and to the extent specified herein, form a part of this Standard.

IPS (IRANIAN PETROLEUM STANDARDS)

E-CE-110	"Soil Engineering"
E-CE-140	"Retaining Walls"
E-TP-740	"Corrosion Considerations in Material Selection"
E-CE-500	"Loads"
C-CE-112	"Construction Standard for Earthworks"
E-CE-130	"Piles"
C-CE-200	"Construction Standard for Concrete Structures"

ISIRI (INSTITUTE OF STANDARDS & INDUSTRIAL RESEARCH OF IRAN)

ISIRI No. 519	"Minimum Design Loads in Buildings and Other Structures"

BSI (BRITISH STANDARDS INSTITUTION)

BS 5930: 1981	"Site Investigation"
BS 6349: Part 1:1984	"Code of Practice for Maritime Structures, Part 1: General Criteria"
BS 6349: Part 2: 1988	"Code of Practice for Maritime Structures, Part 2: Design of Quay Walls, Jetties and Dolphins"
BS 6349: Part 3: 1988	"Code of Practice for Maritime Structures, Part 3: Design of Dry Docks, Locks, Slipways and Shipbuilding Berths, Shiplifts and Dock and Lock Gates"
BS 6349: Part 4: 1985	"Code of Practice for Maritime Structures, Part 4: Design of Fendering and Mooring Systems"

BS 6349: Part 5: 1991	"Code of Practice for Maritime Structures, Part 5: Dredging and Land Reclamation"
BS 6349 : Part 6: 1989	"Code of Practice for Maritime Structures, Part 6: Design of Inshore Mooring and Floating Structures"
BS 6349: Part 7: 1991	"Code of Practice for Maritime Structures, Part 7: Guide to the Design and Construction of Breakwaters"
BS CP 1021:1973(1979)	"Cathodic Protection"

ACI (AMERICAN CONCRETE INSTITUTE)

ACI 318 M-89	"Building Code Requirements for Reinforced Concrete"

3. DEFINITIONS AND TERMINOLOGY

The following terms are defined for general use in this Standard.

- Anchorage Area:

A place where ships may be held for quarantine inspection, to await docking space, sometimes while removing ballast in preparation for taking on cargo, or to await favorable weather conditions.

- Artificial Harbor:

Harbor protected from the effect of waves by breakwaters or one created by dredging.

- Bollard:

On a quay or vessel, a short upright post round which ropes are secured for purposes of mooring.

- Breakwater:

A structure protecting a shore area, harbor, anchorage, or basin from waves.

- Bulkhead:

A structure separating land and water areas, primarily designed to resist earth pressures. see also Seawall.

- Buoy:

A float; especially a floating object moored to the bottom, to mark a channel, anchor, shoal rock, etc.

- Cofferdam:

A structure, usually temporary, built for the purpose of excluding water or soil sufficiently to permit construction to proceed without excessive pumping and to support the surrounding ground.

- Cellular Cofferdam:

A cofferdam consisting of a series of filled cells of circular or other shape in plan.

- Double-wall Cofferdam:

A cofferdam enclosed by a wall consisting of two parallel lines of sheeting tied together, supporting against external pressure.

- Dock:

A general term used to describe a marine structure for the mooring or tieing up of vessels, for loading and unloading cargo, or for embarking and disembarking passengers.

- Dolphins:

Marine structures for mooring vessels. They are commonly used in combination with piers and wharves to shorten the length of these structures and are a principal part of the fixed-mooring-berth type of installation.

- Groin:

A shore protective structure (built usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore. See also Jetty.

- Harbor:

A water area partially enclosed and so protected from storms as to provide safe and suitable accommodation for vessels seeking refuge, supplies, refueling, repairs, or the transfer of cargo.

- Jetty:

A structure extending into a body of water, and designed to prevent shoaling of a channel by littoral materials, and to direct and confine the stream or tidal flow. Jetties are built at the mouth of a river or tidal inlet to help deepen and stabilize a channel. In European usage jetty is synonymous with "wharf" or "pier".

- Marine Terminal:

That part of a port or harbor that provides docking, cargo-handling, and storage facilities.

- Offshore Mooring:

Such an anchorage consists of a number of anchorage units, each consisting of one or more anchors, chains, sinkers, and buoys to which the ship will attach its mooring lines. These anchorages are supplemented in most cases by the ship’s bow anchors.

- Pier:

A structure extending out into the water from the shore, to serve as a landing place, a recreational facility, etc., rather than to afford coastal protection.

- Port:

A harbor where marine terminal facilities are provided. These consist of piers or wharves at which ships berth while loading or unloading cargo, transit sheds and other storage areas where ships may discharge incoming cargo, and warehouses where goods may be stored for longer periods while awaiting distribution or sailing.

- Quay or Wharf:

A stretch of paved bank, or a solid artificial landing place parallel to the navigable waterway, for use in loading and unloading vessels.

- Quay Wall:

Similar to a wharf which is backed up by ground.

- Seawall:

A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action. See also Bulkhead.

- Seich:

An apparent tide in a lake due to the pendulous motion of the water when excited by wind.

- Training Wall:

A wall or jetty to direct current flow.

- Tsunami:

A tidal wave caused by an earthquake or volcanic eruption.

4. UNITS

This Standard is based on international System of Units (SI), except where otherwise specified.

5. GENERAL CONSIDERATIONS

Before starting design activities it is necessary to collect all existing data pertaining to topography, meteorology and climatology, water level, wave, sediment transport, water quality, operational requirements of maritime structures, loads etc. The following paragraphs give short descriptions about the above mentioned items.

5.1 Environmental and Physical Considerations

This Clause describes the various environmental and physical phenomena which should be considered for investigation at a coastal site and gives information and guidance on methods of data collection.

5.1.1 Surveying, bathymetry and topography

Surveying activities should be related to the established land survey system of National Cartographic Center (NCC). Should this not prove possible then a local grid system orientated by azimuth should be established prior to all other site operations, with sufficient permanently monumented survey stations to allow recovery of the survey grid at least during the construction period of the structure.

For further information on the various techniques available and guidance on their application in this respect refer to Clauses 6 and 8 of BS 6349: Part 1: 1984.

5.1.2 Meteorology and climatology

Authoritative meteorological and climatological data can generally be obtained from the Iranian Meteorological Organization. These data generally consist of information about wind, precipitation, air temperature, humidity, atmospheric pressure and visibility.

Clause 7 of BS 6349: Part 1: 1984 describes the meteorological and climatological considerations which should be taken into account during the data collection, design, construction and operational stages of a proposed maritime structure.

5.1.3 Water levels

Predictions of extreme water levels are required in several aspects of the design of maritime structures, including overtopping, hydrostatic pressures and the level of action of waves, currents, mooring and berthing loads. Values of rates of rise and fall may also be required in relation to soil pore water pressures, flood relief valve discharge capacities and for the prediction of tidal flows.

Details about tidal prediction, observation and analysis and meteorological effects including seiches and different methods of measuring water movements are given in Clauses 10 and 11 of BS 6349: Part 1: 1984.

5.1.4 Waves

Exposure to wave attack can have a profound influence on the selection of sites for maritime structures and the consideration of designs and construction methods requires detailed knowledge and understanding of the wave activity and persistence, in average as well as extreme conditions.

Detailed consideration of wave form, generation, recording, analysis and prediction is included in Section Four of BS 6349: Part 1: 1984.

5.1.5 Sediment transport

In any operation involving the alteration of the inshore hydrodyamic regime, the subsequent effects on sediment movement have to be considered.

A general appreciation of sediment transport in an area can be gained by studying old charts and photographs, including aerial views, and in the case of beaches, by carrying out a preliminary inspection.

For detailed information about sediment transport refer to Clause 14 of BS 6349: Part 1:1984.

5.1.6 Water quality

The effect of water quality on the safe and efficient functioning of the structure should be evaluated and this would require the gathering of the usual data on temperature, corrosive elements, suspended solids, marine growth, etc. For detailed information on different aspects of water quality data including the effects of temperature on corrosion, chemistry, turbidity, marine life and pollution refer to Clause 13 of BS 6349: Part 1: 1984.

5.2 Operational Considerations

The following subjects should be considered for possible individual study in each case:

a) numbers, types, sizes and shapes of present and/or expected vessels;

b) provision of tugs, navigational aids and marine traffic control;

c) pilotage;

d) berthing and mooring patterns, practices, systems and load measurements;

e) requirements of cargo handling, roll-on roll-off (ro-ro) traffic, storage and other activities, including the need or otherwise to allow for future change, or flexibility in operational usage;

f) regulations affecting any of the above operations.

One of the main considerations in this respect is to select a proper design life for the structures.

The design life is significant when assessing:

1) time-dependent factors running against the security of the structure such as fatigue loading, corrosion, marine growth and soil strength reductions;

2) probability levels for limit state design and for design condition return periods;

3) economic feasibility of the project and future developments.

For design life values of various maritime structures refer to Clause 16 of BS 6349: Part 1: 1984.

