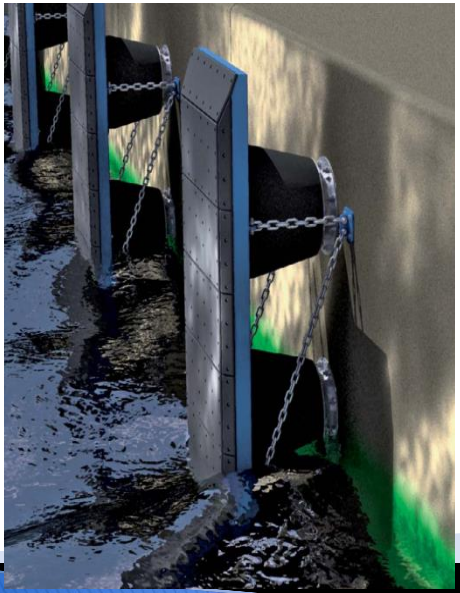
PORT ENGINEERING

Wharves, Quays, Fenders and Dolphins

13 – 14 September 2021



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Day 1

13 September 2021

Wharf, Quay and Pier

Types of Quay Wall

Basin Layout

Code of practise & design requirements of maritime structures

Gravity wall Structure

Sheet Pile wall structure

Open berth structures

Introduction
to
Maritime Stucture

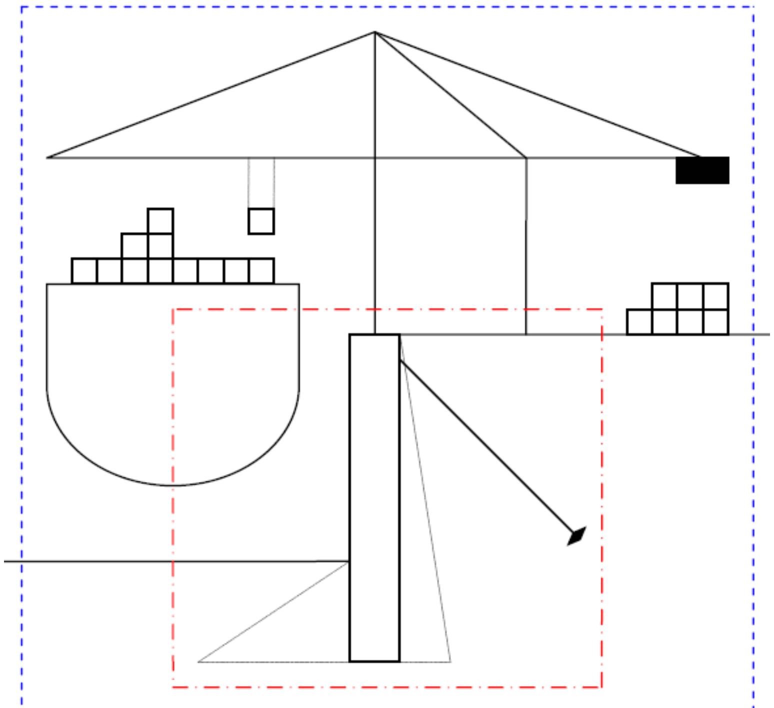
Introduction

Wharves, quays & piers are marine structures which are used for the mooring or tying of vessels while there are loading or discharging cargo or passengers.

Terminology – Wharf, Quay & Pier

- Wharf – a structure built along or at an angle from the shore of water so that ships may lie alongside to receive and discharge cargo and passengers.
- Quay – it is a wharf running parallel to the shore.
- Pier – a structure extending into the water for use as a landing place or promenade.

Terminology – Wharf, Quay & Pier



Quay – part of the harbour for mooring, loading and unloading ships, where bulk and cargo can be transported and/or stored.

Quay wall – a retaining structure, separating the land from the water, for the mooring of ships.

Source: TU Delft

Vessel Characteristics

Vessel Characteristics		*Design*
• Length	–	Length and layout of the pier.
• Beam	–	Width of the berthing basin and approach channel, reach of cargo-handling equipment.
• Draft	–	Water depth along the berth and approach channel.
• Displacement	–	Berthing energy and fendering system.
• Size and shape of hull and configuration of vessel superstructure	–	Fendering and mooring systems, positioning of pier superstructure and facilities.
• Passenger carrying capacity	–	Waiting area, access ramp and passenger facilities.
• Cargo type and handling capacity	–	Storage requirement and cargo handling equipment.

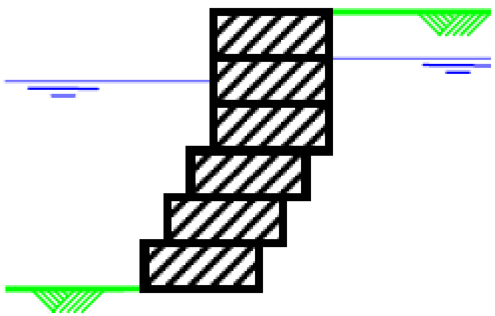
Types of Quay Wall

- Quay wall is a soil retaining structure, which occurs in many shapes. All these structures have the same function:
  - *Bearing capacity for crane loads, goods and storage*
  - *Sometimes a water retaining function*
  - *Mooring place for ships*
  - *Soil retaining function*

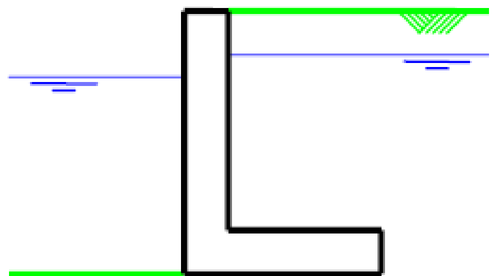
- To fulfil all these functions, 4 main types of structures can be considered.

Types of Quay Wall

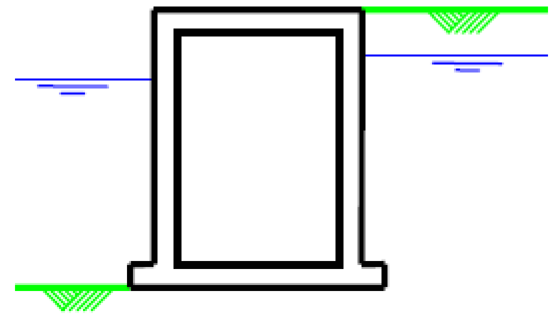
1) Gravity Wall



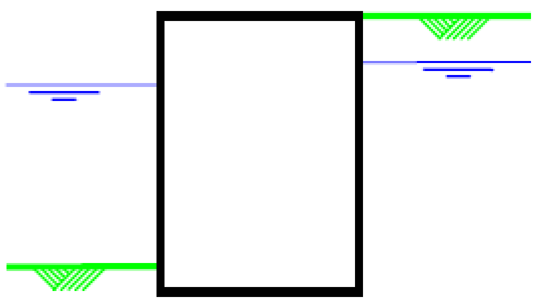
Block Wall



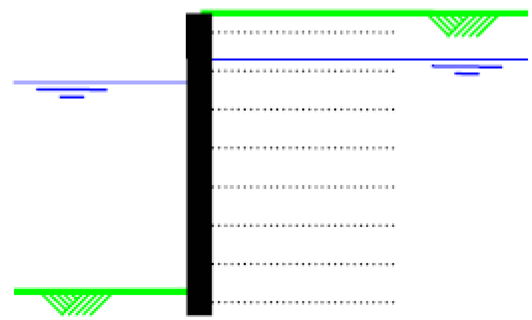
L-Shape Wall



Caisson Wall



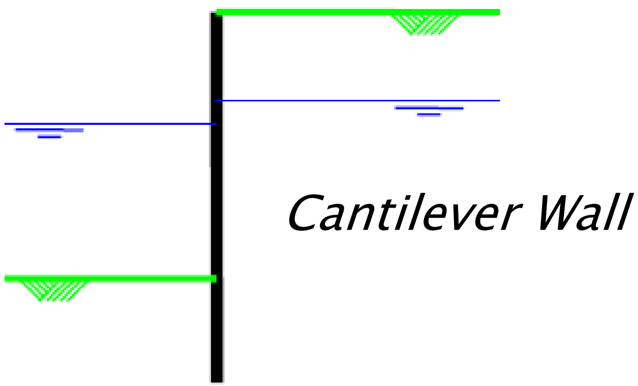
Cellular Wall

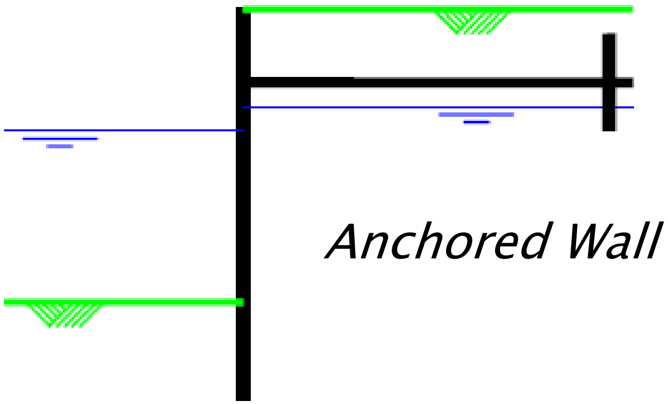


Reinforced Earth Structure

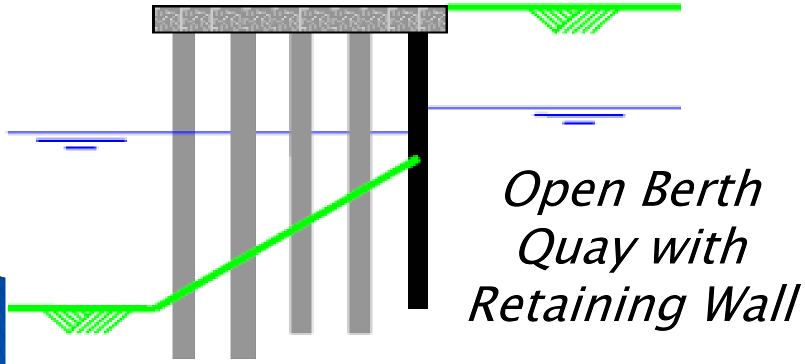
Types of Quay Wall

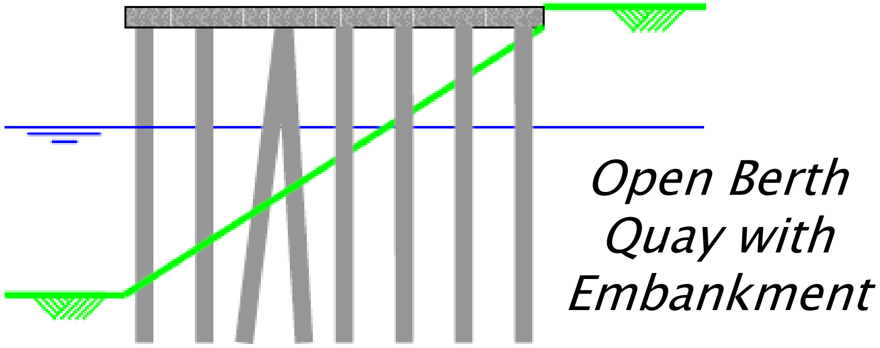
2) Embedded Wall (Sheet Pile)





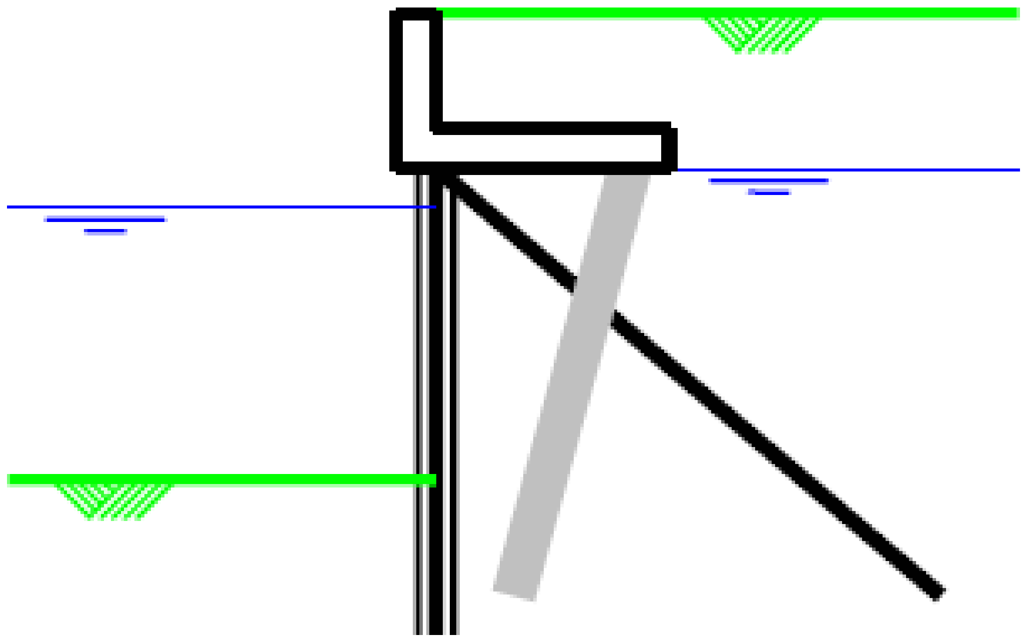
3) Open Berth Quay





Types of Quay Wall

4) Embedded Wall (with Relieving Platform)



Layout of Quay

- Minimum length of a quay should be sufficient for mooring the longest ship expected to berth.
- Alongside berthing requires a quay length equal to the vessel plus 30 ~ 40m, 1.2 times the length.
- Apron width; 20m ~ 40m (for cargo handling). Transit shed or storage area = 60m. Road & rail access behind storage facilites = 10m ~ 20m. Total width of the lad behind quay face = 90m ~ 120m.
- Minimum depth at the quay; Max draft of vessel + 1.0~2.0m (to cover any heaving motion due to wave disturbance)

- Example 1;
  - Medium-sized port
  - Water depth = 9.0m
  - Length of vessel = 160m
  - Total length of quay = Length of vessel + 40m* = 200m
    - * Adding 20m at both ends for mooring.

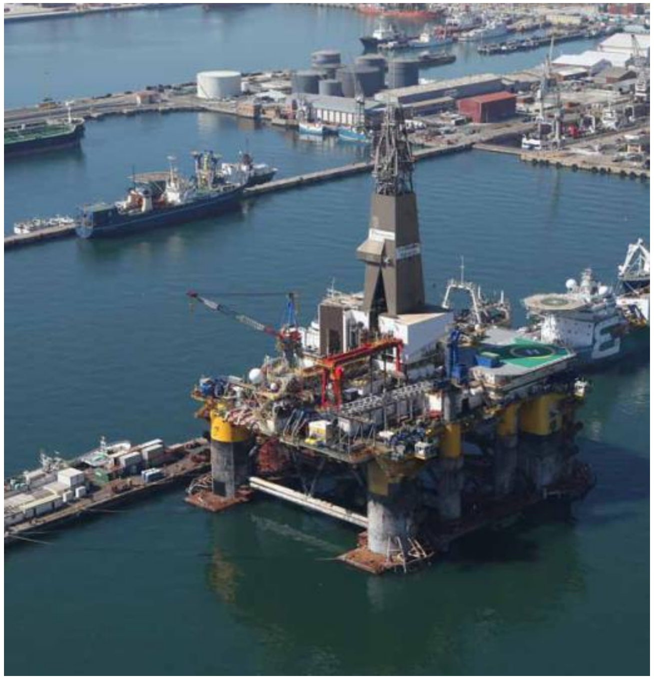
Layout of Quay

- For port linked with railway track, 1 berth is uneconomical. Thus, large and small ship are to be accommodated at a quay.