5.3 Loads

5.3.1 General

In addition to dead loads and soil pressures the other forces which may act upon maritime structures are those arising from natural phenomena such as winds, snow, ice, temperature variations, tides, currents, waves and earthquakes and those imposed by operational activities such as berthing, mooring, slipping, dry-docking and cargo storage and handling.

Guidance is given in this Clause on the selection of relevant design parameters and methods of calculation to derive the resulting direct forces on structures, taking into account the nature and characteristics of the structures.

5.3.2 Soil pressures

General guidance on the calculation of soil pressures is given in IPS-E-CE-110.

For the purpose of calculating soil pressures the following procedure should be followed:

a) Live loading on surface should be determined as described in Clauses 44 and 45 of BS 6349: Part 1: 1984.

b) Extreme water levels should be derived as described in Clause 37 of BS 6349: Part 1: 1984.

c) Ground pore-water pressures should be determined with reference to tidal range, soil permeability, drainage provisions and any artesian or sub-artesian ground water conditions; refer to IPS-E-CE-110.

d) Allowance should be made for reduced passive resistance due to overdredging and/or scour.

5.3.3 Winds

For values of design wind speeds in different parts of the country appropriate information should be obtained from Iranian Meteorological Department and for guidance on the calculation of wind loads on buildings, plant, equipment and other superstructure, reference should be made to ISIRI 519 or IPS-E-CE-500 "Loads".

5.3.4 Snow and ice

For the coastal areas around the country,accumulated snow is unlikely to affect the design of heavier maritime structures significantly. It should, however, be considered in the design of ancillary structures such as cargo sheds, port buildings and cargo handling installations, for which the appropriate imposed roof loading's recommended in ISIRI 519, or IPS-E-CE-500 should be considered.

In the recent past, loading from floating sea ice has not been a problem around the coastal areas of the country and need not be considered for structures whose design life is of the order of 50 years.

5.3.5 Temperature variations

The loads, or load effects, arising from thermal expansion or contraction of the structure and from temperature gradients in the structure should be considered in the design, taking due account of local climate. Relevant information in this respect may be obtained from Iranian Meteorological Organization.

5.3.6 Tides and water level variations

Maritime structures should be designed to withstand safely the effects of the extreme range of still water level from Extreme Low Water (ELW) to Extreme High Water (EHW) expected during the design life of the structure. These extremes should be established in relation to the purpose of the structure and the accepted probability of occurrence (see Clause 21.4 of BS 6349: Part 1: 1984), but should generally have a return period of not less than 50 years for permanent works.

5.3.7 Currents

The design current speed should be the maximum value expected at the site during the design life of the structure and should be established in relation to the purpose of the structure and the accepted probability of occurrence but should generally have a return period of not less than 50 years for permanent works. Methods of determining water movement are described in Clause 11 of BS 6349: Part 1: 1984.

5.3.8 Waves

Maritime structures should be designed to withstand safely the effects of wave induced loads.

Wave induced loads are to be determined by use of generally recognized methods taking proper account of water depth, size, shape and type of structure.

For detailed information on wave characteristics and basic wave properties including wave height, period, frequency, wave length and speed refer to Clauses 21 and 39 of BS 6349: Part 1:1984.

5.3.9 Earthquakes

The effects of earthquakes are to be considered for maritime structures located in seismically active areas.

Detailed information on seismic activity should be obtained according to detailed investigation made on the basis of previous record of earthquake activities, as well as a study of the geological history and the seismic events of the region.

5.3.10 Berthing and mooring

a) Berthing

In the course of berthing a vessel, loads will be generated between the vessel and the berthing structure from the moment at which contact is first made until the vessel is finally brought to rest. The magnitude of the loads will depend not only on the size and velocity of the vessel but also on the nature of the structure, including any fendering, and the degree of resilience they present under impact.

b) Mooring

Mooring loads comprise those loads imposed on a maritime structure by a vessel tied up alongside, both through contact between the vessel and structure or its fendering system and through tension in mooring ropes. They also include loads arising from maneuvers of the vessel at the berth, including casting off, leaving berth, warping and heaving of breast lines during berthing, but exclude the impact and frictional berthing loads discussed under paragraph (a) above.

For detailed information about berthing and mooring loads refer to Clauses 41 and 42 of BS 6349: Part 1: 1984.

5.3.11 Other loadings

In addition to the loads mentioned in Clauses 5.3.1 to 5.3.10, other loadings may be considered necessary when appropriate, such as loads due to cargo storage, rail and road traffic, conveyors and pipelines, etc. For more detailed information refer to Clauses 44 to 46 of BS 6349: Part 1: 1984.

5.4 Geotechnical Considerations

A study of the surface and subsurface conditions at and near the site of proposed works is an essential preliminary to the design of maritime structures.

The study should include assessment of the characteristics of soil or rock formations which may be retained by structures or provide their foundations or which may be incorporated in or affected by earthworks in the form of dredging and reclamation.

General procedures for the investigation of subsurface conditions by means of trial pits, trenches, shafts, boreholes and geophysical surveying for overland investigation are described in IPS-E-CE-110, which is also generally valid in many respects for over-water investigation.

For procedures particular to the maritime situation refer to Clause 49 of BS 6349: Part 1: 1984.

6. HARBOR PROTECTION-BREAKWATERS

6.1 General

Breakwaters are structures constructed for the purpose of forming a water area so protected from the effect of sea waves as to provide safe accommodation for shipping. Most breakwaters function only to provide protection, but occasionally they serve a dual purpose by becoming part of a pier or supporting a roadway.

The former is termed a breakwater pier or quay and the latter a mole.

6.2 Types of Breakwaters

There are several types of breakwaters depending on materials out of which they are constructed, but they may generally be categorized under three main types:

- Rubble mound breakwaters (natural rock, concrete blocks, combination of rock and concrete blocks, concrete tetrapods and tribars).

- Vertical face breakwaters (concrete block gravity walls, concrete caissons, rock filled sheet-pile cells, concrete or steel sheet-pile walls).

- Composite breakwaters (submerged rubble mound foundations or breakwaters surmounted by a vertically faced structure projecting above sea level).

The above-mentioned types are briefly described under Clauses 6.5 to 6.8 of this Standard.

6.3 Factors Affecting Selection of the Type of Breakwaters

The type of breakwaters to be selected is usually determined by the availability of materials at or near the site, the depth of water, the conditions of the sea bottom, its function in the harbor, suitable and available equipment for its construction and construction cost and period.

6.4 General Design Considerations

Generally in the design of breakwaters the following considerations shall be made:

- The relations with waterways and basins, mooring and other facilities;
- the influence exerted on nearby water area, facilities, topography, prevalent and assumed environment conditions after construction of the protective facilities;
- the direction of development of the port facilities in the future.

For details of design considerations related to navigational aspects, wave penetration, wave overtopping, breakwater alignment, etc. refer to Clause 2.2 of BS 6349 :Part 7: 1991.

One of the most important items which should be considered is hydraulic model testing.

Hydraulic model testing is the most reliable method of assessing the hydraulic performance of a breakwater. The reliability of test results depends upon the quality of the input data.

The primary object of testing is to check the stability of the breakwater up to and exceeding the design state and its hydraulic performance in respect of run-up, overtopping, wave transmission and reflection.

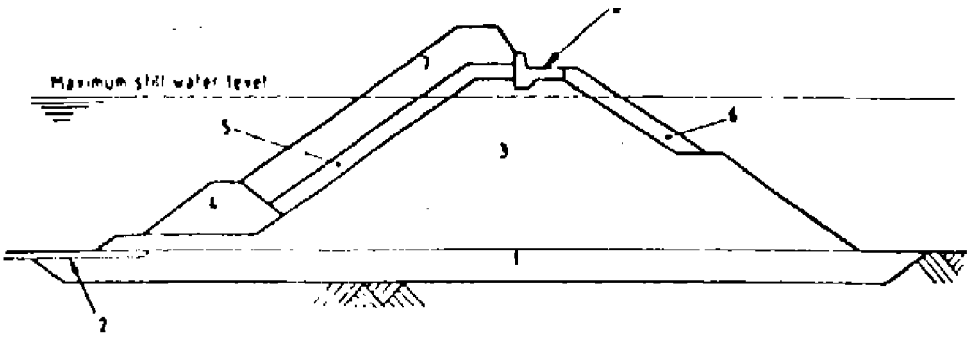
For more details on the hydraulic model testing and also physical and computational modelling refer to Clauses 3.6 and 2.2.6 of BS 6349: Part 7: 1991.

6.5 Rubble Mound Breakwaters

A rubble mound breakwater is a structure composed primarily of rocks dumped or placed upon the sea bed. An outer layer, or layers, of more massive rock or precast concrete units provides an armor layer to protect the less massive rock core from wave attack. A concrete crest structure which contributes to the function of the breakwater may be constructed on the mound.

Fig. 1 shows the main elements and functions of a typical rubble mound breakwater. It should be however noted that in this figure the general arrangement of elements in the cross-section is given in the most difficult condition, whereas in simpler conditions some simplification may be accepted.

The armor layer is probably the most important feature of a rubble mound breakwater since damage or failure can lead to failure of other parts.



Element	Function
1 Foundation improvement of necessary	Provides embankment stability
2 Scour protection apron	Prevents erosion
3 Core	Provides bulk of structure and reduces wave transmission
4 Toe mound	Supports the main armor
5 Underlayer	Contains the core and provides foundation for armor
6 Rear face armor	Protects core from overtopping waves Provides wave provides wave protection
7 Main armor	Provides wave protection
8 Concrete crack structure (with key or cut off tax.)	Provides access and reduces overtopping (Key prevents siding failure)

ELEMENTS AND FUNCTIONS OF TYPICAL RUBBLE MOUND BREAKWATERS

Fig. 1

Reference: BS 6349: Part 7: 1991.

6.5.1 Rock armor

The use of rock armor is limited by the largest size of rock which can be economically produced. This is commonly found to be in the range of 10t to 15t but in many rock formations the limiting size is much smaller and it can be necessary to quarry very large quantities to produce a small percentage of the largest stones.

The size of rock required can be reduced by using flatter slopes but extra quantities of material are then required for core, underlayer and armor.

6.5.2 Concrete armor units

Many different types of concrete armor unit have been developed but few have been adopted for general use. Nearly all are of mass concrete construction and can be broadly classified as random placed or regular pattern placed.

a) Random placed units.

The majority of concrete armor units are of this type, placed normally in two layers but sometimes in a single layer. They range from massive approximately cubical units through intermediate types to the more complex forms (e.g. Tetrapods, Tribars, etc.).

b) Regular pattern placed units

The stability of these units depends upon the placing pattern, the support provided by the toe and crest structures and the preparation of the underlayer. The units are placed in a single layer to form a continuous revetment.

Information on the use of particular armor units should be obtained from literature published by the originator or licensee of the unit.

For more detailed information refer to Clause 4.33 of BS 6349: Part 7: 1991.

6.6 Vertical Face Breakwaters

Vertical face breakwater is the one in which wave attack is resisted primarily by a vertically faced structure extending directly from sea bed level.

The seaward face is usually vertical but batters or slopes can be provided over part or all of the height. The seaward face is usually straight in plan but shaped faces are sometimes adopted.

The structural form can be either a gravity structure or a piled structure, and many aspects of quay wall design and construction will be found relevant to such breakwaters. Many different cross sections have been adopted for vertical face breakwaters including but not limited to:

- Caissons either floated or lifted into position.
- blockwork structure requiring extensive divers' work;
- sheet piling to contain the structural fill and act as gravity structures.

For more details refer to Section 5 of BS 6349: Part 7: 1991.

6.7 Composite Breakwaters

A composite breakwater is a submerged rubble mound foundation or breakwater surmounted by a vertically faced structure projecting above sea level.

This type of structure can be used as a breakwater in very deep water, when the volume of rock required for a rubble mound structure is not available, and when it is not practicable to design a vertical face structure to carry the design wave loading to the full depth or to reduce the cost.

The vertical face structure can comprise reinforced concrete caissons or precast concrete blockwork. Variations in water depth can be accommodated by the rubble mound, so that the base of the vertical structure can be horizontal throughout the breakwater.

For more detailed information refer to Section 6 of BS 6349: Part 7: 1991.

7. BERTHING STRUCTURES

7.1 General

Berthing structures are needed to accommodate a particular vessel or range of vessels. The detailed design of a particular structure can not be considered in isolation from the overall planning which is required to ensure that it meets its functional requirements. In the following paragraphs brief description of various types of berthing structures are given. For detailed information refer to BS 6349: Part 2:1987.

7.2 Types of Structures

The commonest types of berthing structures are:

- marginal berth (also termed quay or wharf)
- pier
- jetty
- dolphin
- roll-on, roll-off ramp (Ro-Ro berth)

The definition of these terms are given in Clause 3 of this Standard. Marginal berths require a vertical face against the ship berths and an adjoining working area alongside for cargo-handling equipment and cargo storage.

A pier normally requires a vertical face on both sides against which ships are berthed, with the deck of the pier providing the working area for cargo handling and sometimes cargo storage. As with marginal berths, the pier can also be of a solid type or a suspended structure on piles.

A jetty is a structure providing a berth or berths at some distance from the shore where the required depth of water is available. It consists normally of a jetty head which provides the actual berth, which is connected to the shore by an approach trestle or causeway.

The two other types of berthing structures i.e.: dolphins and roll-on, roll-off berths are discussed under Clauses 7.5 and 7.6 of this Standard.

Detailed discussion of quay walls and jetties is made under Clause 7.4 of this Standard.

7.3 Choice of Structures

Choice of the type of structures depends on depth of water, the foundation condition and the availability of suitable materials. For any important structure, a variety of different types should be compared and a choice made on the basis of the capital and maintenance costs or ease of construction. In case of piers, as they extend into the seaway, particular considerations need to be given to its effect on the hydraulic regimen and littoral drift. The choice of whether the pier is solid or open will frequently depend on these considerations although foundation conditions and availability of fill material may also affect the choice.

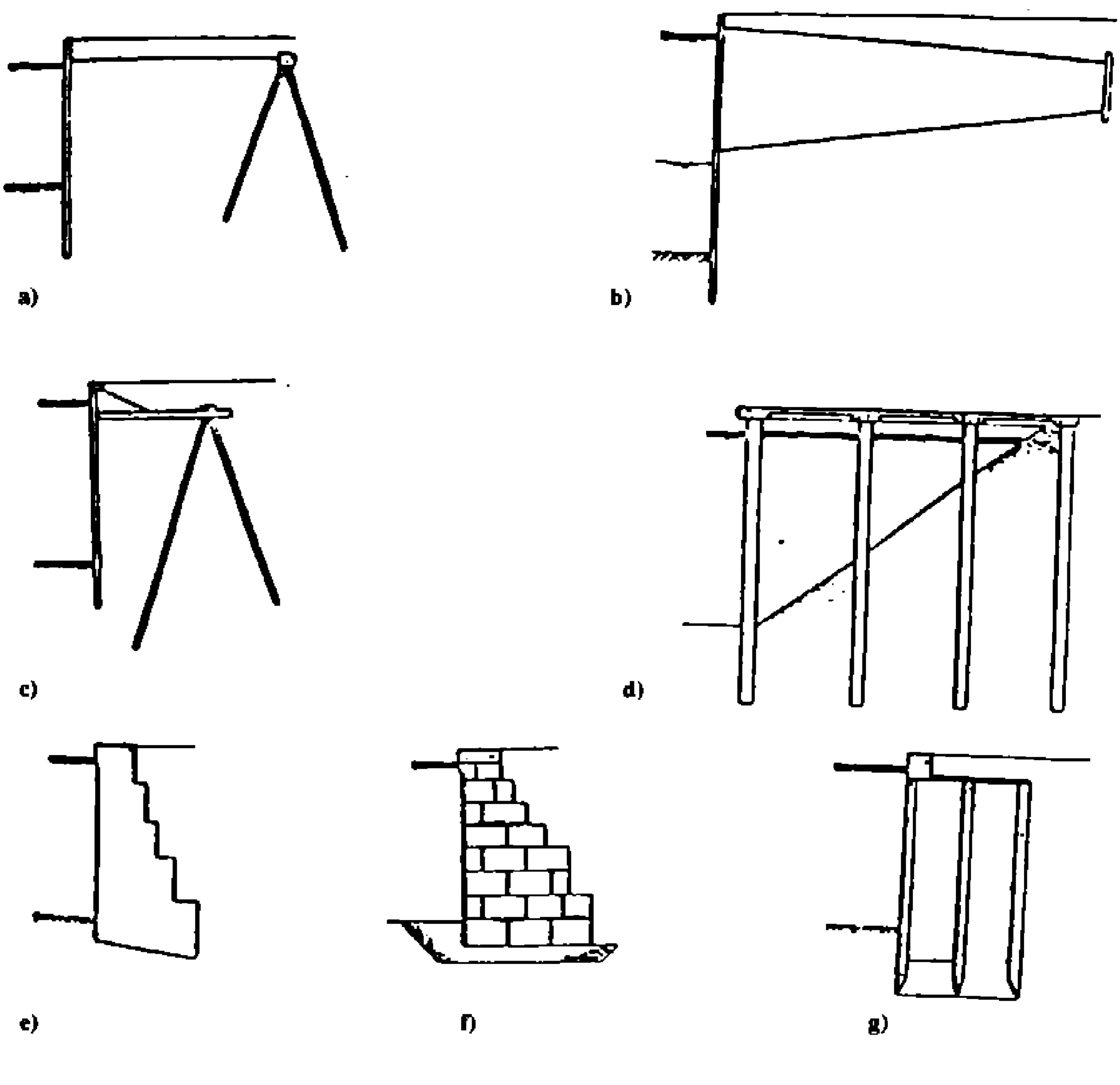
7.4 Quay Walls and Jetties

7.4.1 General

Quay walls and jetties may be categorized under the following types:

1) Sheet-walls
2) Gravity walls
3) Suspended deck structures

The jetty head is normally an open-piled structure although a solid "island-type" structure is used occasionally. The approach section is generally built as an open-piled trestle type of structure, mainly to avoid affecting the hydraulic regimen, and often also on grounds of cost; although in shallow waters a solid causeway may be cheaper. In some cases a causeway is used for the first section of the jetty approach from the shore, until the depth of water increases to such extent where a piled structure becomes more economical. Fig. 2 shows the main types of quay walls and jetty structures.