- Example 2;
  - Big-sized port
  - Water depth = 16.0m
  - Length of vessels = 150m + 110m
  - Total length of quay = Length of vessels + 60m* = 320m
    - * Adding 20m at both ends + 20m in between of vessels for mooring.

Basin Layout

- Suitable length of Basin, 600 ~ 700m
- Diameter of Turning Basin ~ 5 times the length of the longest ship.



Example:
Length of Ship = 56m (suezmax vessel)
Thus, diameter of turning basin = 280m (min)

Note: Turning maneuver requires at least 2 very large and powerful tugs having length of up to 35m.

Basin Layout

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- Diameter of Turning Basin ~ 5 times the length of the longest ship.

<u>Example:</u>

- Length of Ship = 56m (suezmax vessel)
- Thus, diameter of turning basin = 280m (min)

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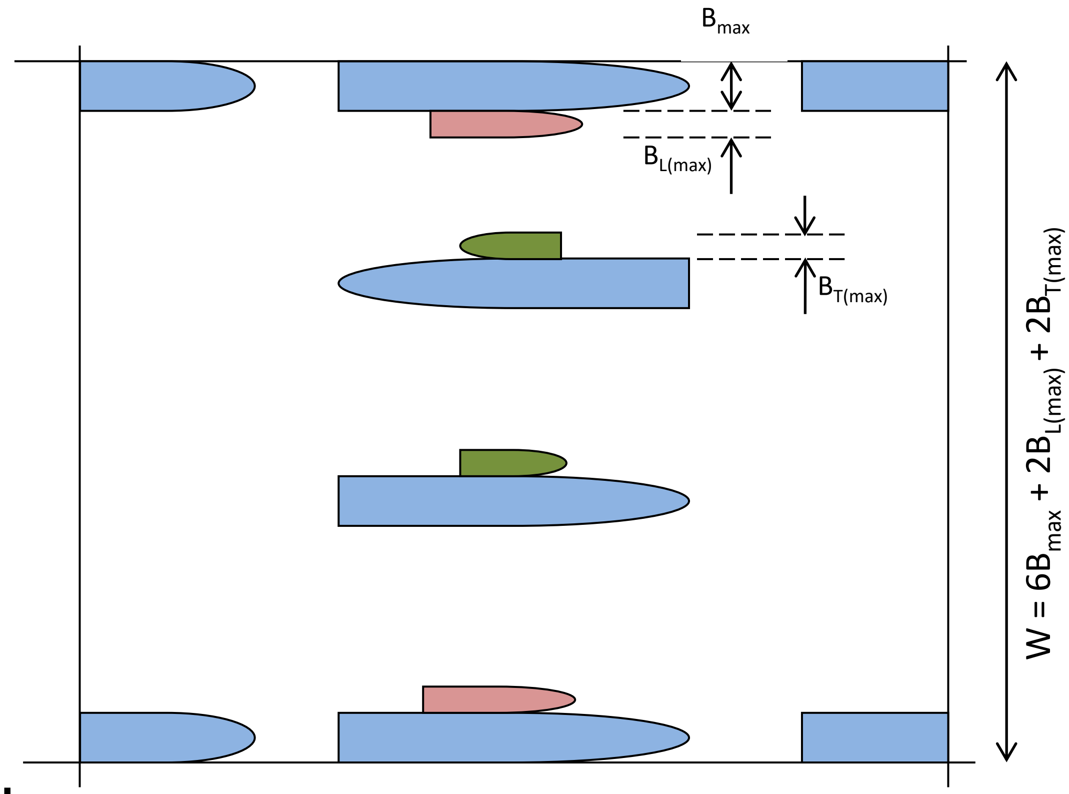
Basin Layout

Basin width as equal to the beams of the maximum-sized ships located at both sides of the basin with 2 rows of lighters on the outer side of each ship and a fairway twice the beam of the largest ship between moored ships.



Quay Design

Before the structure is designed, a planning process should be undertaken to determine the way in which the structure is to be used. As part of this process, the various parts of the structure should be zoned for different types of use.

Code of Practice

Code of Practice for Maritime Structures, BS 6349 Part 1 & 2 [6]

General

BS 6349 is written by the British Standard Institute, the national normalization institute of the United Kingdom. Only the first 2 parts are studied: part 1, "General Criteria" written in 2000 and part 2, "Design of quay walls, jetties and dolphins" written in 1988. The British Standards are not adapted to the latest European guidelines, because **they rather trust their own standards**, than the European codes who are just under investigation. In the first part a basic description is given of criteria that are important in the design of maritime structures. In the second part the design methods of sheet pile walls, gravity walls and jetties are given in a short way. The BS 6349 refers a lot to BS 5400 for steel and concrete bridges, BS 6031 for soil structures, BS 8004 for foundations and BS 8002 for retaining structures. Not much attention is paid to calculation models and methods.

Design Considerations

Design Considerations

- The design load for a limit state is defined as the most unfavorable combination of the characteristic load multiplies by a load coefficient.

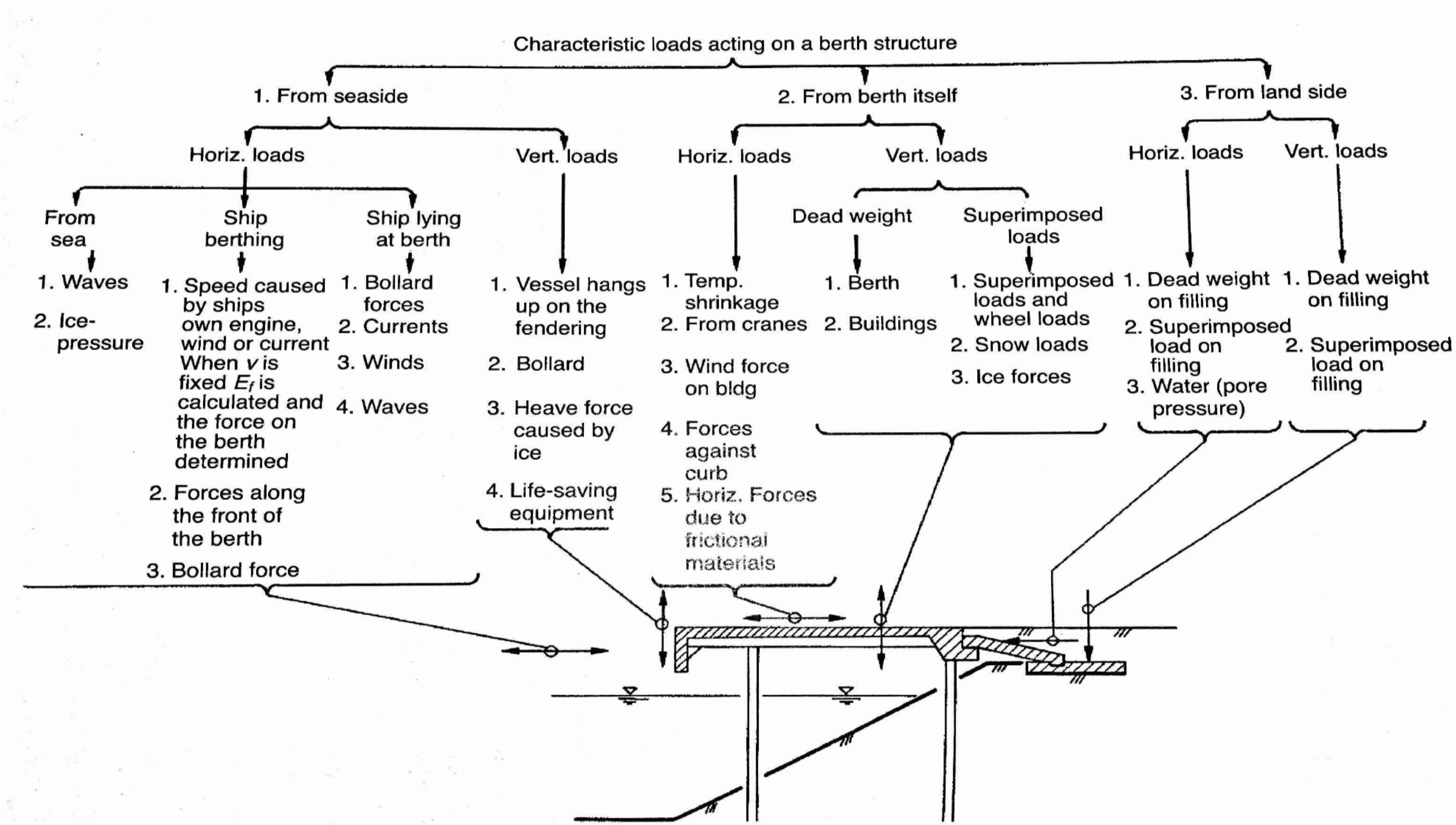
- The limit states are:
  - ULS – related to the risk of large inelastic displacement
  - SLS – related to durability
  - FLS – related to the risk of failure (fatigue) due to the effect of repeated loading.

Quay Design – Loadings

The load that work on the quay wall structure are:

Permanent Loads	Variable Loads	Special Works
• Dead weight structure • Water and earth pressure • Shear force between soil and superstructure	• Earth pressure due to extra vertical loads • Water pressure (ground water flow) • Ship operations • Berthing forces • Mooring forces • Load and unload • Storage • Crane load • Traffic load • Wave load • Temperature variations	• Extreme water levels • Storage in an emergency situation • Falling loads • Earthquake • Extreme excavation

Quay Design – Loadings



Characteristic loads acting on a berth structure

Quay Design – Loadings

- The loads on the apron deck are determined by the type of traffic utilising the berth, not much by the size of the ships.
- For instance;
  - Oil Piers – ships of 100,000 DWT, live loadings of say 10 kN/m^2
  - Offshore Oil Industry – ships 2,000 tons displacement, live loadings between 50~200 kN/m^2
  - Fishing harbours – live load of at least 15 kN/m^2

Quay Design – Loadings

Recommended Live Loads for the Apron and the Terminal AREA

Type of traffic and cargo	Loading in kN/m^2
Light traffic or small cars	5
Heavy traffic or trucks	10
General cargo	20
Palletized general cargo	20–30
Multi-purpose facility	50
Offshore feeder bases	50–200
Heavy vehicles, heavy crane, crawler crane, etc. that operate from the berth front and 3 m inboard	60
Heavy vehicles, heavy crane, crawler crane, etc. that operate from 3 m behind the berth front and further inwards	40–100
Containers	
Empty and stacked 4 high	15
Full and stacked 2 high	35
Full and stacked 4 high	55
General ro/ro loads	30–50

Quay Design – Loadings

- Berths accommodating ocean going dry-cargo ships should be designed for container loads.
- 20-foot containers stacked two high imply a load of 25-35 kN/m^2

Container	Size	Weight (empty)	Weight (max)
20-ft	*6.06x2.44.2.44m*	19~22 kN	28~36 kN
40-ft	*12.12x2.44x2.44m*	240 kN	305 kN

- Aprons & Ramps for Container Traffic, 40 kN/m^2

Quay Design – Loadings

- Berth Structures which have direct road connection to the public highway network, should at least be designed for loads in accordance with the Highway Department's Regulations (BD37/01).
- The loads should be at least 20 kN/m^2

Berthing Requirements

For a ship moored at a berth with a strong current, either parallel or at an angle to the ship, the current may create long periodic ship movements. These periodic movements will depend on the stiffness of the fender and the mooring system, the inertia of the ship around the centre of gravity of the virtual mass of the ship, the moment of the respective forces around the centre of gravity and the current velocity.

Berthing Requirements

Mooring System

- The term 'mooring' refers to the system for safely securing the ship to the berth structure.
- The mooring of the ship must resist the forces due to the most severe combination of wind, current, waves, tides and surges from the passing vessels.

Berthing Requirements

Bollards

- Bollards should be provided at intervals of approximately 5~30m depending on the size of the ship along the berthing face.
- Bollard loads are assumed to act in any direction within 180º around the bollard at the seaside, and from horizontally to 60º upwards.

Solid Berth Structure

The fill is extended right out to the berth front where a vertical front wall is constructed to resist the horizontal load from the fill and a possible live load on the apron. The solid berth structures can be divided into two main groups, depending on the principle on which the front wall of the structure is constructed in order to obtain sufficient stability:

- Gravity Wall Structure
- Sheet Pile Wall Structure

Gravity Wall Structure

Gravity Wall Structure

The front wall of the structure with its own deadweight and bottom friction will be able or self sufficient to resist the loadings from backfill, useful load and other horizontal and vertical loads acting on the berth wall structure itself.

The gravity berth wall structure may be used where the seabed is good and the risk for settlement is low. Three groups namely block wall berths, caisson berth and cell berths.

Gravity Wall Structure

Block Wall Berths

- Oldest type of Berth structure
- Consist of large blocks placed one upon the other in a masonry wall pattern
- To be built on firm ground with blocks of costly natural stone (150~500kN) or concrete (150~2000kN).
- Construction work; under water by divers – costly

Gravity Wall Structure

Caisson Berths

- Precast concrete caissons placed in a row of berth
- Caissons made ashore and then launched, towed out and sunk in position on a prepared gravel or rubble base (underwater work is minimum)
- Dimensions (for economic reasons); shall be lesser than 30m long, 25m wide and 20m high.

Gravity Wall Structure

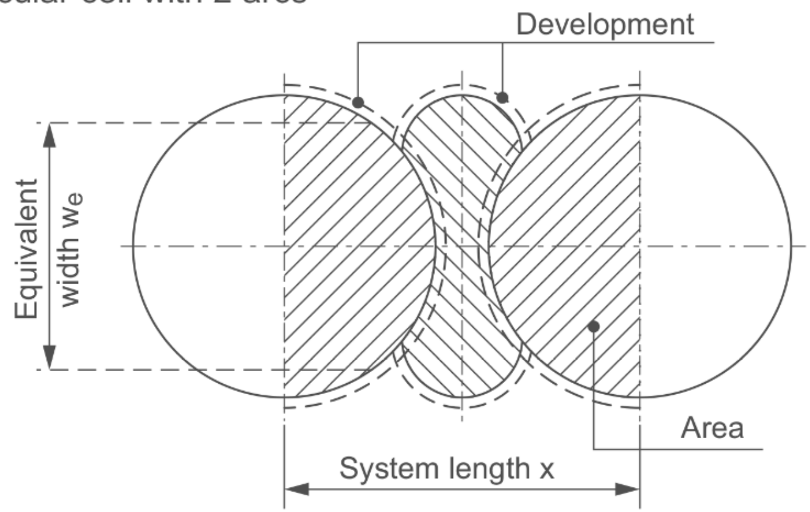
Cell Berths

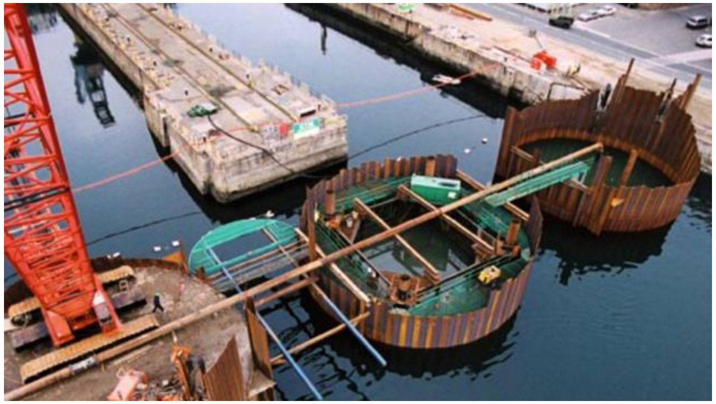
- Most used types of gravity wall berth (ratio of the cost of labor to the cost of material, compared to block wall and caissons berths).
- Circular main cells connected with arched cells are the most used form of construction – each cell can be individually constructed and filled.
- The diameter of main cells, 10~20m.
- The circular and arched cells are formed by flat steel sheet piles of width 40~50cm, web thickness 9~12.7mm