TYPES OF QUAY WALLS
Fig. 2

a) anchored sheet pile wall-single tie
b) anchored sheet pile wall-double ties
c) sheet-pile with relieving platform
d) open-piled construction with suspended deck
e) concrete wall built in the dry
f) concrete wall built in the wet
g) monolith

In the following paragraphs a brief description of different types of quay walls are given.

7.4.2 Sheet walls

Sheet walls are retaining walls of thin cross section that resist loads by bending. The general principles of determining earth pressures behind retaining walls are covered in IPS-E-CE-140 "Retaining Walls and Slope Protection".

Sheet wall structures can be divided into three groups:

a) anchored single-wall (including propped single-wall structures;
b) cantilevered single-wall;
c) single-wall with relieving platform.

The distribution of earth pressure and resistance of these structures depends on the type and flexibility of the structure as well as on the nature of the soil. This interdependence also applies to surcharge loads. For detailed information refer to Clause 4.4 of BS 6349: Part 2: 1988.

7.4.3 Gravity walls in quay and jetty construction

Gravity structures may be used where the seabed is of good quality. They may therefore be considered where the foundation near dredged level is of rock, dense sand or stiff clay.

Gravity walls used in maritime works are generally required to retain reclaimed ground, the quality of which can be selected. It is usual to use rubble or a free-draining granular fill immediately behind a quay wall so that the effects of tidal lag are minimized and earth pressures are reduced.

The selection of the most appropriate type of gravity wall will be influenced by the site conditions and method of construction.

For more detailed information refer to Section Five of BS 6349: Part 2: 1988.

7.4.4 Suspended deck structures

Suspended deck structures are commonly used for marginal quays and finger jetties.

Suspended deck structures may be of steel, concrete or timber, or of a combination of more than one of these materials.

Suspended deck structures will usually be the most suitable type in the following circumstances:

a) ground consisting of weak upper materials overlying a stronger stratum;
b) ground immediately below seabed consisting of suitable material for bearing piles;
c) non-availability of suitable backfill for use in a retaining wall type of quay;
d) necessity to minimize interference with hydraulic regimen;
e) great depth of water.

For more detailed information about suspended deck structures refer to Section Six of BS 6349: Part 2: 1988.

7.5 Dolphins

Dolphins are isolated structures or strong-points used either to maneuver a vessel or to facilitate holding it in position at its berth.

Structurally, they are classified under two main categories:

- Flexible structures;
- Rigid structures.

Functionally, dolphins may be classified as:

- Breasting dolphins (also termed berthing);
- Mooring dolphins;

A breasting dolphin is an isolated structure designed to fulfill two distinct functions: (1) it must absorb the kinetic energy of the berthing vessel; and (2) it must assist in restraining the vessel at the berth.

Breasting dolphins may be rigid or flexible type.

The choice between a rigid or flexible dolphin will usually be determined by the depth of water and the foundation conditions.

Mooring dolphins are isolated structures to which mooring lines are attached to restrain the ship at the berth. They are not normally subject to impact from a berthing vessel and do not therefore need fendering or to be flexible to absorb energy.

For more detailed information refer to Section Seven of BS 6349: Part 2: 1988.

7.6 Roll-On/Roll-Off Terminal (Ro-Ro) Ramps

In some places where tidal ranges are small, Ro-Ro vessels can berth, offload and load at any state of the tide, bridging the ship-to-ship gap with their own short ramps. Where tidal ranges are large, Ro-Ro vessels must either use impounded docks or more elaborate ship-to-shore ramps must be provided which can tolerate greater differences in level between ship and quay.

Ro-Ro terminals with shore ramps generally require the vessels to be berthed against fixed structures to hold them in position. These structures may comprise a single continuous berthing face, a series of dolphins or pontoons, or a combination of the two.

Occasionally, vessels may be held off the ramp by buoys or anchors.

A typical fixed shore ramp and a typical adjustable ramp are shown in Fig. 3.

For more detailed information refer to Section 8 of BS 6349: Part 2: 1988.

7.7 Pedestrian Access

Walkway, stairway, ladder and handrailing should be installed to facilitate the access of pedestrians to various parts of maritime structures. For detailed information refer to Section 9 of BS 6349: part 2:1988.

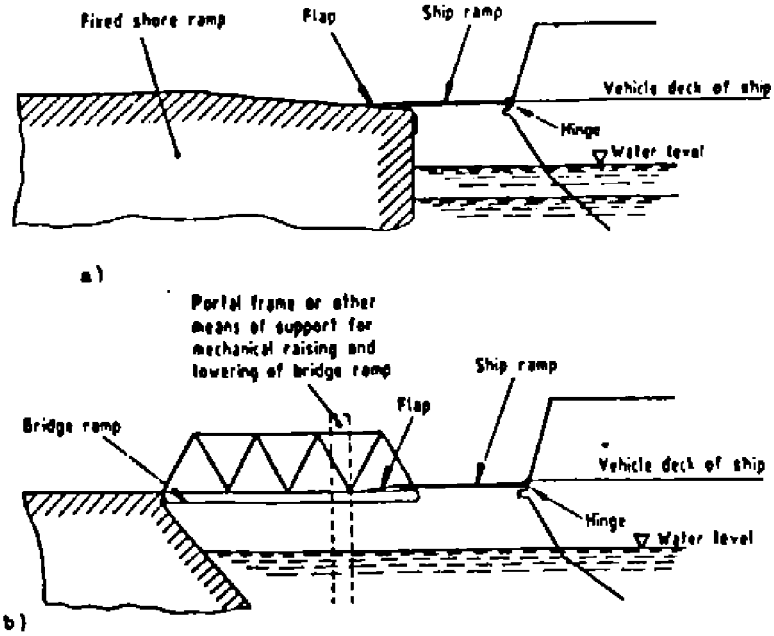
8. MOORING AND FENDERING SYSTEMS

8.1 Mooring

8.1.1 General

Present situations often require the ship to be accurately held in place in relation to berth-mounted ship loading or discharging equipment which itself may be very limited in movement, e.g. container cranes and articulated booms.

The principle to be followed, regardless of the size of the vessel, is to restrain movement to within acceptable limits by means of an adequate number of mooring lines, which can be readily handled by the operating personnel, compatible with the conditions of wind, tide, weather and other effects likely to be experienced during the relevant period of vessel stay at the berth.



a) Fixed Ro-Ro shore ramp
b) Adjustable Ro-Ro shore ramp

TYPICAL RO-RO RAMPS

Fig. 3

8.1.2 Mooring patterns

The normal mooring pattern consists of ropes issuing at the extremities of the ship that make horizontal angles of about 45°-90° and -45° to its axis, plus spring lines at about 10° to its axis, together with breast lines as appropriate.

For more detailed information refer to Section 3 of BS 6349: Part 4: 1985.

8.1.3 Forces acting on the moored ship

The principal forces acting on a moored vessel are generally caused by wind and current. However the mooring system has to be capable of withstanding any combination of the following as may be applicable:

a) wind;
b) current;
c) off-quay hydrodynamic and hydrodynamic interference from passing ships;
d) ocean or long swell waves;
e) waves caused by passing ships in narrow channels;
f) tidal rise and fall, and change in draft or trim due to cargo operations;
g) ice.

Normally, if the mooring system is designed to accommodate the maximum wind and current forces the reserve strength will be sufficient to resist other forces that may arise.

However, if appreciable surge, waves, ice or other abnormal conditions exist at the terminal, considerable loads may be developed in the vessels' moorings. These forces are difficult to analyze and model testing or field measurement should be used.

8.1.4 On-shore mooring equipment

On-shore mooring equipment generally comprise of bollards, quick-release hooks, mooring rings and capstans. In the following paragraph a short description of bollards is given; for more detailed information about the rest of equipments refer to Clause 11 of BS 6349: Part 4: 1985.

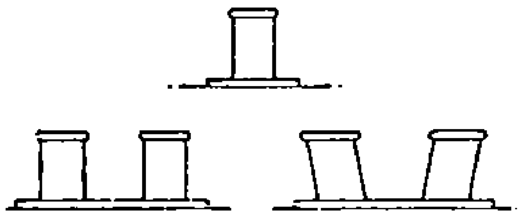
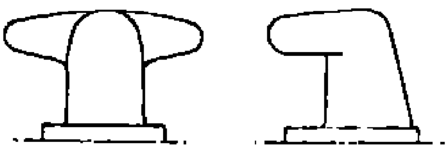
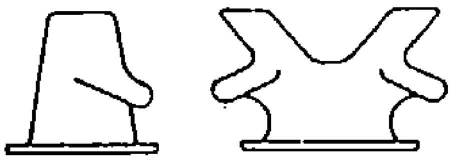
8.1.4.1 Bollards

Bollards are short upright posts around which ropes are secured for mooring purposes. Many bollard designs are commercially available, but they may be broadly classified into 3 categories, as follows:

- Pillar type
- Tee-head type
- Twin-head type sloping lobes

These types are illustrated in Table 1, together with their individual characteristics and applications.

TABLE 1 - MOORING BOLLARDS

Single and double pillar		t 200 total	General mooring applications where rope angle is not steep Single pillar type should be used with lines from one ship only Suitable for warping ships along berths, etc.
Tee. Head		150	All general mooring applications including steep rope angles Any one bollard should preferably be allocated to lines from one ship only
Sloping lobe		200 total	All general mooring applications including steep rope angles Lines from two ships may be attached without interference

8.2 Fendering Systems

8.2.1 General

Fender systems are designed to protect both the vessel and the breasting structure from damage caused by berthing impacts. The factors determining the type and capacity of a suitable fender system include the nature and size of the berthing vessels, the form of the structure to be protected, the environmental conditions (i.e. wind, waves, currents, etc.) the operational requirements and the consequences of damage to the vessel or structure.

8.2.2 Types of fender systems

Fender systems may be classified in three general categories, i.e. those for continuous quays, those for island berths and those for lead-in jetties. Other systems will generally be variants of or combinations of these three categories. In the following paragraphs a brief description of the above-mentioned systems are given; for more detailed information refer to Clause 4.11 of BS 6349 : Part 4: 1985.

a) Continuous quays

On continuous quays there is generally no precise delineation of individual berths in order to give flexibility of operation and the accommodation of a wide range of vessels. In such cases the fendering system should allow a ship to berth at any position along the length of the quay. It may consist of either:

- A continuous berthing frame supported on fender piles driven in front of the quay or directly on the face of the quay on elastomeric units;

- a series of individual fenders, the spacing of which should comply with the following:

1) The fenders should prevent the vessels striking the berth structure when berthing on the bow or stern quarters, and allow sufficient fenders to be mobilized for energy absorption;

2) the fenders should allow vessels to lie alongside with adequate support from the fenders along the straight run of the ship's hull.

b) Island berths

Where vessels are berthed about a fixed point such as oil loading arms, the primary fendering can be concentrated at two or more points depending on the range of vessels to be accommodated. These can be in the form of localized strong points within a loading platform or separate berthing dolphins positioned about the loading platform.

c) Lead-in jetties

Fendering systems for guiding vessels into the entrances of confined areas, such as locks, dry-docks, ship-lift systems and passageways, may comprise either a continuous faced structure or a series of individual dolphins.

In addition to the above-mentioned systems, the fenders may be categorized as follows:

- Fenders using elastomeric units
- Pneumatic and foam-filled fenders
- Flexible dolphins
- Fender piles
- Gravity fenders
- Timber fenders

For a detailed discussion on the fender types refer to Clause 5 of BS 6349: Part 4: 1985.

9. SHORE PROTECTION

9.1 General

This part contains recommendations and guidance about various methods of shore protection as may be required for the protection of land which is being eroded by the sea, of low-lying land against flooding by the sea, or for the purpose of reclaiming land from the sea.

9.2 Types of Shore Protection

Several types of shore protection methods may be considered among which the following may be mentioned:

- Seawalls and bulkheads
- Jetties
- Groins
- Revetments

In the following paragraphs brief description of each type are given.

9.3 Factors Affecting Selection of the Type of Shore Protection

Major considerations for selection of a structural type are as follows:

- foundation conditions;
- exposure to wave action;
- availability of materials;
- costs, including initial and repair costs.

Foundation conditions may have a significant influence on the selection of the type of structure, either from the point of view of foundation material or settlement and possibility of foundation failures.

Wave exposure may control the selection of both the structural type and the details of design geometry.

In areas of severe wave action, light structures such as timber crib or light riprap revetment should not be used. Where waves are high, a curved, re-entrant face wall or possibly a combination of a stepped-face wall with a recurved upper face may be considered over a stepped-face wall.

Availability of materials is related to construction and maintenance costs as well as to structural type. If materials are not available near the construction site, or are in short supply, a particular type of seawall or bulkhead may not be economically feasible. A cost compromise may have to be made or a lesser degree of protection provided. Cost analysis includes the initial costs of design and construction and the annual costs over the economic life of the structure. Annual costs include interest and amortization on the investment, plus average maintenance costs. The best structure is one that provides the desired protection at the lowest annual or total cost. Because of wide variations in the initial cost and maintenance costs, comparison is usually made by reducing all costs to an annual basis for the estimated economic life of the structure.

9.4 Seawalls and Bulkheads

In general seawalls are rather massive structures because they resist the full force of the waves. Bulkheads are next in size; their primary function is to retain fill, and while generally not exposed to severe wave action, they still need to be designed to resist erosion by the wave climate at the site.

Curved-face seawalls and combination of stepped-and curved face seawalls are massive structures and are built to resist high wave action and reduce scour. The stepped-face seawalls are designed for stability against moderate waves.

Rubble-mound seawalls are built to withstand severe wave action.

Bulkheads are generally either anchored vertical pile walls or gravity walls; see IPS-E-CE-140 "Retaining Walls and Slope Protection".

9.5 Jetties

Jetties (a term used in U.S.) are structures extending into a body of water (on open sea coasts) which are designed to prevent shoaling of a channel by littoral materials and to direct and confine the stream or tidal flow. Jetties are built at the mouths of rivers or tidal inlets to help deepen and stabilize a channel.

The principal materials for jetty construction are stone, concrete, steel and timber. The general principle for design of jetties may be considered the same as breakwaters. See Clause 6 of this Standard.

Note:

Jetties in British usage are equivalent to wharf or pier and should not be mixed with the shore protection structure.

9.6 Groins

Groins are shore protection structures built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore. Groins are mainly classified as to permeability, height and length. Groins built of common construction materials can be made permeable or impermeable and high or low in profile. The materials used are stone, concrete, timber and steel.

9.7 Revetments

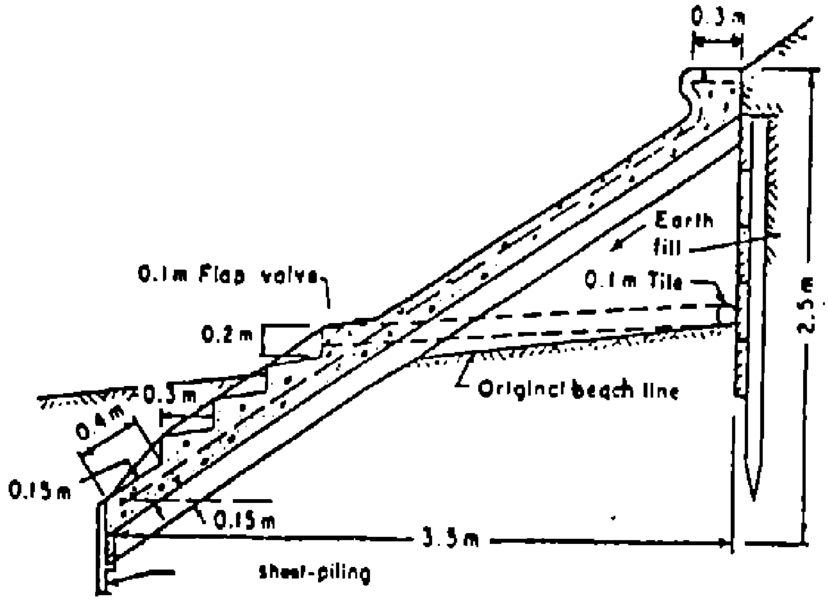
Revetments are facings of stone, concrete etc., built to protect a scarp, embankment or shore structures against erosion by wave action or currents.

There are two types of revetments; the rigid type and the flexible one.

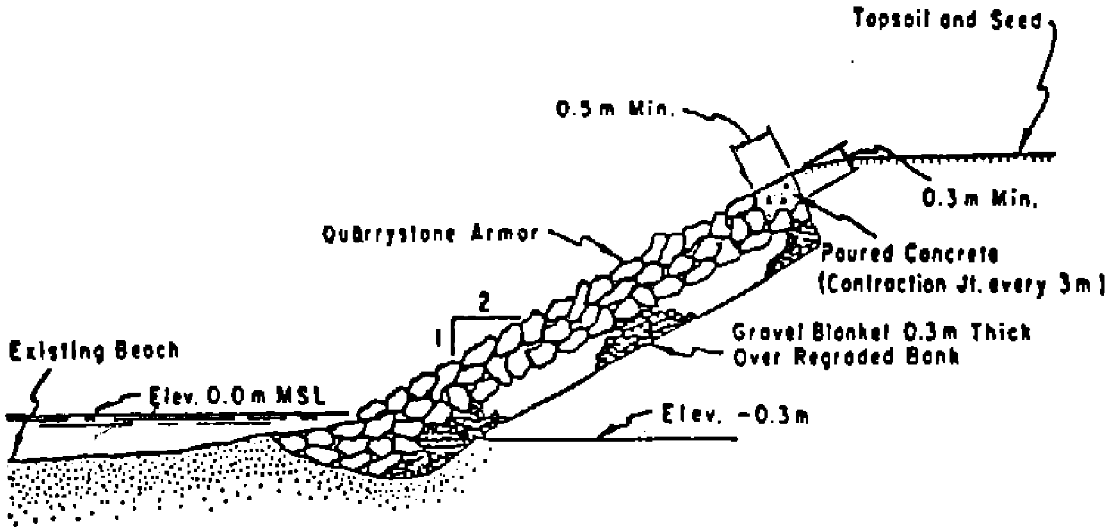
The structural types of revetments are illustrated in Fig. 4. A rigid concrete revetment provides excellent bank protection, but the site must be dewatered during construction so that the concrete can be placed.