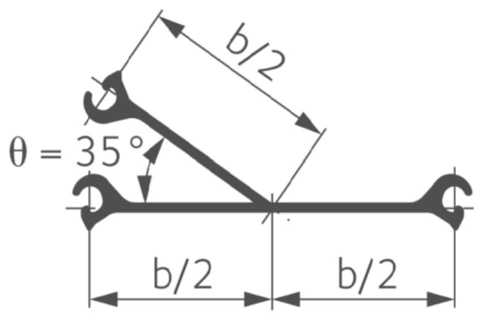
Gravity Wall Structure

Circular cells

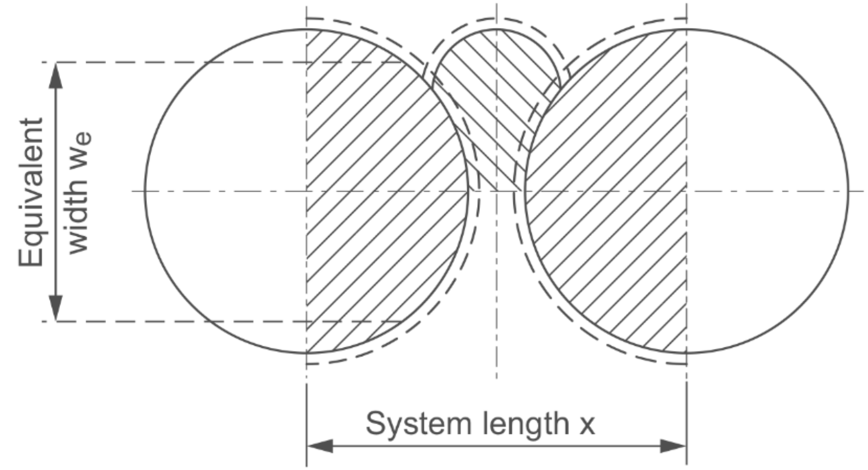
Circular cell with 2 arcs







Circular cell with 1 arc

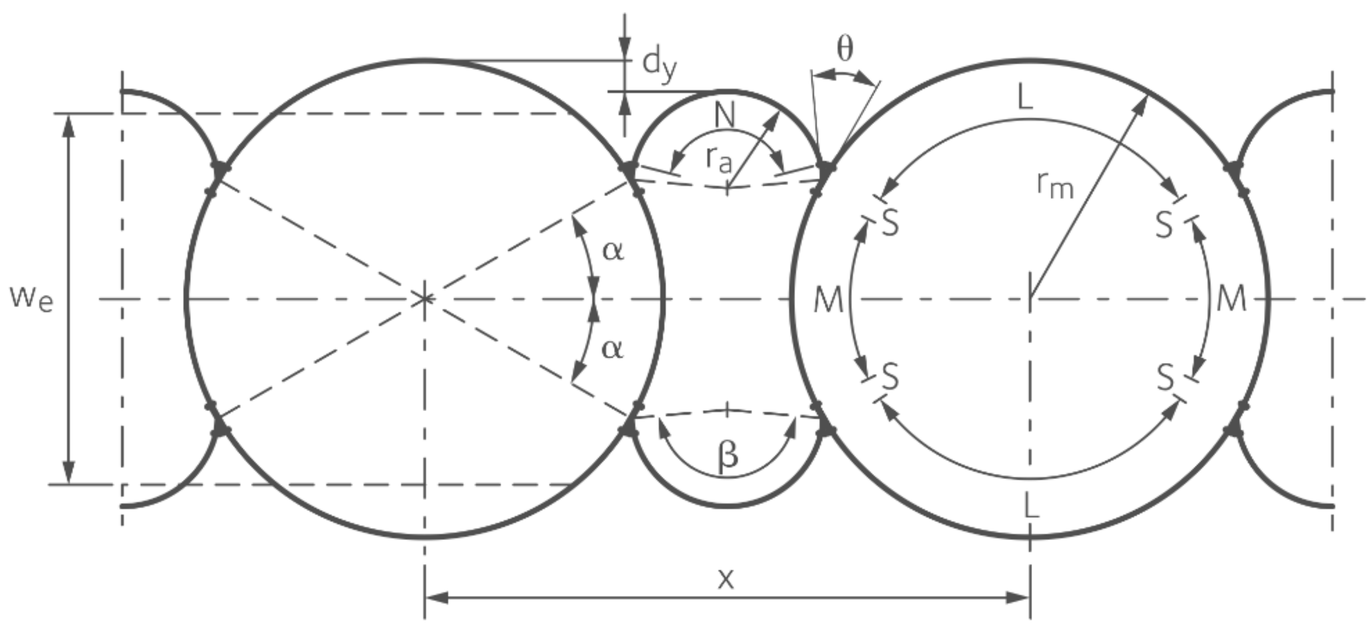


Gravity Wall Structure

Circular cells with 2 arcs:

1 System = 2 half cells + 2 arcs

Number of piles for 1 System = 2 · number of piles for $\frac{1}{2}$ cell + 2 · number of piles for 1 arc + 4 junction piles
= 2 (L + M) + 2 · N + 4 · S

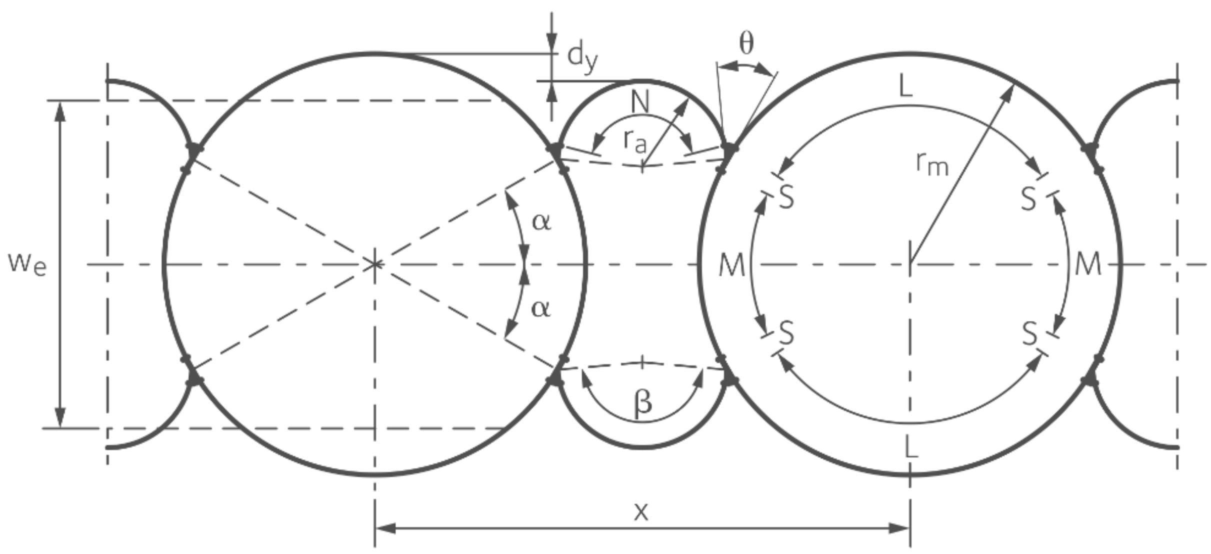


Gravity Wall Structure

Circular Cells with Arch(s)

The **Equivalent Width w_e** which is required for stability verification, is determined by the geometry chosen for the cellular construction. It is calculated with:

$$w_e = \frac{\text{Area within 1 cell + Area within 1 (or 2) arc(s)}}{\text{System length x}}$$



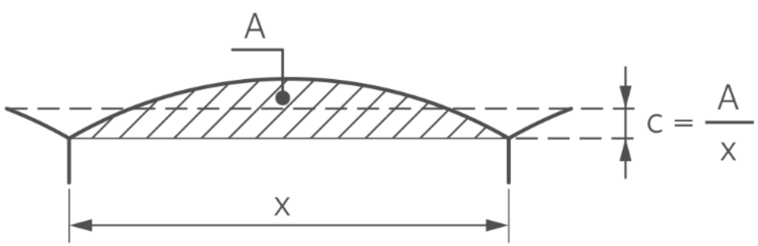
Gravity Wall Structure

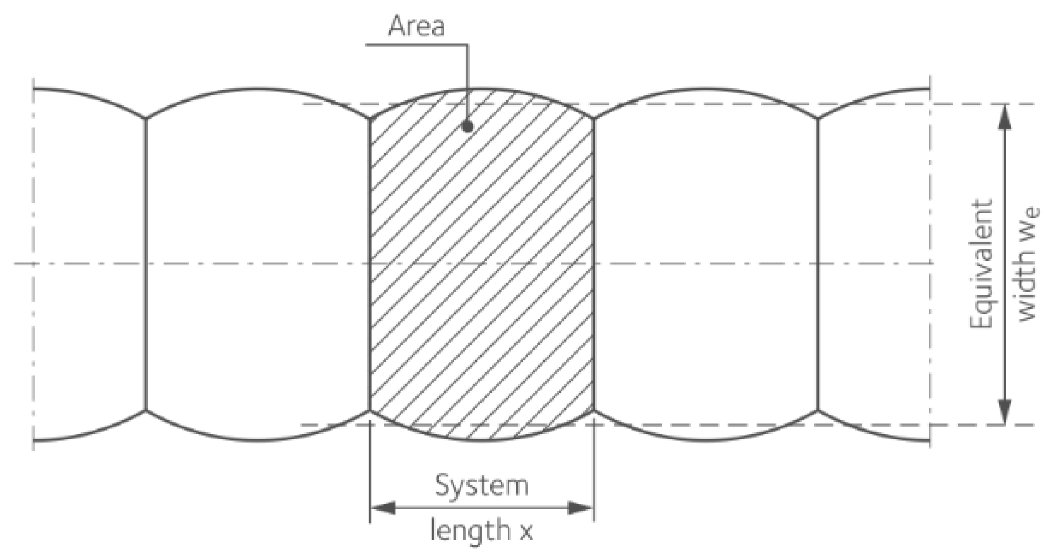
Diaphragm cells

The **Equivalent Width w_e** for a diaphragm cell is defined as:

$$w_e = \frac{\text{Area within 1 diaphragm}}{\text{System length x}} = \text{diaphragm length (dl)} + 2 \cdot c$$

$$\text{with } c = \frac{\text{Area of arc segment}}{\text{System length x}}$$



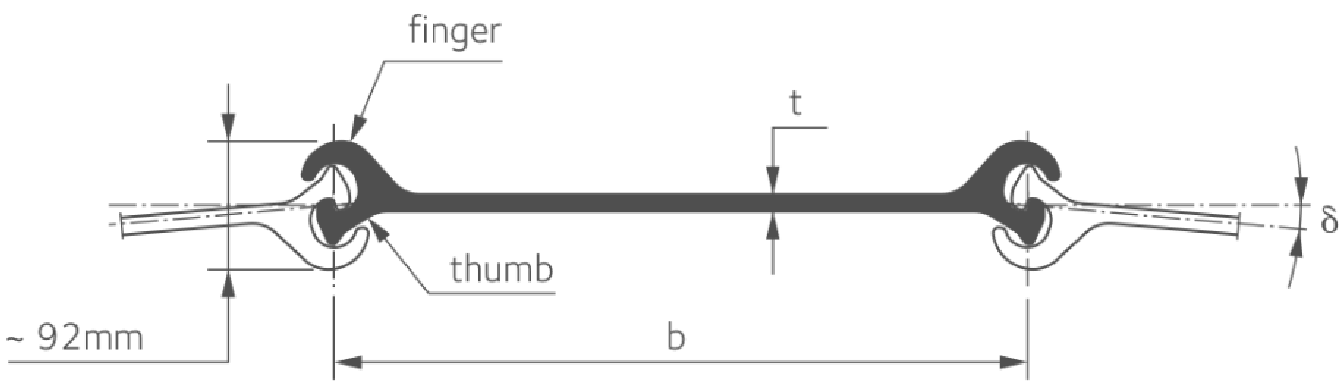


Gravity Wall Structure

Diaphragm cells:

1 System = 1 diaphragm + 2 arcs

Number of piles for 1 System = 1 · number of piles for 1 diaphragm + 2 · number of piles for 1 arc + 2 junction piles.
= N + 2 · M + 2



Sheet Pile Wall Structure

The front wall is not adequate to resist any horizontal loads acting on the structure and must be anchored to an anchoring plate, wall or rock behind the berth.

Sheet pile wall is not suitable where the bedrock is found. Thus, to fix the sheet pile to the rock by dowels or to provide an anchored concrete beam on the rock to prevent sliding of the piles from the horizontal forces.

Sheet Pile Wall Structure

Sheet Pile Wall Structure

Cantilever Wall

(Suitable for heights, up to max of 4.5m)

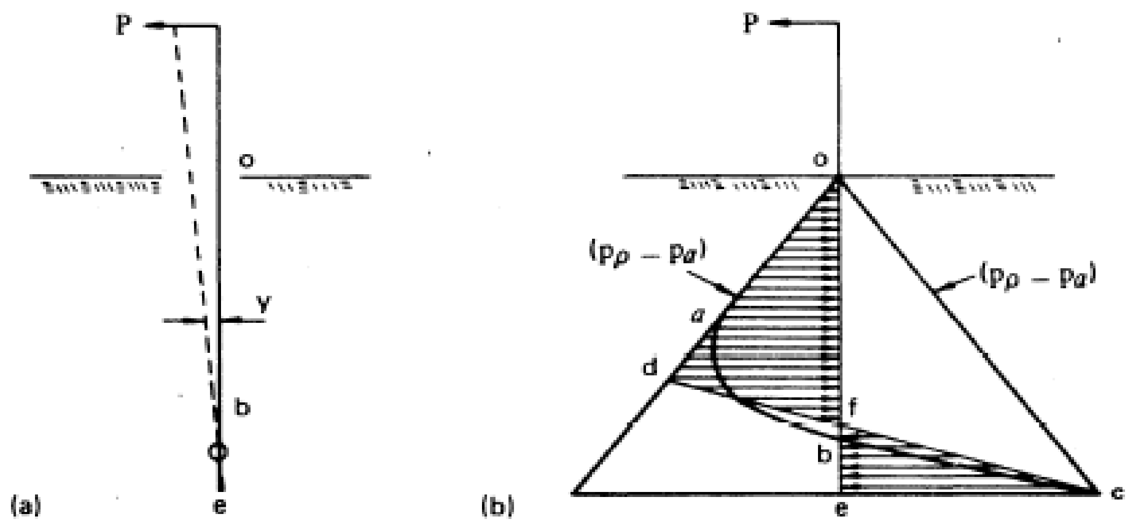
- Cantilevered wall, sheet piling is driven to a sufficient depth into the ground to become fixed as a vertical cantilever in resisting the P_a.
- Large lateral deflections, readily affected by scour and erosion in front of the wall.
- Lateral support for the cantilevered wall comes from passive pressure exerted on the embedded portion, penetration depths can be quite high, resulting is excessive stresses and severe yield. Therefore, cantilevered walls using steel sheetpiling are restricted to a max. height of approx 4.5m

Sheet Pile Wall Structure

Cantilever Wall

When the lateral active pressure (P) is applied to the top of the wall, the piling rotates about the pivot point, b, mobilizing passive pressure above and below the pivot point.