A flexible structure also provides excellent bank protection and can tolerate minor consolidation or settlement without structural failure; this is also valid for the quarrystone or riprap revetments and to a lesser extent for the interlocking concrete block revetment.

a)



b)



a) Concrete revetment

b) Quarrystone revetment

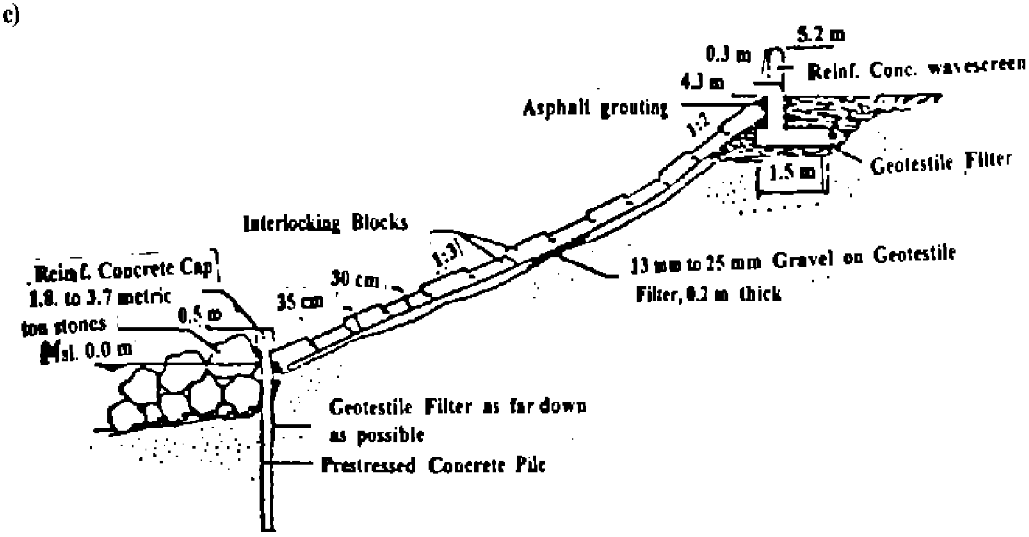
REVETMENTS

Fig. 4

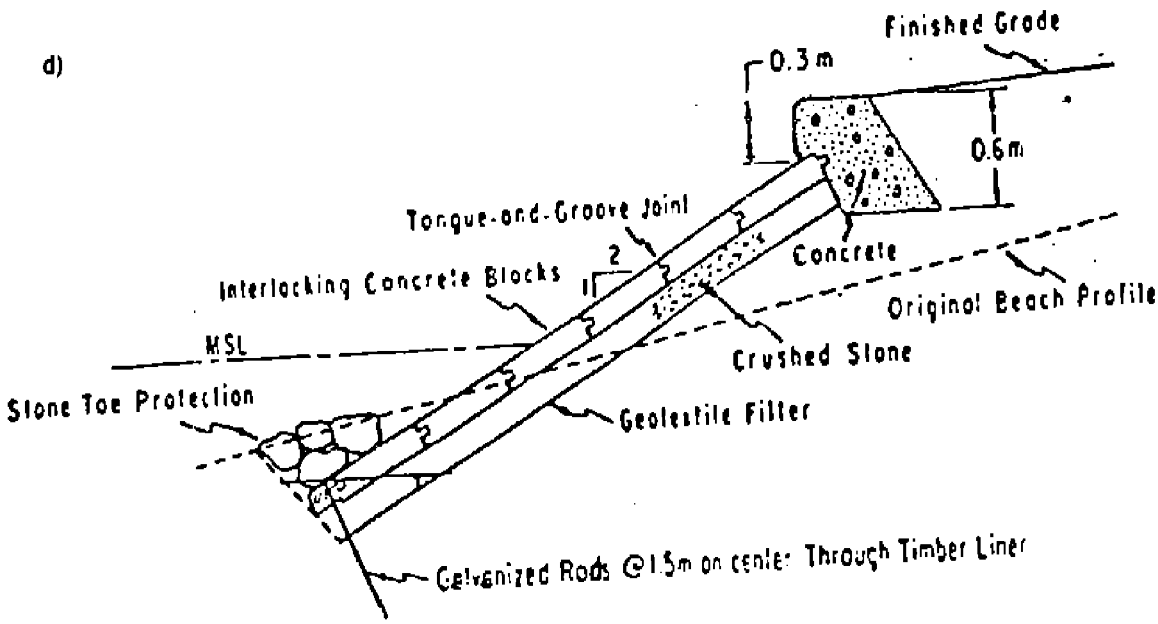
(to be continued)

Fig. 4 (continued)

c)



d)



c) & d): Interlocking Concrete-Block Revetment

REVETMENTS (CONCLUDED)

Fig. 4

10. CONSTRUCTION MATERIAL

10.1 General

The materials covered by this Clause include the basic materials generally used in maritime constructions. The materials covered in this clause are as follows:

a) Stone
b) Concrete
c) Structural steel
d) Timber
e) Pipes
f) Masonry
g) Bituminous materials
h) Rubber and plastics

10.2 Stone

Stone for maritime works should be hard and of best quality, with good durability. It should be free from laminations and weak cleavage planes and should be of such a character that it will not disintegrate or erode from the action of air, water, wetting and drying, freezing and thawing and impact due to wave action. It should be capable of being handled and placed without undue fracture or damage. Individual pieces should be prismoidal in shape and the maximum dimension of stones should generally not exceed twice the minimum dimension.

In considering alternative sources of suitable stone, the first choice should be igneous rocks which are generally the most durable. Sedimentary and metamorphic rocks require more care in selection but the best sources can provide suitable materials.

For more detailed information about test of quality, riprap, bedding filter and core materials refer to Clause 57 of BS 6349: Part 1:1984, IPS-E-CE-110 "Soil Engineering" and BS 5930: 1981 "Site Investigation".

10.3 Concrete

Generally the concrete materials used in maritime structures should comply with the requirements of IPS-M-CE-165; additionally the following should be considered.

10.3.1 Reinforcement

Reinforcement should comply with ACI 318 M-89 and/or IPS-C-CE-200. The reinforcement should not be surrounded by concrete unless it is free from salt deposit.

10.3.2 Underwater concreting

Underwater concreting can be carried out in situ either by placing conventionally mixed fresh concrete by the methods listed in this subclause or by the process of pumping cement grout into previously placed aggregate.

The principal methods of placing fresh concrete underwater are by the following:

a) tremie;
b) skip or similar device;
c) pumping;
d) bagwork.

Concrete bagwork should be limited mainly to temporary work.

For more information refer to Clause 58.11 of BS 6349: Part 1: 1984.

10.3.4 Chemical attack and prevention of corrosion

The presence of salts in seawater makes maritime conditions most aggressive to steel reinforcement. Chlorides present in seawater pose the main threat of corrosion to reinforcement. In the presence of moisture and oxygen, local concentrations of chloride ions in the concrete can set up electrical potential differences which can promote serious corrosion. Alternate wetting and drying with salt water encourages salts to be deposited as crystals in concrete and high concentrations can build up internally in porous zones. The splash zone is the area where this effect is most severe.

The best method of ensuring that the natural alkaline protective mechanism is maintained is by providing concrete which has the lowest possible permeability and this can be obtained by adopting mixes designed to produce a concrete of the highest practicable density.

Sulphate ions are present in seawater at relatively high concentrations and can react with the tricalcium aluminate hydrate in hardened Portland cement. The rate of attack which only occurs in warm or polluted waters can be reduced by using sulphate-resisting Portland cement.

Cathodic protection should be in accordance with BS. CP 1021: 1973 (1979).

For more detailed information refer to Clauses 58.2 and 58.10 of BS 6349: Part 1:1984.

10.4 Structural Steel and Other Metals

The most commonly used metals in maritime structures are weldable structural steels which should comply with BS 4360. Other metals which are sometimes used in maritime structures, usually for special reasons, are copper alloy steels, stainless steels, cast steels, cast irons, wrought irons, brasses, bronzes, aluminium alloys and Monel.

For more detailed information in this respect refer to Clause 59 of BS 6349: Part 1:1984:

10.5 Timber

A wide range of species of timber can be used in maritime structures, the choice will depend largely on availability in the region in which the works are situated. The timbers are commonly used in the main structural elements as, deck structures, kerbs and capping pieces, fendering and rubbing strips, sea defence works, etc.

For more detailed information refer to Clause 60.3 of BS 6349: Part 1:1984.

10.6 Piles

Piles in maritime works can be divided into two groups:

a) Bearing piles as used in foundations, wharf, jetty and dolphin construction, or in fendering systems;
b) Sheet piles as used in retaining walls or for wave protection.

Materials used for bearing and sheet piles include concrete and steel. Fender piles are designed primarily to withstand or transmit horizontal impact forces. There are a number of specialized piling systems, some of which use combinations of materials.

For more detailed information refer to IPS-E-CE-130 "Piles" and Clause 61 of BS 6349: Part 1: 1984.

10.7 Pipes

Pipes used in the maritime environment can be divided into four main categories:

a) pipelines laid on or under the seabed;
b) pipelines laid below ground on land in quays, piers, marginal and inland storage areas;
c) pipelines supported above ground;
d) flexible pipelines for ship-to-shore connection.

Pipes are manufactured in a wide variety of materials, a list of pipes currently available being given below. These should comply with the requirements of the appropriate standard where such exists:

1) Aluminium.
2) Asbestos cement.
3) Concrete.
4) Copper.
5) Ductile iron.
6) Glass reinforced plastics (GRP).
7) Plastics (PVC, low density polyethylene, etc.).
8) Steel
9) Resin coated and bonded helically wound steel strip construction with resin coatings on inner and outer surfaces.

Selection of pipe material for a particular situation is governed by its suitability for the duty involved, taking account of availability, strength, durability and the construction methods to be adopted.

For more detailed information refer to Clause 62 of BS 6349: Part 1: 1984.

10.8 Masonry

The uses of brickwork, blockwork and masonry in maritime works are usually similar to those in general building and civil engineering works. Materials and workmanship for maritime applications, however, should always be of the highest quality in order to provide satisfactory durability.

Masonry is seldom used now in new construction but repairs to existing masonry structures are frequently required. Repair can often be effected more economically by alternative means but in some cases, either for engineering or aesthetic reasons, repairs in masonry are necessary.

For more detailed information refer to Clause 65 of BS 6349: Part 1: 1984.

10.9 Bituminous Materials

Bituminous materials are used in maritime works for the following:

a) Pavements;
b) coatings;
c) waterproofing;

d) sealing compounds;
e) coast and bank protection.

The choice of the various materials available for different maritime protection works are summarized in Table 2.

For more detailed information about bituminous materials refer to Clause 66 and for application of bituminous materials in the construction of pavements refer to Clause 63 of BS 6349: Part 1:1984.

10.10 Rubber and Plastics

a) Rubber

Because of its energy absorbing characteristics, rubber is used as a fendering material on quays and dolphins in order to reduce the forces between structure and berthing vessel, thereby minimizing costly impact damage and reducing significantly the basic cost of the structure.

Manufacturers of rubber fenders produce a variety of shapes of rubber section each of which has its own particular application. Selection of the fender is generally based on data produced by each manufacturer.

b) Plastics

Plastics bearings are used in similar circumstances to those in which rubber bearings are used but, whereas rubber bearings usually permit lateral movements by shear distortion, the low coefficient of friction associated with plastics bearings is utilized to allow lateral movements by sliding, usually against a stainless steel plate.

Glass Reinforced Plastics (GRP) is a versatile material which can be used for a variety of applications and is generally used where light strong construction is required.

For more detailed information about rubber and plastics refer to clause 67 of BS 6349: Part 1:1984.

TABLE 2 - USES OF BITUMINOUS MATERIALS IN MARITIME PROTECTION WORKS

TYPES OF BITUMINOUS MATERIALS	DYKES AND CLOSURE DAMS	DUNE PROTECTION AND SEA-WALLS	PROTECTION OF SEABED, RIVER BEDS, CANAL BOTTOMS	GROINES	BREAKWATERS AND HARBOR DAMS	SILLS IN CLOSURE GAPS
ASPHALTIC CONCRETE	REVETMENT ABOVE HIGH WATER LEVEL	REVETMENT ABOVE HIGH WATER LEVEL	—	SPECIAL CASES (CAPPING)	—	—
SAND MASTIC GROUTING	REVETMENT	REVETMENT	—	REVETMENT AND CAPPING	MODERATELY ATTACKED REVETMENT	HEAVILY ATTACKED SILL
SAND MASTIC CARPET (PLACED IN SITU)	TOE PROTECTION	TOE PROTECTION	PLAIN OR STONE WEIGHTED OR STONE ROUGHENED	TOE PROTECTION	TOE PROTECTION	—
PREFABRICATED MATTRESSES	TOE PROTECTION	TOE PROTECTION	SPECIAL CASES	TOE PROTECTION	TOE PROTECTION	—
LIGHT STONE ASPHALT	REVETMENT	REVETMENT EITHER DIRE-CT OR BY GROUTING OF HEAVY RUBBLE	—	REVETMENT EITHER DIRECT OR BY GROUTING OF HEAVY RUBBLE	GROUTING OF HEAVY RUBBLE	—
HEAVY STONE ASPHALT	—	REVETMENT	—	REVETMENT	REVETMENT	—
LEAN SAND ASPHALT	CORE, FILL RETAINING WALL, FILTER LAYER	FILL RETAINING WALL, FILTER LAYER	—	CORE	SPECIAL CASES (GORE) FILTER LAYER	CORE RETAINING WALLS

11. CONSTRUCTION PROCEDURES

11.1 General

Under this Clause brief description of constructional procedures related to maritime structures are presented.

For detailed information refer to BS 6349 "Maritime Structures" Parts 2, 3, 4 and 7.

11.2 Breakwaters

Construction procedures are briefly discussed for the following three main types of breakwaters:

- Rubble mound breakwaters.
- Vertical face breakwaters.
- Composite breakwaters.

11.2.1 Rubble mound breakwaters

Construction of rubble mound breakwaters can be carried out by plant based on land or sea. On major structures it can be economic to use both. The possible methods of construction should be considered at an early stage of design since the potential methods will influence it.

A rubble mound breakwater should be constructed in a sequence of bed preparation, toe construction, core placing, underlayer, armor and crest structure.

Core construction below water level can be economically done from floating craft, particularly if there is a convenient loading point from the quarry.

Each rock should be placed individually, after inspection to ensure that it is within the specified weight range, uncracked and of acceptable shape. It is preferable that the whole thickness of armor layer is placed in one pass to ensure good bonding of the individual blocks.

In the case of concrete armor units, the manufacture, transport and placing of concrete armor units should be carefully controlled. In particular, concrete mixes for large units should be designed to reduce temperature differentials and moulds should be designed to avoid cracking due to thermal stresses. Low heat cement can also be used. Concrete production, casting, curing, stripping of formwork, moving to stockyard, transporting and placing should be arranged and programmed to minimize stresses.

A working area with capacity to store at least 1½ to 2 months' production, plus the space needed for manufacturing will be required.

For more detailed information refer to Section 4 of BS 6349: Part 7:1991.

11.2.2 Vertical face breakwaters

The structural form of vertical face breakwaters can be either a gravity structure or a piled one, and many aspects of quay wall construction procedure may be found relevant to such breakwaters. For piled structures refer to clause 11.3.2 of this Standard. The most common forms of structures with vertical solid faces are of gravity construction (i.e. caissons and blockwork,etc.). In the following paragraphs brief description about these types are given:

a) Caisson structures

Structures comprising reinforced concrete caissons are a common form of vertical face breakwaters.

They can be constructed either by floating into position and sinking or by lowering directly to the sea bed using a crane traveling on the completed work or floating plant.

Floating caissons are generally multi-cellular structures and can be constructed to almost any size compatible with ground conditions and construction methods.

Non-floating caissons are usually open-bottomed single circular cells; their size is limited by available lifting capacity.

For more information refer to Clause 5.4 of BS 6349: Part 7:1991.

b) Concrete blockworks structures

A prepared base of either rubble or concrete is usually needed for blockwork construction; bed preparation by divers requires calm weather. For accurate placing of blocks the block placing crane can be mounted on the previously constructed wall.

Where foundation settlement is unlikely to be significant, bonded blockwork should be used. The blocks should in general be interlocked to strengthen the mass of the breakwater and the joints should be sealed and grouted in order to prevent the build-up of air pressure caused by wave action.

If the sea bed is rock and the blocks are bedded on in-situ concrete, it is important to achieve a good bond between the rock and concrete foundation layer to prevent transmission of water pressure through cracks. With soft sedimentary or weakly cemented rocks, erosion can be caused at the interface by wave action particularly when sand is carried in suspension.

Particular attention should be given to anti-scour protection.