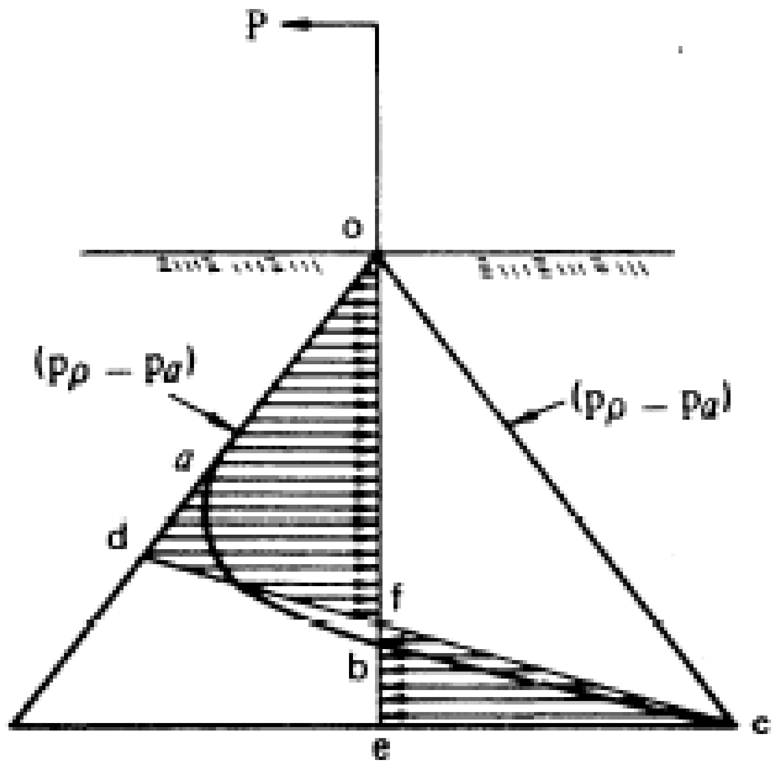
The term $(p_p - p_a)$ is the net passive pressure, P_p, minus the active pressure, P_a.



Sheet Pile Wall Structure

Cantilever Wall

- At point b the piling does not move and would be subjected to equal and opposite at-rest earth pressures with a net pressure equal to zero.
- The resulting earth pressure is represented by the diagram 'oabc'.
- For the purpose of design, the curve 'abc' is replaced by a straight line 'dc'.
- The point d is located so as to make the sheet piling in a state of static equilibrium.

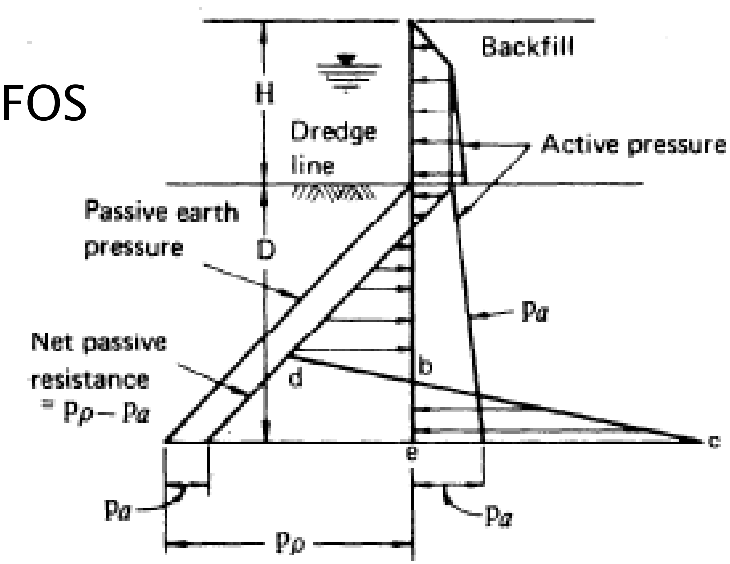


Sheet Pile Wall Structure

Cantilever Sheet Piling

Standard Penetration Resistance, *N* Blows/Foot	Relative Density of Soil, D_d	Depth of Penetration*
0-4	Very loose	2.0 H
5-10	Loose	1.5 H
11-30	Medium dense	1.25 H
31-50	Dense	1.0 H
+50	Very dense	0.75 H

* Preliminary depth, add 20 ~ 40% for FOS



Sheet Pile Wall Structure

Anchored Bulkheads

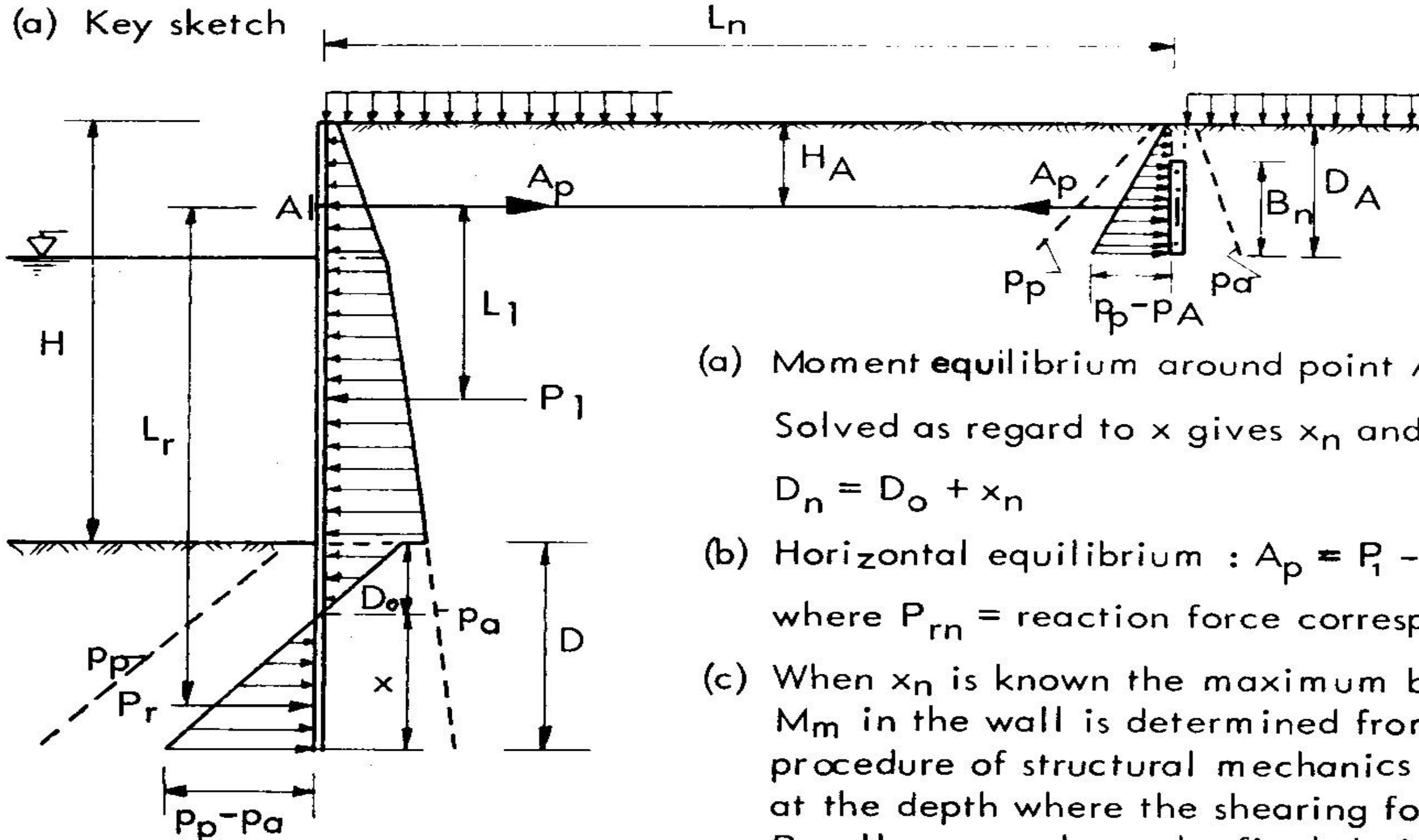
(Suitable for heights, >10.0m)

Basis for Design

- Necessary depth of embedment, D_n – to achieve a sufficient safety against failure and pressing-out of the embedded part of the bulkhead.
- Max. anchor pull, A_p – necessary for designing the anchorage.
- Max. bending moment, M_m – necessary for determining the cross-sectional area of sheet piling

Sheet Pile Wall Structure

(a) Key sketch



(a) Moment equilibrium around point A : $P_1 L_1 = P_r L_r$

Solved as regard to x gives x_n and hence

$D_n = D_o + x_n$

(b) Horizontal equilibrium : $A_p = P_1 - P_{rn}$

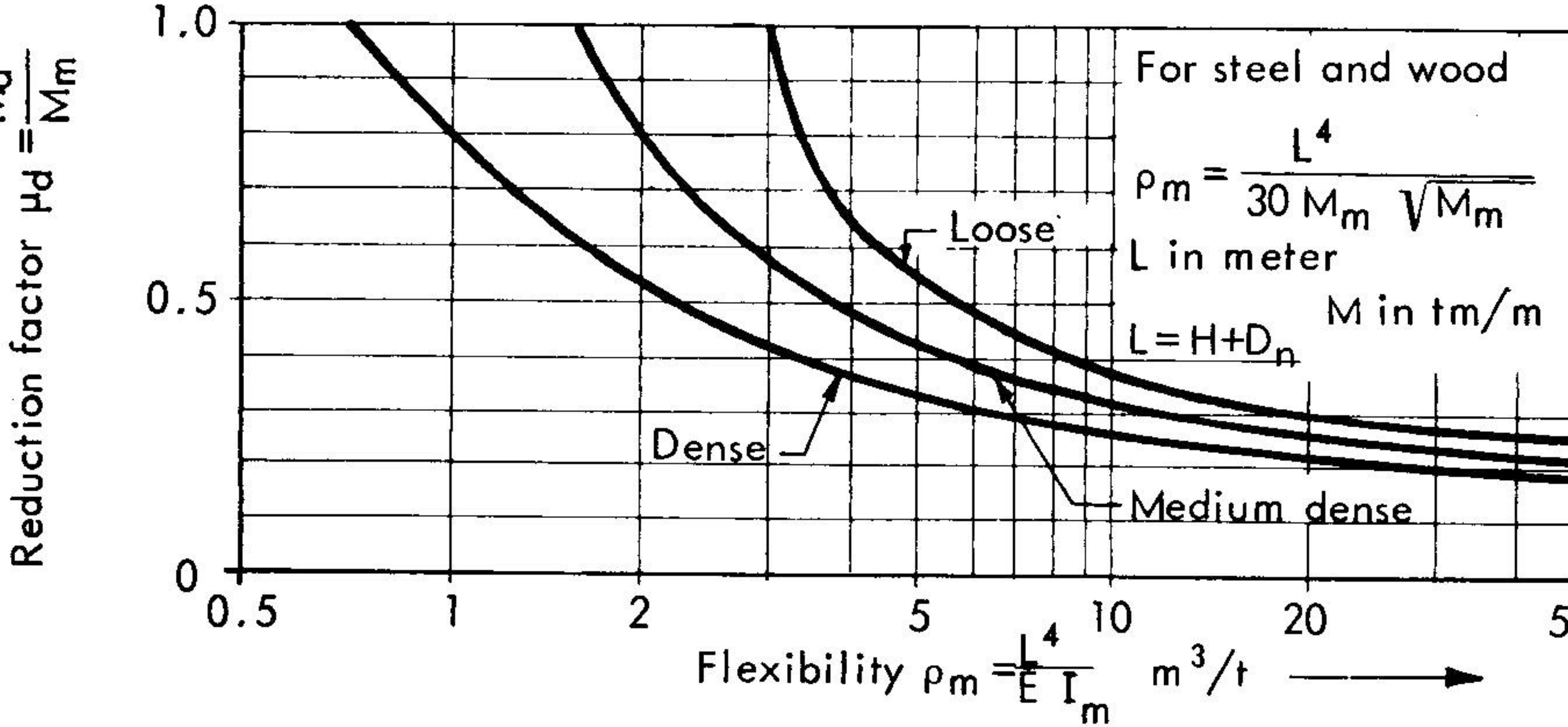
where P_{rn} = reaction force corresponding to x_n.

(c) When x_n is known the maximum bending moment M_m in the wall is determined from the customary procedure of structural mechanics (M_m is acting at the depth where the shearing force equals zero). By all $c\varphi$ - analyses the final design moment M_d is calculated from the formula :

$M_d = \mu_d M_m$ where μ_d is taken from the diagram below.