For more details refer to Clause 5.5 of BS 6349: Part 7: 1991 and Clause 5.4 of BS 6349 Part 2: 1988.

c) Mass concrete structures

Mass concrete structures can be constructed within a steel sheet pile cofferdam, the piling forming a permanent facing. The mass concrete filling within a cofferdam can be placed by either of the following methods:

a) Place concrete underwater by tremie or bottom opening skip up to low water level and continue construction above this level tidally.

b) Place a plug of underwater concrete to seal the base and then de-water, continuing construction above this level in the dry. This method requires calmer sea conditions than the first as the cofferdam is more liable to damage by wave action.

d) Cellular sheet piled structures

Cellular sheet piled structures are particularly liable to damage by wave action during construction before internal filling is complete. Each free standing cell should therefore be filled as soon as the piles have been installed. For continuous diaphragm cell construction a carefully controlled sequence of filling should be used as each section is closed. Abrasion of steel sheet piles by granular sediments carried by wave action can limit their life; corrosion should also be considered. Cathodic protection and other methods of protection against corrosion should be considered.

For more detailed information refer to Clause 5.7 of BS 6349: part 7:1991. For other types of vertical face structures such as double-wall and single-wall sheet piled structures refer respectively to Clauses 5.8 and 5.9 of BS 6349: Part 7:1991.

11.2.3 Composite breakwaters

This type of structure can be used as a breakwater in very deep water, when the volume of rock required for a rubble mound structure is not available, and when it is not practicable to construct a vertical face structure. This type of structure consists of a rubble mound which will be utilized as a platform for a vertical face super structure.

The surface of the rubble core should be carefully leveled to provide an even bearing for floating caissons and other types of superstructure as appropriate.

It is desirable to construct the rubble mound as long a period as possible in advance of caisson placing to allow settlement of the mound and the sea bed soil. To do this the temporary stability of the mound should be assured, if necessary, by providing temporary protection to the crest. Settlement of the superstructure can continue for some time after completion and joints should be designed to allow for this.

For more detailed information refer to Section 6 of BS 6349: Part 7:1991.

11.3 Quay Walls and Jetties

Quay walls and jetties are mainly categorized under the following types:

- Sheet walls
- Gravity walls
- Suspended deck structures

11.3.1 Sheet walls

Sheet walls may be categorized under two main groups:

- Steel sheet piles
- In situ concrete diaphragm walls

In the following clauses brief description about construction procedures for each type is presented:

a) Steel sheet piles

Sheet piles may be installed by percussion methods in most soils, by vibration in granular soil or by hydraulic methods in cohesive soil. Driving should be done in such a way that additional stresses due to deformation of the pile clutches are kept to a minimum.

Piles installed with a large unsupported length require temporary support to maintain line and to avoid buckling. Where the line of installed piles is irregular, the walings may be used to assist in straightening the top of the piles, but care should be taken to avoid over stressing the piles and walings resulting in locked-in stresses.

It is generally convenient to install tie rods so that their center section rests directly on the ground. This may require that backfilling be done in two stages at walls where a considerable height of fill is required.

The filling in front of deadman anchors should be completed before the anchorage is required to resist load.

Care should be taken in handling tie rods not to damage them by impact or bending.

b) In situ concrete diaphragm sheet walls

Bentonite slurry is generally used as a means of stabilizing excavations in weak ground for shoreside structures such as quay walls and lock chambers, thereby avoiding the need for support by timbering or sheet piling.

Trenches for the foundations and walls of these structures are supported, during excavation, by the pressure from the slurry. Concrete is then placed through a tremie pipe thus displacing the slurry which is then reused or discarded.

The excavation is made from the ground surface above the highest level of the ground water table. Guide walls are constructed to retain the slurry in permeable ground above the water table and to assist maintenance of vertical and horizontal alignment on the concrete substructure.

The constituent materials and methods of mixing and testing of the bentonite slurry should conform with the recommendations of current specifications issued by recognized specialist organizations. Attention should be paid to the effect of saline water on the properties of the slurry and where necessary special forms of bentonite or processing methods should be used to prevent undesirable flocculation of the slurry in the trench.

11.3.2 Gravity walls

Gravity quay walls can be divided into three categories, as follows:

Category 1

- concrete or masonry blockwork walls
- precast reinforced concrete walls
- concrete caissons
- cellular sheet-piled structures
- double-wall sheet-piled structures

Category 2

- in situ mass concrete walls
- in situ reinforced concrete walls

Category 3

- diaphragm wall construction
- monoliths

Walls in Category 1 would normally be constructed in water using floating plant, those in Category 2 in the dry, often behind cofferdams, and those in Category 3 from ground above water level, the soil in front of the wall being subsequently removed.

In the following paragraphs a brief description about the above-mentioned types are given.

For more detailed information refer to Section Five of BS 6349: Part 2: 1988:

a) Concrete blockwork walls

Heavy precast mass concrete blocks provide a robust maintenance-free structure. The blocks are usually placed to just above low water level. Above this, an in-situ concrete capping is cast up to cope level.

The size of blocks used can be chosen to suit the availability of plant. Blocks of about 15t are probably the smallest that will be economic.

b) Precast reinforced concrete walls

Precast reinforced concrete walls are used in maritime works, both as quay walls and as bulkhead walls adjacent to suspended deck quays. Plain cantilever walls are generally uneconomic for heights in excess of 8 m and for greater heights a counterfort wall may be used.

The units are usually designed so that the top is just above low water level after placing. An in situ concrete capping is cast above this up to cope level after filling.

c) Concrete caissons

See Clause 11.2.2.(a) of this Standard.

d) Cellular sheet-piled structures

See Clause 11.2.2 (d) of this Standard.

e) In-situ mass concrete walls

In situ mass concrete walls may be of solid or voided construction. Alternatively a buttressed-arch form of construction may be used to reduce the volume of concrete. This type will generally require ground anchors to provide the stability required.

Where a sheet wall is used as a permanent shutter on the face of a mass concrete wall, ties are normally provided to anchor the sheet wall to the concrete.

f) In-situ reinforced concrete walls

In-situ reinforced concrete walls should be constructed in the dry, either behind a cofferdam or within an excavation in existing ground.

g) Diaphragm walls

Refer to clause 11.3.1(b) of this Standard.

h) Monoliths

Monoliths, also known as open caissons, are built directly above their final position by alternately raising the walls and sinking the structure into the ground. They are generally constructed using mass concrete or lightly reinforced concrete.

11.3.3 Suspended deck structures

Suspended deck structures consist of two main parts:

- piling systems
- superstructures (i.e. decks...)

Generally the decks are constructed of reinforced concrete. For concrete superstructures reference is made to IPS-C-CE-200 "Concrete Structures". For piling systems refer to IPS-E-CE-130 "Piles".

For more detailed information about suspended deck structures refer to Section Six of BS 6349: Part 2: 1988.

11.4 Mooring and Fendering Systems

The most important features of mooring and fendering systems should be taken into consideration in the design stage so that the system be able to resist the proper forces due to mooring and berthing of ships. The constructional procedures for different elements of mooring and fender systems (like dolphines etc.) are similar to the other maritime structures. For more detailed information refer to BS 6349: Part 4: 1985.

11.5 Shore Protection

The general rules and procedures for design of different types of shore protection are described in Clause 9 of this Standard. In the following sub-clauses main constructional aspects are discussed.

11.5.1 Sea walls and bulkhead

Different types of seawalls and bulkheads are described in Clause 9.4 of this standard. The materials used in construction of seawalls and bulkheads may be stone, concrete, steel and timber including different types of piles for foundation improvements. Sheet pile cutoffs are generally used to prevent loss of foundation materials by wave scour and leaching from overtopping water or storm drainage beneath the wall. The general procedures for construction of gravity type sea walls are similar to the vertical faced quay wall stated in Clause 7.3 of this Standard. The same applies for bulkheads which are similar to procedures stated under 11.3.1 of this Standard.

11.5.2 Jetties (in united states usage)

The principal materials used for jetty construction are stone, concrete, steel and timber. The general principles of jetty construction are similar to breakwaters (see Clause 11.2 of this Standard). Jetties may be constructed as:

- rubble mound jetties
- sheet-pile jetties
- cellular-steel sheet pile structures

Where quarrystone armor units in adequate quantities or size are not available, concrete armor units may be used.

11.5.3 Groins

The materials used in construction of groins are stone, concrete, steel and timber. Asphalt and sand filled nylon bags also have been used to a limited extent. Basically the general procedures for jetty construction are similar to breakwaters, (refer to Clause 11.2 of this Standard).

11.5.4 Revetments

The materials used for revetments are mainly stone, concrete and also gravel or crushed stone and different types of geotextiles are used as filter. Revetments are mainly divided into two types:

Rigid and flexible, the rigid cast-in-place concrete is example of the first type and articulated armor units are examples of the second type. In rigid concrete type the site must be dewatered during construction, so that the concrete can be placed.

Both the articulated block structure and the quarrystone or riprap structure allow for the relief of hydrostatic uplift pressure generated by wave action and there is no need to provide specially constructed weep holes. The underlying geotextile filter or gravel (or crushed stone) layer helps to reduce pressure without moving the fine materials.