Sheet Pile Wall Structure

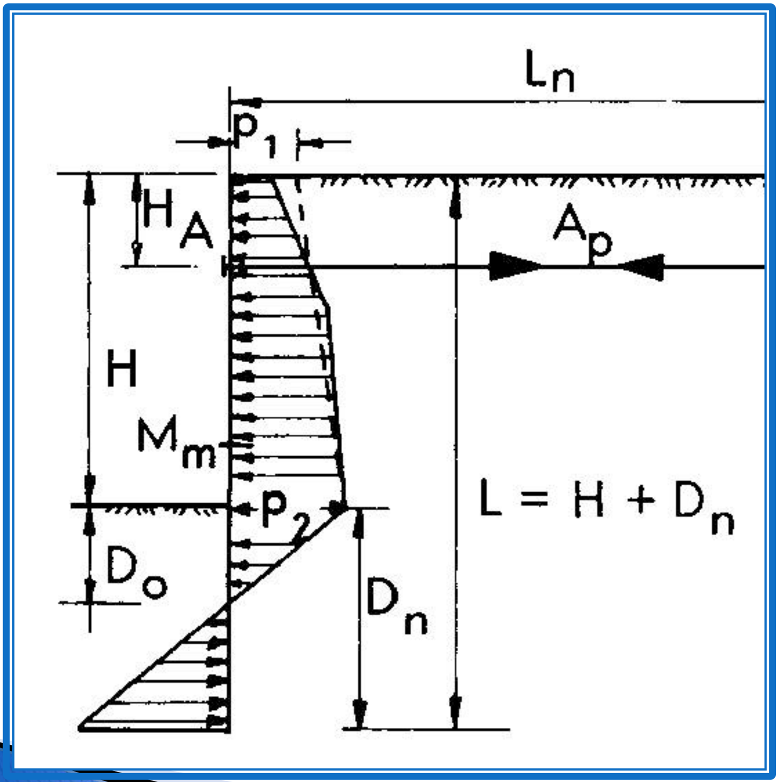
Bending Moment Reduction, M_d

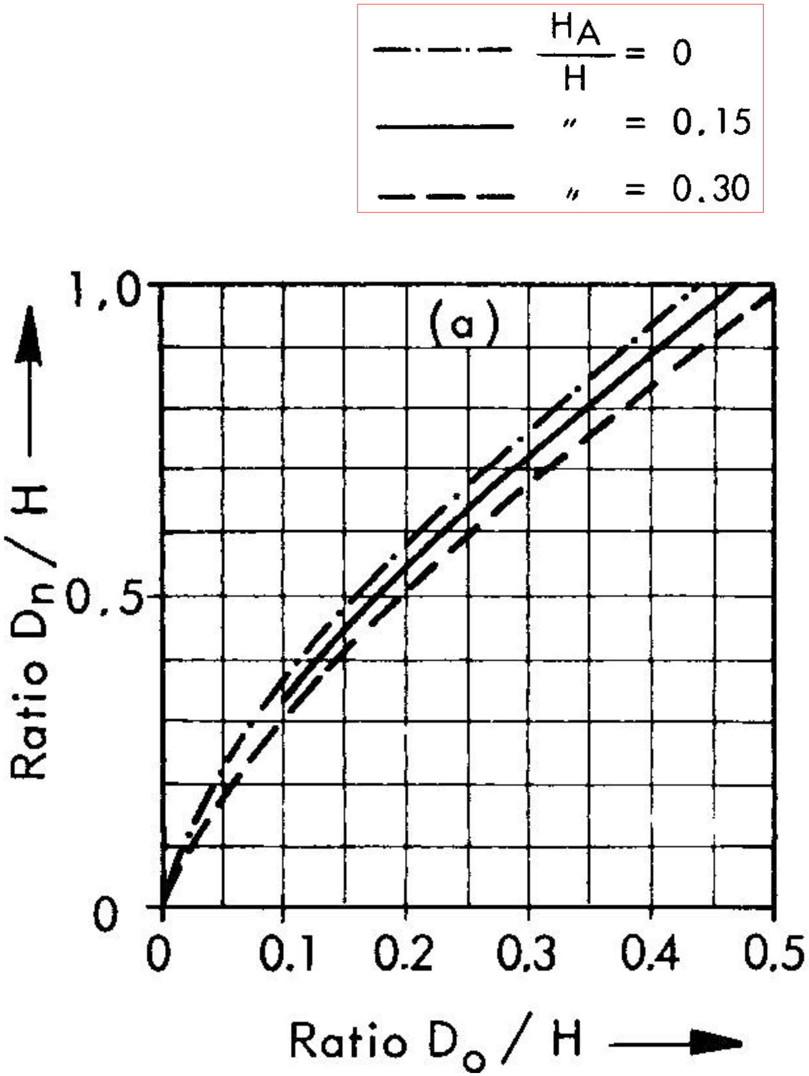


Sheet Pile Wall Structure

Anchorage

Depth of embedment





Sheet Pile Wall Structure

Anchorage

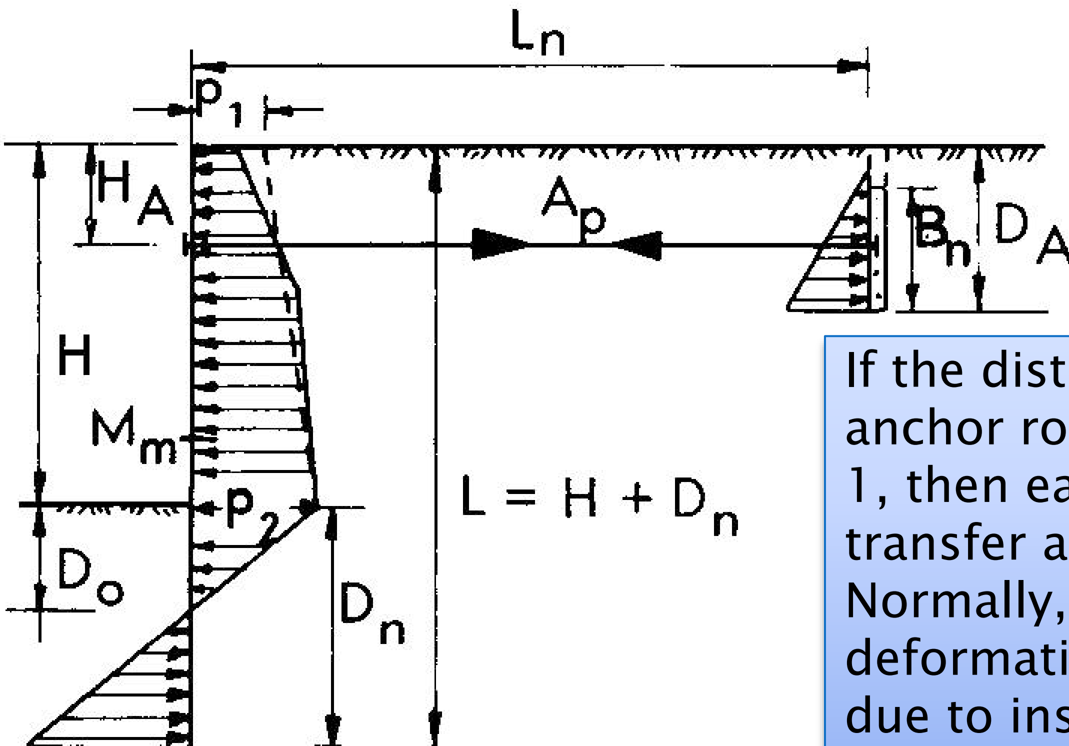
Once the depth of embedment is known, the anchor pull, A_p can be determined from the condition that the sum of the horizontal forces is equal to zero:

$$A_p = P_1 - P_{rn}$$

P_{rn} = reaction force corresponding to the calculated x_n

Sheet Pile Wall Structure

Anchorage



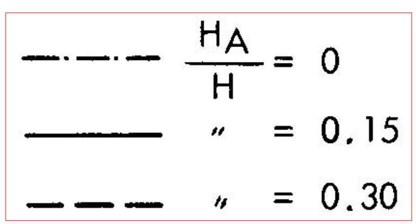
If the distance between the anchor rods is designed by 1, then each rod has to transfer a force of 1 A_p. Normally, failure or large deformations are mainly due to insufficient anchorages.

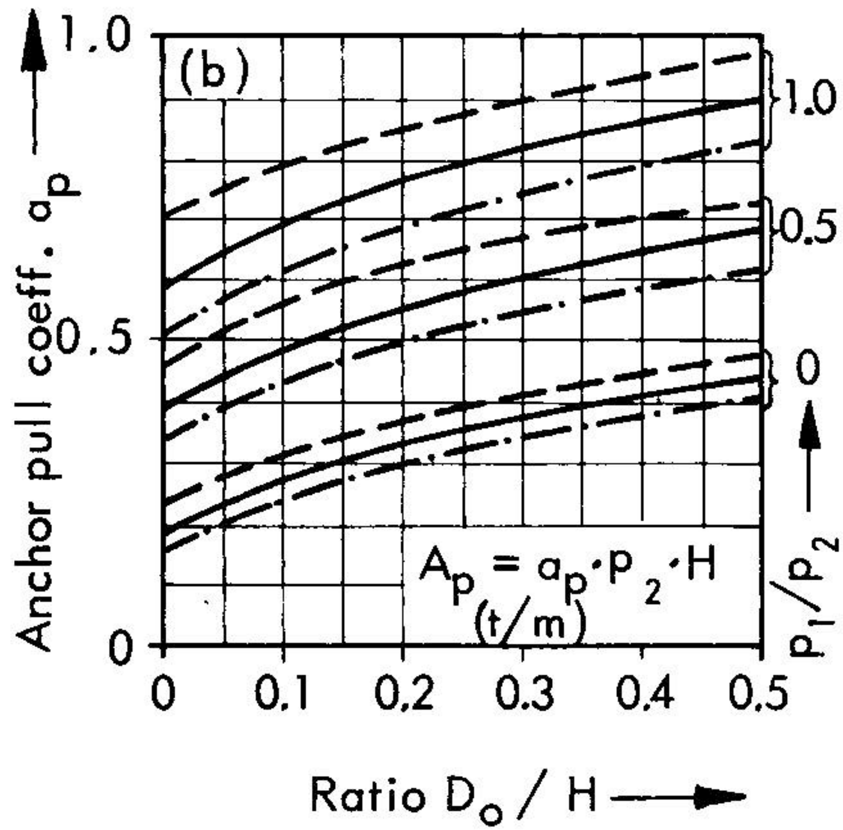
Sheet Pile Wall Structure

Anchorage

For homogenous soil, c = 0, A_p can be determined directly from the formula,

$$A_p = a_p \, p_2 \, H$$





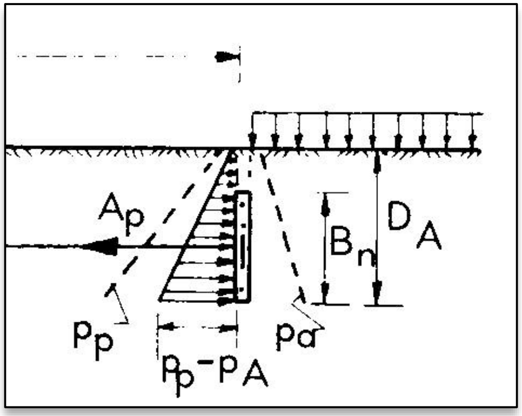
Sheet Pile Wall Structure

Anchorage

The dimensions of the anchor walls or slabs ("deadmen") are governed by the anchor pull which they have to resist.

The depth, D_A is determined from the condition that the area of the resulting earth pressure diagram (p_p – p_A) should be equal to the anchor pull.

Note : Allowable to use full height of the resulting pressure diagram when $B_n \geq 2/3\ D_A$



Sheet Pile Wall Structure

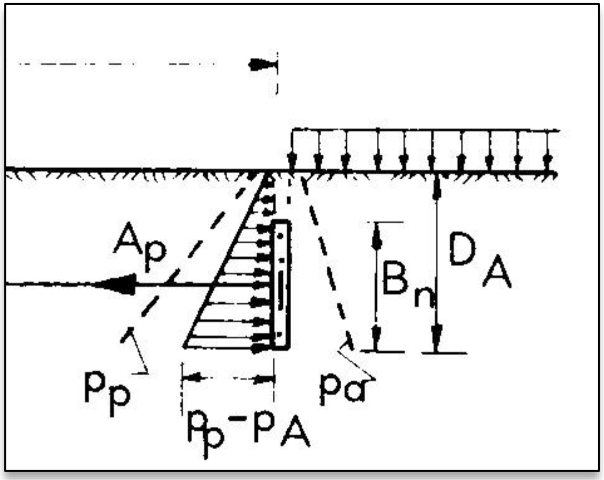
Anchorage

When the anchor rods are horizontal, the max roughness ratio for the anchor wall is given by:

$$r \leqslant \left(W_A / A_p\right)\left(F / tg\phi\right)$$

WA = weight of anchor wall and the overlying soil

F = factor of safety

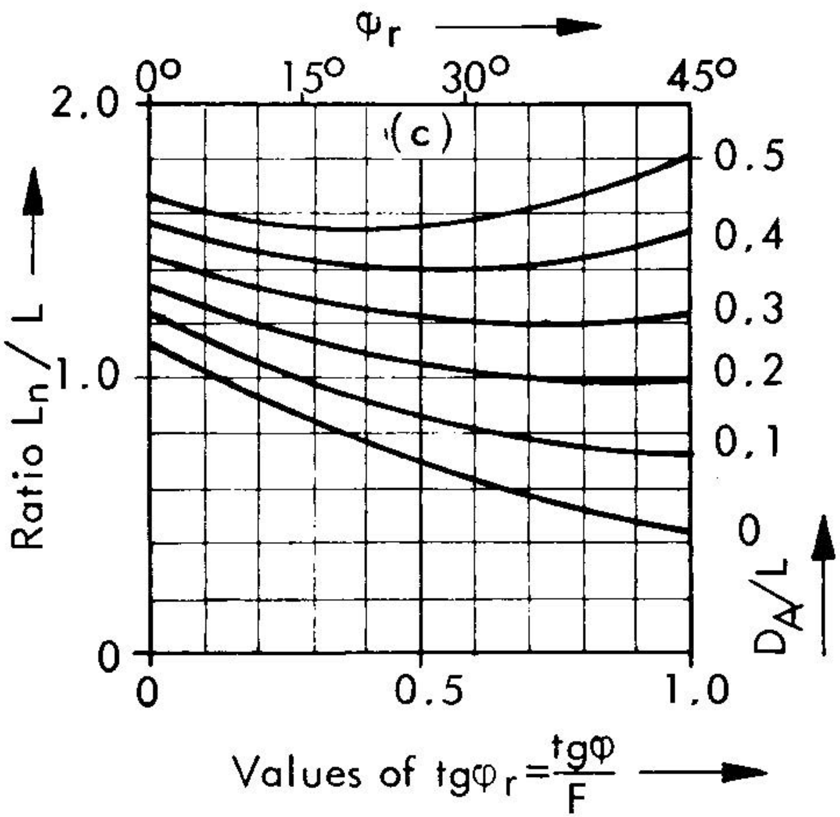


Sheet Pile Wall Structure

Anchorage

The Length (L_n) of the anchor rods can be calculated as below:

**for uniform soil and for*
r = 0.3 to 0.7

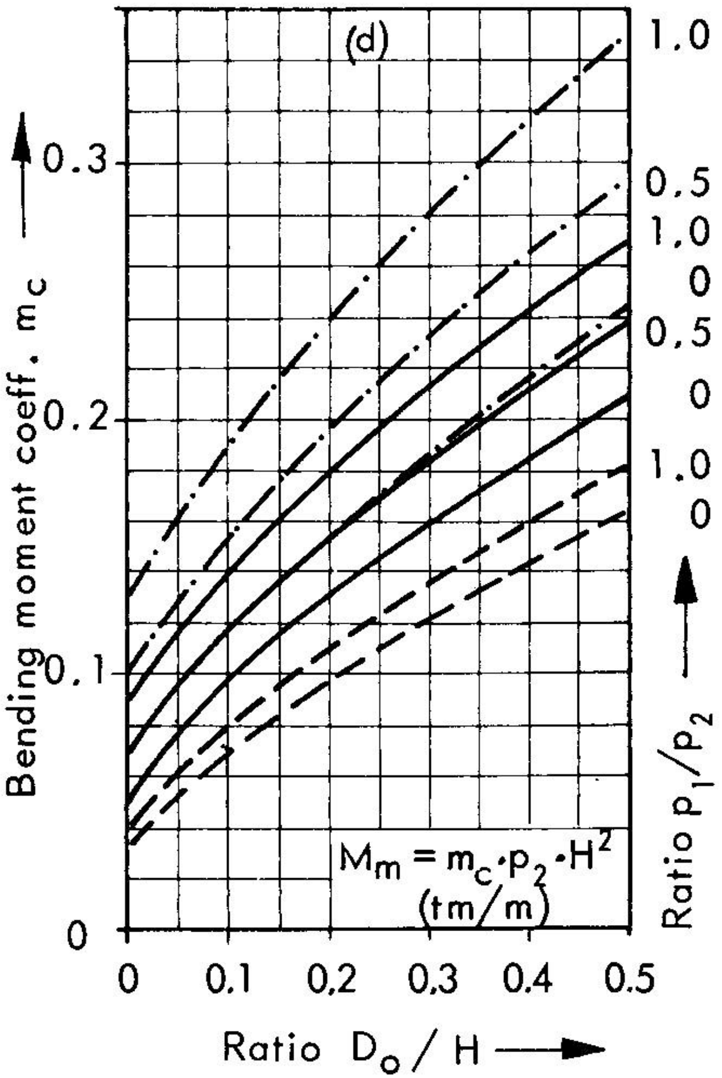


Sheet Pile Wall Structure

Design of the Sheet Pile

Calculate the max bending moment, M_m. Consider the sheet pile as a beam acted upon by the active and passive earth pressures and the anchor pull.

$$M_m = m_c p_2 H^2$$



Sheet Pile Wall Structure

Design of the Sheet Pile

Bending moment decreases with increasing of flexibility of the sheet pile, ρ

$$\rho = L^4 / EI$$

E = *modulus of elasticity of the sheet pile material*
I = *moment of inertia (per unit length of sheet pile)*
$L = H + D_n$

Sheet Pile Wall Structure

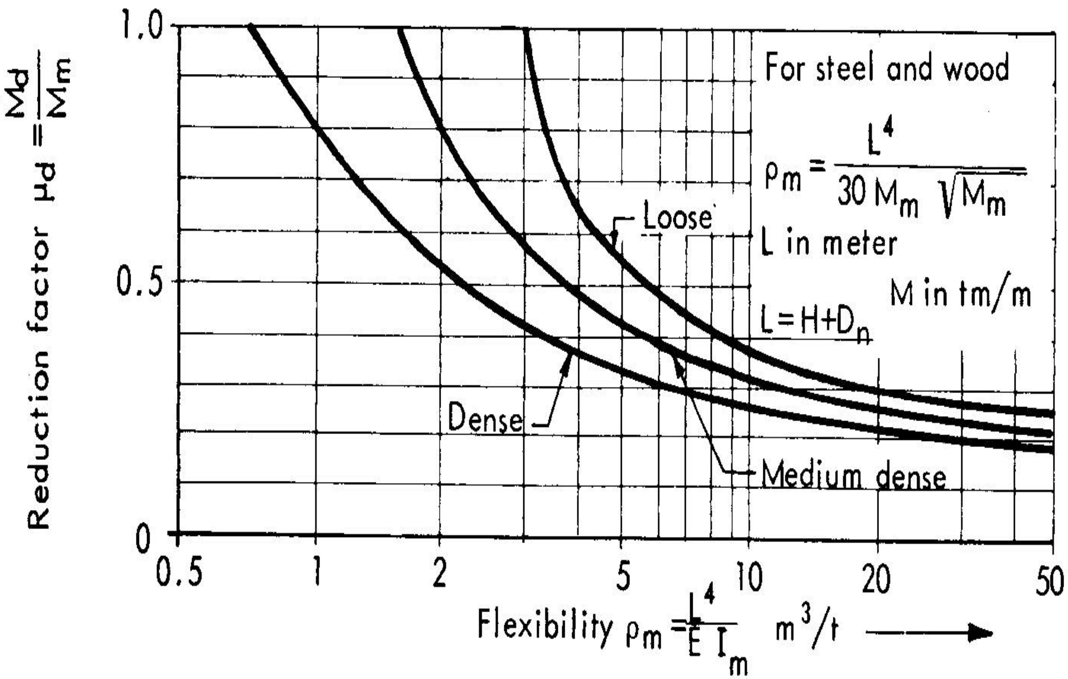
Design of the Sheet Pile

Final design moment, $M_d = \mu_d . M_m$

Where reduction factor, μ_d depends on the flexibility of the sheet pile

$$\rho_m = L^4 / n M_m \sqrt{M_m}$$

L = sheet pile length in m
n = material coeff
(n = 30, steel & wooden sheet pile and n = 120 for concrete sheet pile)



Sheet Pile Wall Structure

Design of the Sheet Pile

Section modulus of the sheet pile, $W \geqslant M_d / \sigma_a$

σ_a = allowable stress in the sheet pile material. It can be chosen as high as 2/3 of the yield stress.

Where the interlocks are located in the neutral axis, the effective section modulus is smaller than the value corresponding to rough interlocking but greater than the value corresponding to smooth interlocking. Thus, σ_a is taken as ½ of the yield stress.

Sheet Pile Wall Structure

Design of the Sheet Pile – Example

- For bulkheads with free water on the front side, the calculation must be based upon the stage where the water level is at its lowest (LWL).
- If in this stage there is a difference (tidal lag), H_u, between groundwater level (GWL) inside the wall and the outer water level (LWL), the unbalanced water pressure must be added to the effective earth pressure in the active zone.

Sheet Pile Wall Structure

Design of the Sheet Pile – Example

- Due to seepage caused by tidal lag, Hu, the seepage force will increase the unit weight of the soil in the active zone and reduce it in the passive zone.

- The change in unit weight is just equal to to the seepage force $= i\,\gamma_w$

  $i =$ hydraulic gradient, can be determined from a flow net.

  $\gamma_w =$ unit weight of water

Sheet Pile Wall Structure

Design of the Sheet Pile – Example

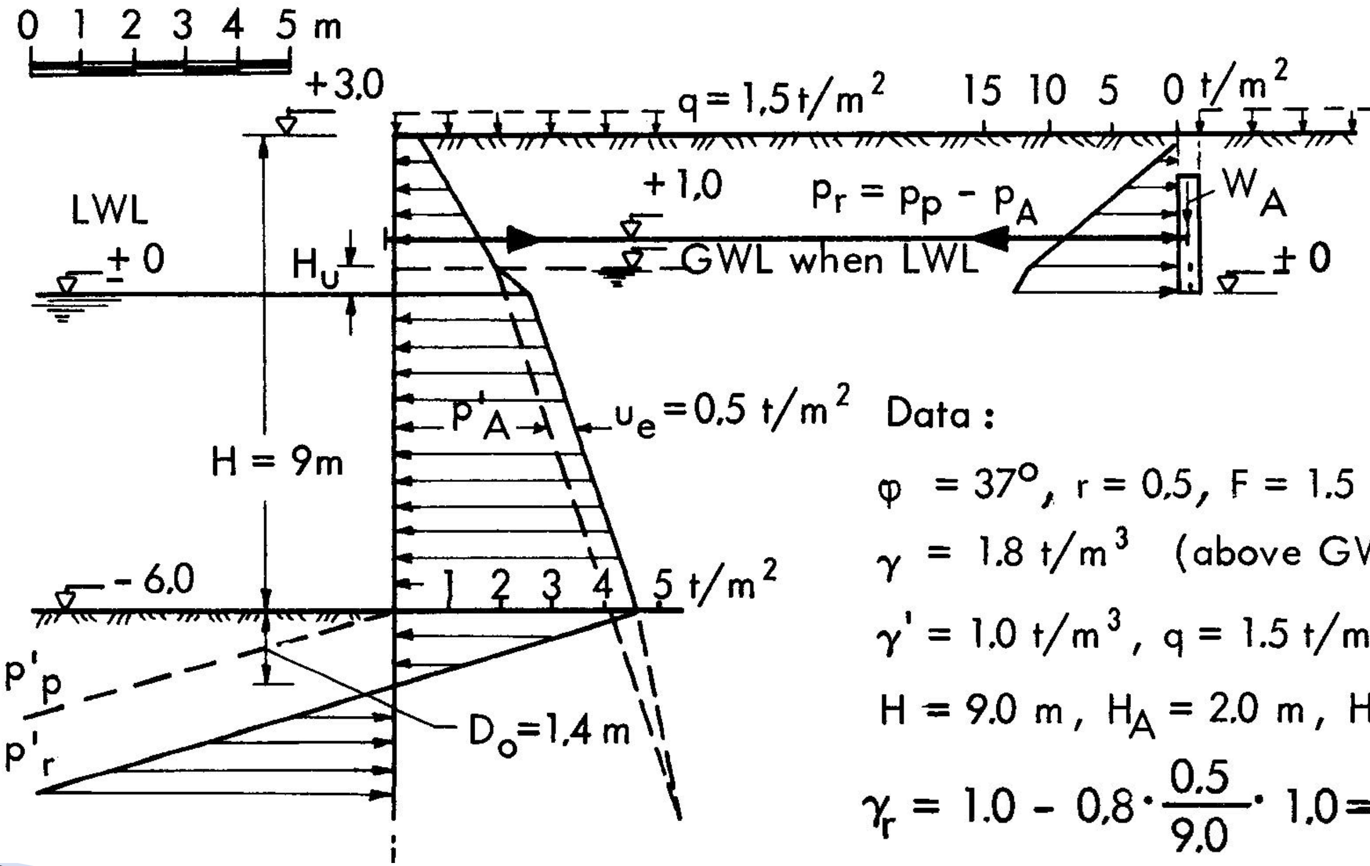
- The influence of the seepage force can be taken into account by using a reduced unit weight in the passive zone,

$$\gamma_r = \gamma' - 0.8(H_u/H)\,\gamma_w$$

γ' = the buoyant unit weight of the soil

Sheet Pile Wall Structure

Design of the Sheet Pile - Example



Data :

$\varphi = 37^{o}$, $r = 0{,}5$, $F = 1.5$

$\gamma = 1.8\ t/m^3$ (above GWL)

$\gamma' = 1.0\ t/m^3$, $q = 1.5\ t/m^2$

$H = 9.0\ m$, $H_A = 2.0\ m$, $H_u = 0.5\ m$

$$\gamma_r = 1.0 - 0{,}8 \cdot \frac{0.5}{9.0} \cdot 1.0 = 0.96\ t/m^3$$

u_e = unbalanced water pressure

Sheet Pile Wall Structure

Design of the Sheet Pile – Example

For sheet pile wall

Earth pressure calculations for sheet pile wall (pressure in t/m²)							
Active zone				Passive Zone		Resulting pressure	Remarks
Elevation	p'_v	p'_A	u_e	p'_v	p'_p	$p'_A + u_e - p'_p$	
+ 3.0	1.5	0.50					$tg\phi/F = 0.75/1.5 = 0.5$
+ 0.5	6.0	1.98	0				when r = 0.5, then
± 0.0	6.5	2.14	0.5				$K_A = 0.33$. $K_p = 3.7$
– 6.0	12.5	4.12	0.5	0	0	+ 4.62	
– 9.0	15.5	5.11	≈0	2.88	10.65	– 5.54	

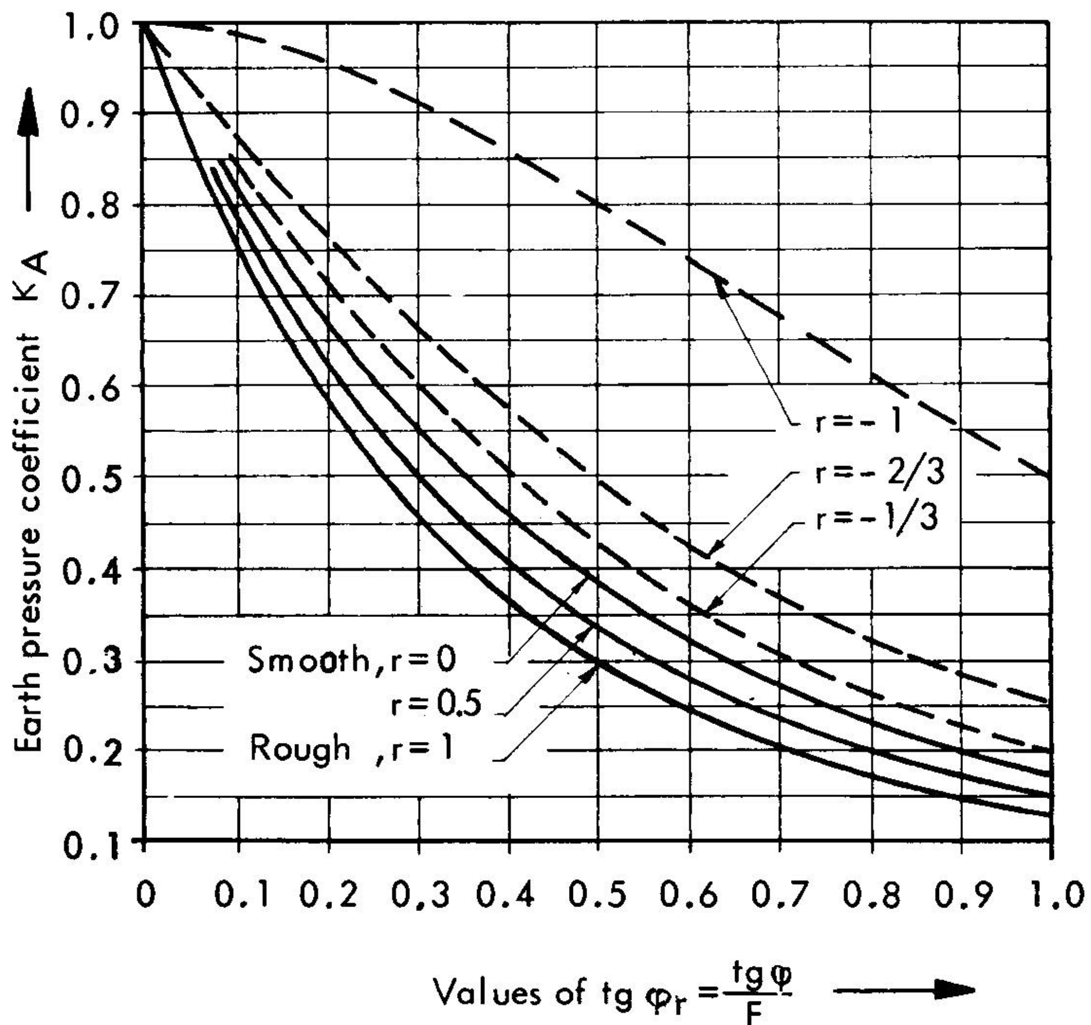
Check values of K_A and K_P

Sheet Pile Wall Structure

Design of the Sheet Pile – Example

For sheet pile wall,

Value of K_A

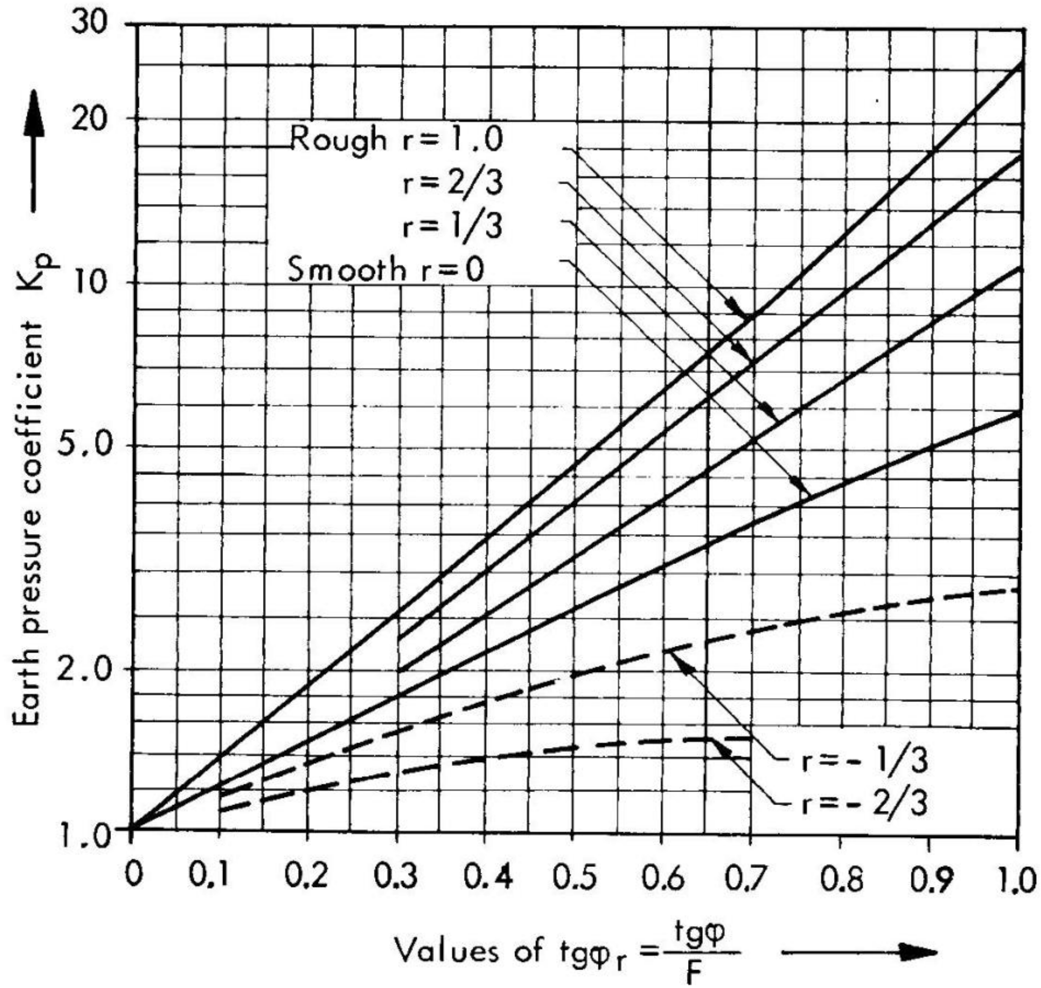


Sheet Pile Wall Structure

Design of the Sheet Pile – Example

For sheet pile wall,

Value of K_P



Sheet Pile Wall Structure

Design of the Sheet Pile – Example

For sheet pile wall

Estimated W_A = 2.0 t/m. Roughness ratio for anchor wall

$$r \leqslant \left(W_A / A_p\right)\left(F / tg\phi\right)$$

Thus,

$$r \leqq \frac{2.0 \cdot 1.5}{17.6 \cdot 0.75} = 0.23 \text{ chosen } r = 0.2$$

Sheet Pile Wall Structure

Design of the Sheet Pile – Example

For Anchor Wall

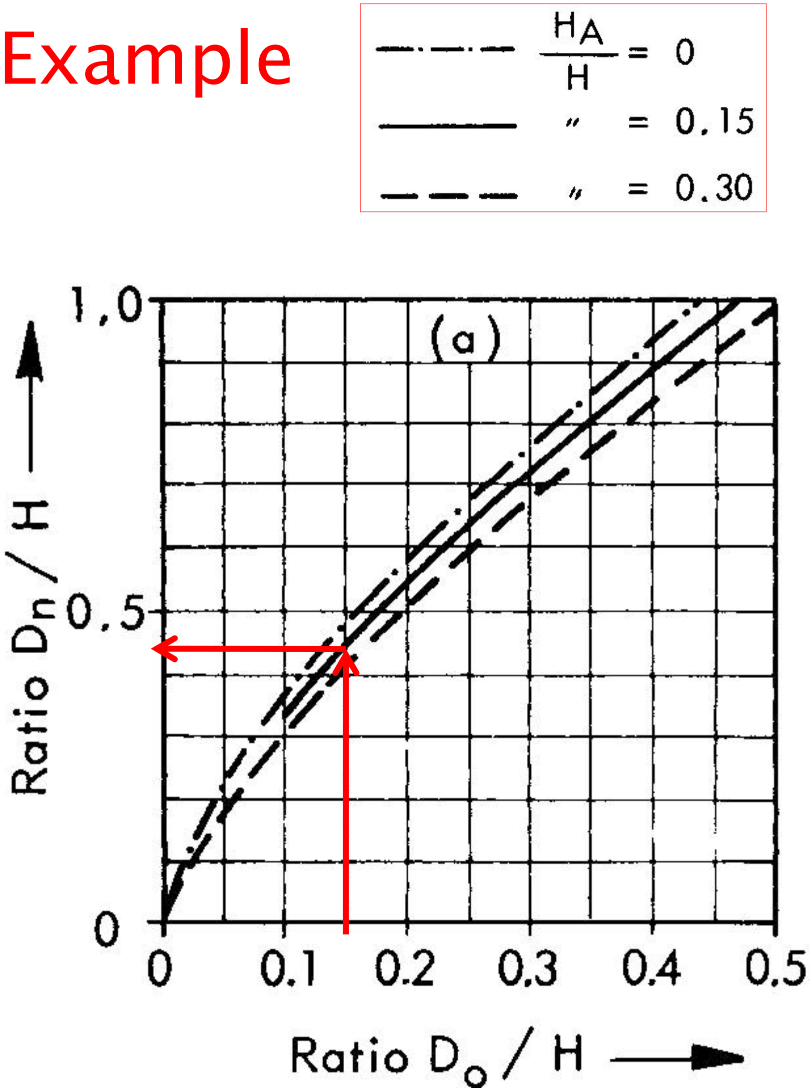
Earth pressure calculations for anchor wall (pressure in t/m^2)						
Active			Passive		Resulting pressure	Remarks
Elevation	p'_v	p'_A	p'_v	p'_p	$p'_p - p'_A$	
+ 3.0 + 0.5 – 0.5	1.5 6.0 7.0	0.60 2.15 2.50	0 4.5 5.5	0 13.95 17.05	– 0.60 11.80 14.55	When $tg\phi/F = 0.5$ and $r = 0.2$ then $K_a = 0.36$. $K_p = 3.1$

Check values of K_A and K_P

Sheet Pile Wall Structure

Design of the Sheet Pile – Example

Depth of Embedment



$D_o/H = 0.155$
$H_A/H = 0.22$

The necessary depth of embedment,

$D_n/H \sim 0.44$

$D_n \approx 4.0\text{m}$

Thus, L = 13.0m

Sheet Pile Wall Structure

Design of the Sheet Pile – Example

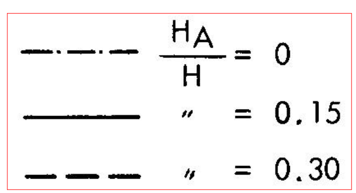
<u>The Anchorage</u>

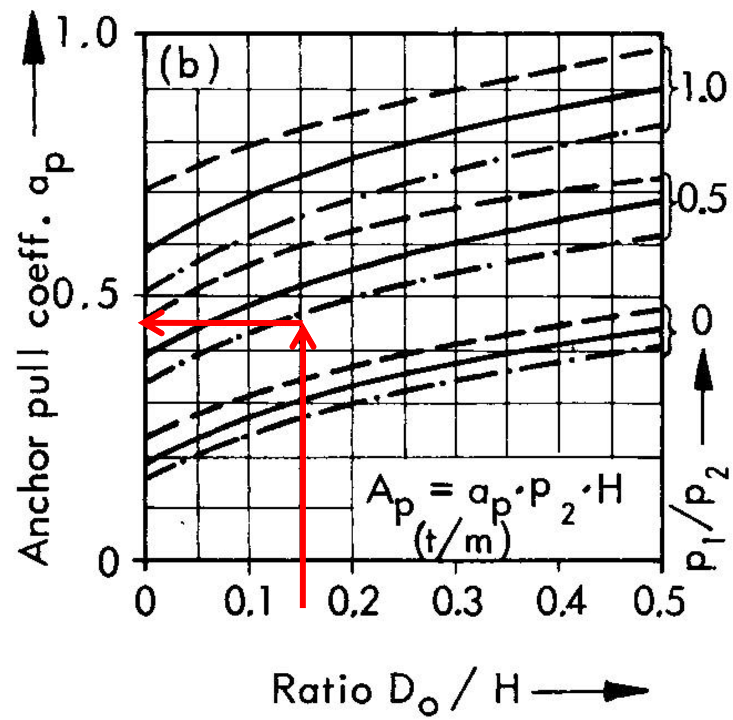
The anchor pull: $A_p = P_1 - P_{rn} = 29.1 - 11.5$
$= 17.6$ t/m

Alternatively,

$A_p = 0.43 \times 4.62 \times 9$
$= 17.8$ t/m

$P_1/P_2 \approx 0.26$





Sheet Pile Wall Structure

Design of the Sheet Pile
– Example

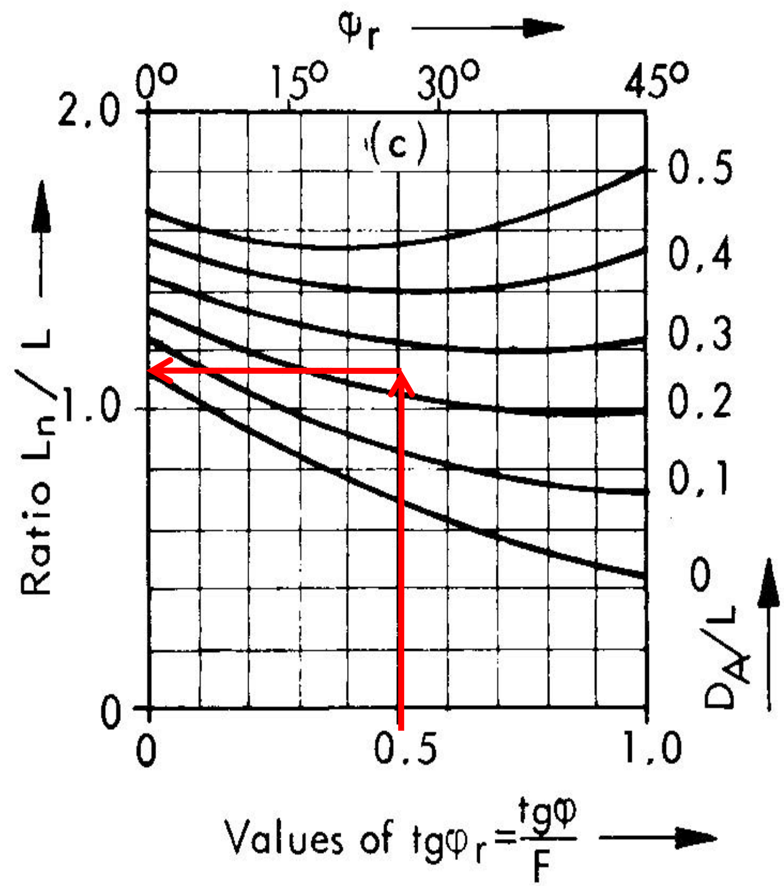
<u>The Anchorage</u>

Necessary rod cross section

= 17600/1400
= 12.6 cm²/m

D_A = 3.0m if the resulting force shall equalize A_p (full height of pressure diagram).

D_A/L = 0.23 and $tg\phi/F$ =0.5, the necessary length of anchor rod, L_n = 1.1 L = 14.3m



Sheet Pile Wall Structure

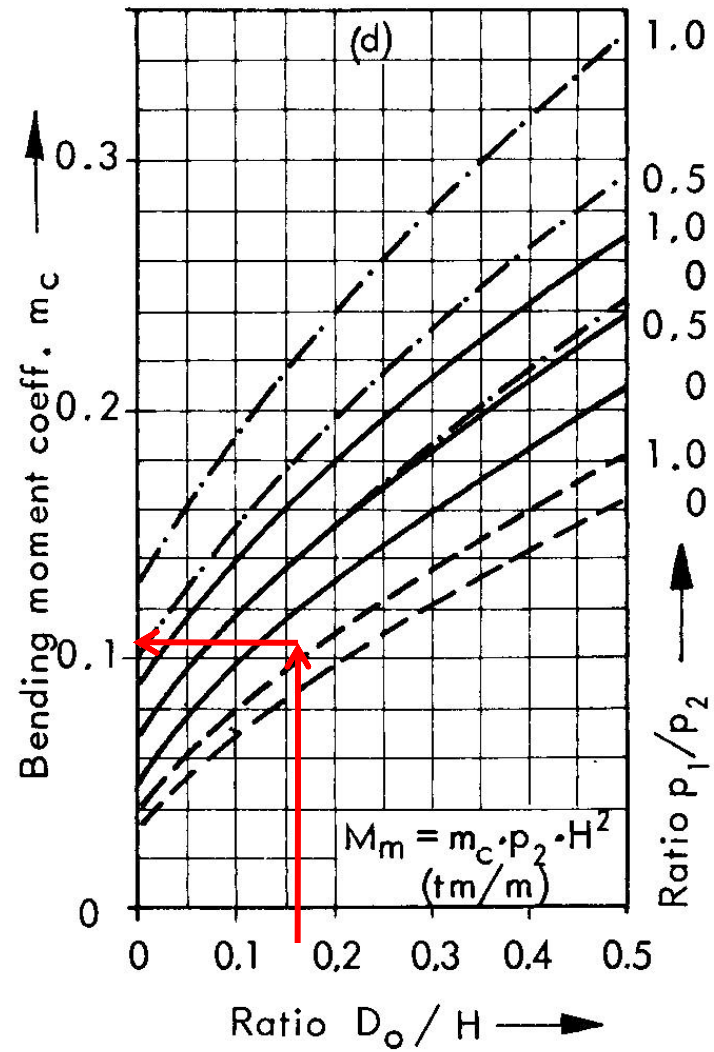
Design of the Sheet Pile – Example

<u>Bending Moment & Section Modulus</u>

Since $D_o/H = 0.155$,
$H_A/H = 0.22$ and $P_1/P_2 \approx 0.26$

$M_c = 0.105$

$M_m = 0.105 \times 4.62 \times 9^2$
$= 39.3$ tm/m



Sheet Pile Wall Structure

Design of the Sheet Pile – Example

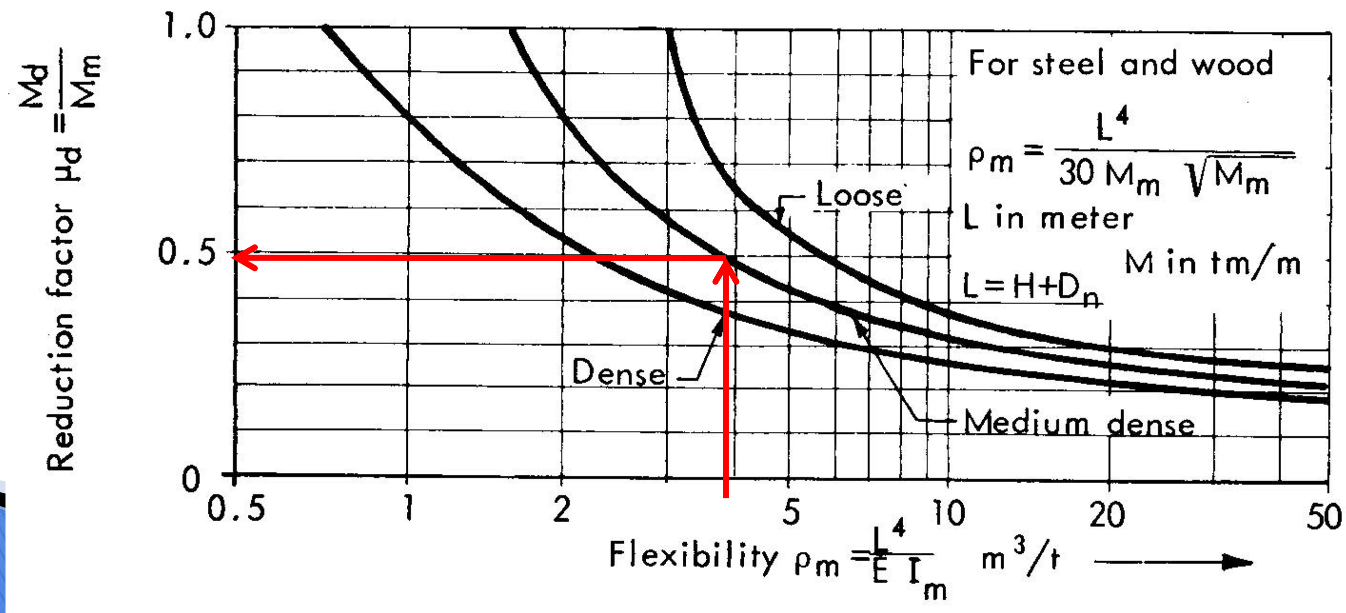
Bending Moment & Section Modulus

With flexibility, $\rho_m = 13^4 / (30 \times 39.3 \times \sqrt{39.3}) = 3.86$ tm/m

Design moment, $M_d = \mu_d . M_m = 0.5 \times 39.3$; $M_d = 19.65$ tm/m

Required effective section modulus, $W \geqslant M_d / \sigma_a$

W = 1965000/1800 = 1090 cm3/m

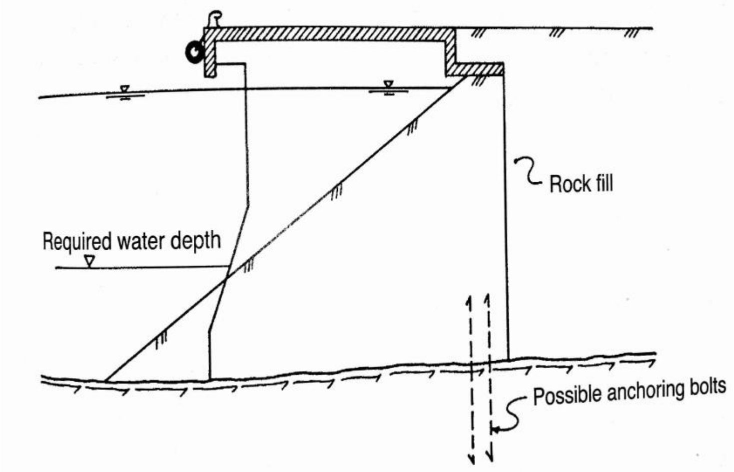


Open Berth Structure

Open Berth Structures

The open berth structure constitute, with their berth platforms, a prolongation over the slope from the top of the filled area out to the berth front. Divided into two main types:

- Column or pile berths – the berth platform and the berth front wall are founded on either column or piles which do not have a satisfactory stability against external forces.
- Lamella berths – the berth platform and the berth front are founded on vertical lamellas, which provide the loaded berth structure with a satisfactory stability.



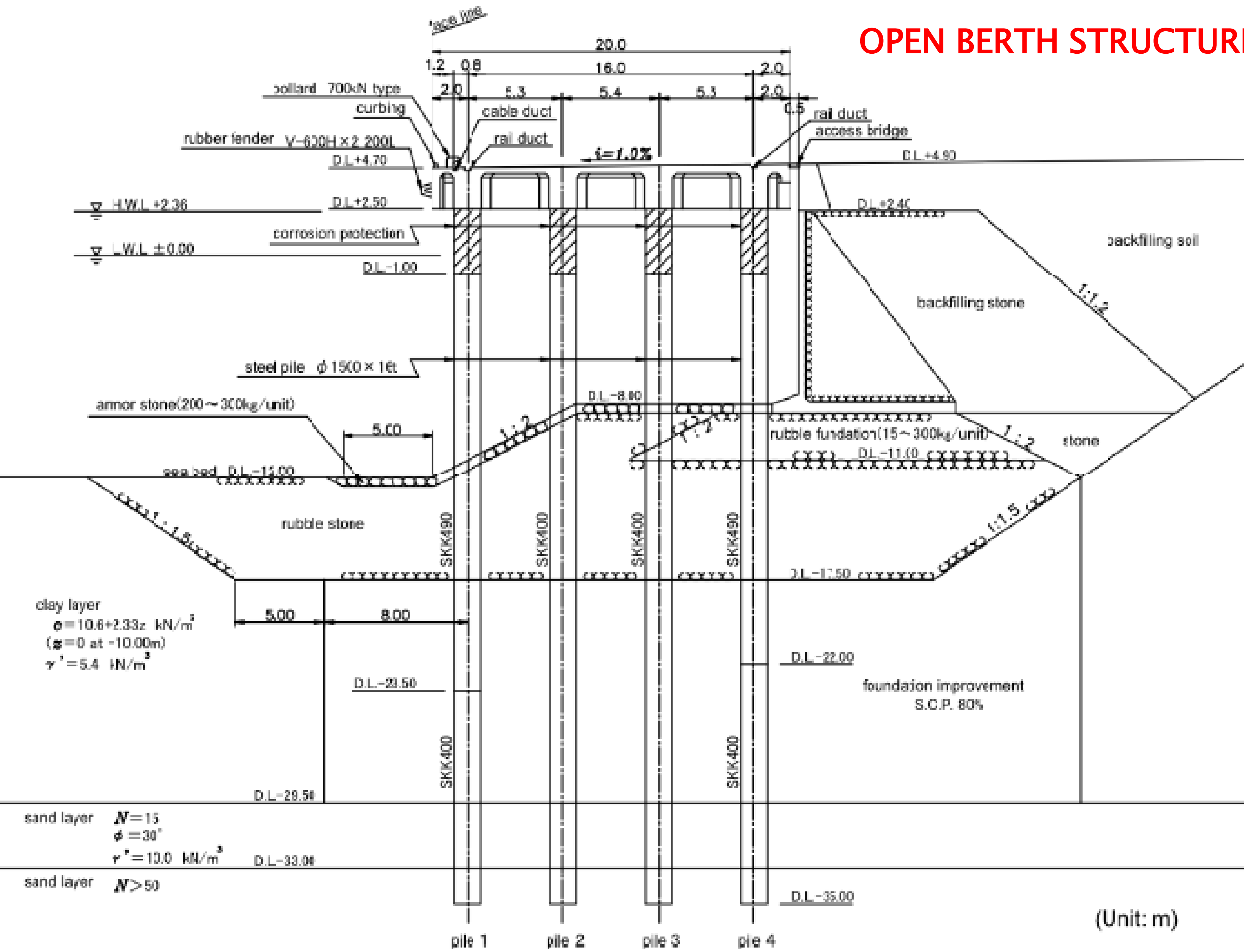
Open Berth Structures

- Open structures usually comprise a deck supported on piles. Piled deck piers can be designed as either flexible or rigid structures, based on the arrangement of piles.

- Flexible structure – vertical piles only.

- Structural weight, vertical live loads and horizontal imposed loads are carried by the deck and distributed to the piles.

OPEN BERTH STRUCTURE



Open Berth Structures

- Loads are transmitted to the soil through the bending of the piles and compressive resistance of the soil.
- Vertical piles; to consider member stiffness, capacity and fixity of the piles in the soil and lateral deflections of the pier are not excessive.
- Otherwise, a rigid structure with raking piles can be adopted to transmit horizontal loads through pile compression to the soil. In both cases, the deck distributes the horizontal loads to the piles.

Open Berth Structures

- A reinforced concrete deck supported by either concrete piles or steel tubular piles is common. The deck is usually composed of precast concrete beam and slab units to minimize formwork over water.

- The advantages of piled deck piers are that they do not cause wave reflection and water circulation problems of solid structures.

- Dredging of soft marine or alluvial deposits is not required because the loads are transmitted down to the supporting soil stratum by the piles.

Open Berth Structures

- As piling works are involved, piled deck structures are usually more expensive than solid structures.

- Maintenance is necessary for the reinforced concrete deck and concrete piles due to chloride induced corrosion of the reinforcement, and the corrosion protection for steel piles.

Day 2

Pier deck, piles dolphins
Impact from ships
Types of Fender

Pier Deck

The pier deck is commonly constructed in the form of a reinforced concrete frame structure consisting of beams and slabs supported by piles.

At the serviceability limit state, crack width anywhere in a concrete structure should be limited to a maximum of 0.3 mm.

Compliance with the bar spacing rules given in BS8110: Part 1 will generally ensure that, for the most severe combination of the loads under the serviceability limit state, crack width will be limited to this maximum.

For concrete within the tidal and splash zones, it is recommended that crack widths under typical average long-term loading conditions should be limited to 0.1 mm.

Piles

Global factors of safety should be used when designing piled foundations of marine works against shear failure of the ground.

The loads used should be unfactored values.

When considering the interaction between the structure and the soil, all appropriate loading conditions should be examined.

For any pile, the ultimate bearing or pull-out capacity should be assessed from loading tests, and the working load should not be greater than the ultimate bearing or pull-out capacity, as appropriate, divided by a factor of safety.

Dolphins

A dolphin is an isolated structure or strong-point used either to manoeuver a vessel or as a mooring. Dolphins may be used in combination with piers to shorten the length of the piers. There are generally two types of dolphins, namely, berthing (or breasting) dolphins and mooring dolphins.

Berthing dolphins are designed to take the berthing impact of the vessel and to hold the vessel against the action of wind and current.

Mooring dolphins are designed for mooring and not
for berthing of vessels. They are usually located some distance behind the berthing face of the pier.

Depending on the berthing and mooring layout, it is possible for a dolphin to be used for both berthing and mooring purposes.

Impact from Ships

Vertical loads on a berth from dead load, live load, crane loads, etc. can be determined accurately.

Difficult to evaluate the horizontal loads caused by ships' impacts (due to size and velocity of ships when berthing, monoeuvring, direction and strength of current, wind and waves at the berth).

The Berthing energy and the impact forces from the berthing ship against the berthing structure can be estimated from one of the following:

- Kinetic Energy Method
- Empirical Method
- Statistical Method

Impact from Ships

The most commonly used approach is the KINETIC ENERGY METHOD. It is the traditional method and is subject to the judgement of the engineer/designer, however, it is time tested and seems to account for the major variables influencing vessel berthing.

The Kinetic Energy of the berthing ship is calculated using the formula:

$$E_{Ship} = 1/2\ MV^2$$

Where E_{Ship} = Energy on Berthing

M = Mass or Water displacement of the ship

V = Approach Velocity of the ship at the moment of impact with the fender

Impact from Ships

Energy on Berthing must be factored depending on rotation of the vessel and the amount of water moving with the vessel.

Energy induced by the ship to be absorbed by the fender system as below:

$$E_{Fender} = E_{Ship} \times f$$

Where

$$f = C_e \times C_m \times C_s \times C_c$$

C_e = Eccentricity Factor

C_m = Virtual Mass Factor

C_s = Softness Factor

C_c = Berth Configuration Coefficient

Impact from Ships

Calculating Berthing Energy

$$E_{Fender} = 1/2\, MV^2 \times C_e \times C_m \times C_s \times C_c$$

Weights;

DT – Displacement Tonnage; the weight of water displaced by the immersed part of the ship

DWT – Dead Weight Tonnage; the weight that the ship can carry when loaded to a specified load draft. It is the most common measurement.

GT – Gross Tonnage; the cubic capacity of the ship below the tonnage deck.

Impact from Ships

Calculating the mass – M, use the loaded displacement tonnage, DT.

Typically DT is 30~40% greater than DWT

Where: $M = \dfrac{DT}{g}$

DT = Displacement Tonnage (tonnes)

g = Acceleration Due to Gravity = 9.81 M/Sec^2

Impact from Ships

Velocity – V

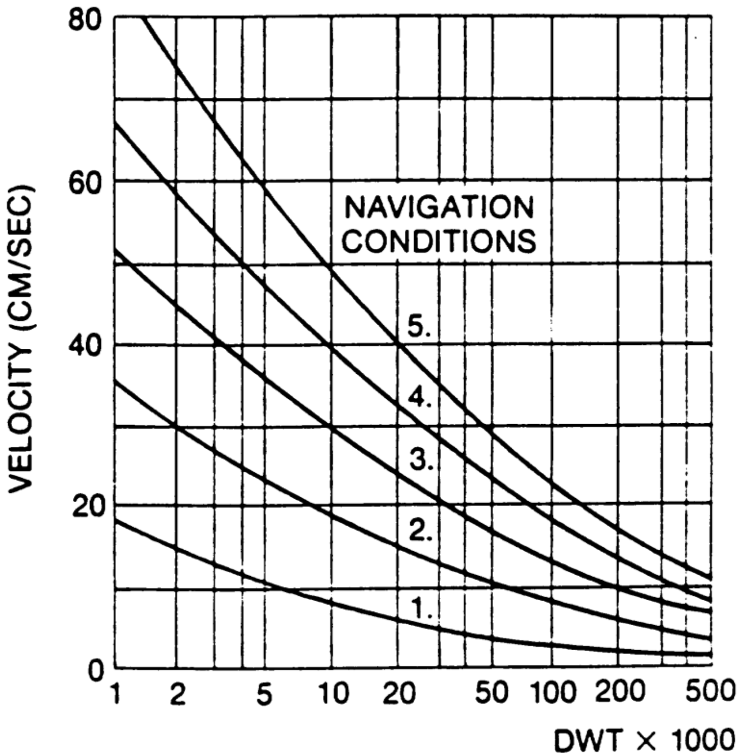
The energy to be absorbed is a function of the square* of the approach velocity.

*determining the velocity is one of the most important decisions in the design

Chart as a guide to assist in selecting a design velocity

Navigation Conditions

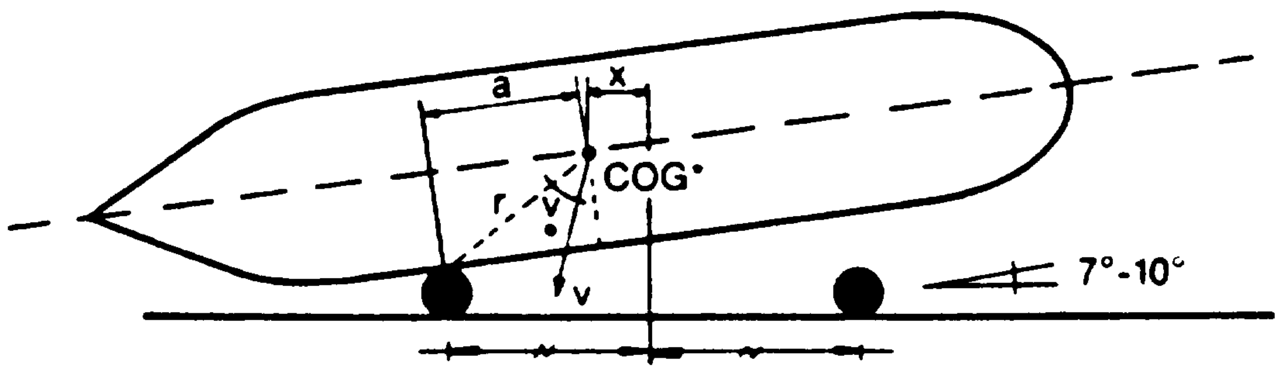
1. Easy Docking; Sheltered
2. Difficult Docking; Sheltered
3. Easy Docking; Exposed
4. Good Docking; Exposed
5. Difficult Docking; Exposed



Impact from Ships

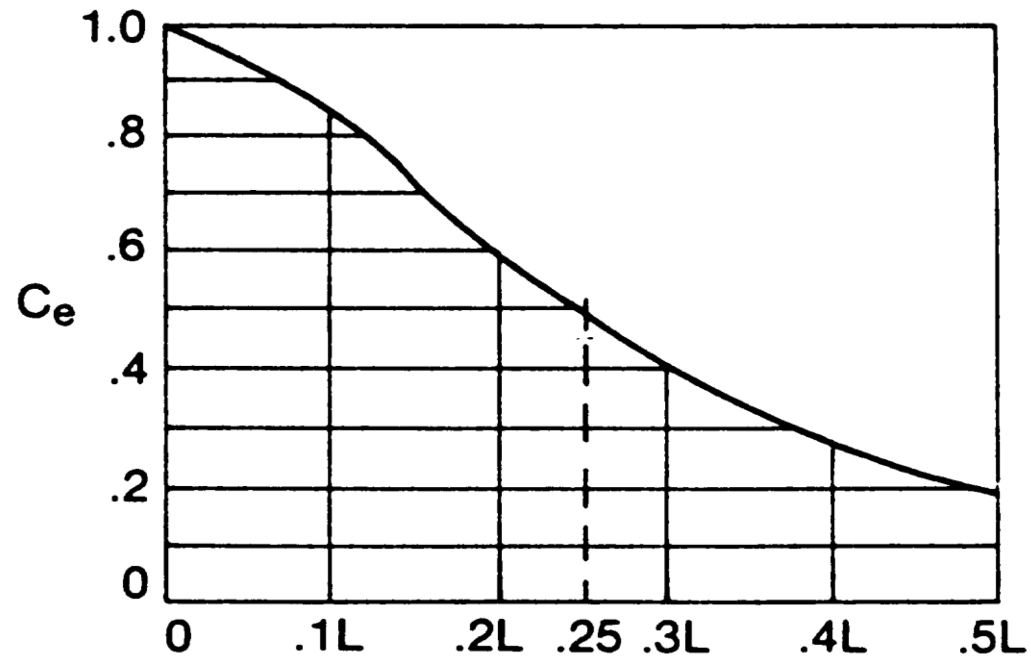
Eccentricity – Ce

- The ship in not parallel to the pier face during berthing. As a result, not all of the Kinetic Energy will be transmitted to the fenders. At impact, the ship will start to rotate around the contact point thus dissipating part of its energy.



Impact from Ships

- Graph illustrates the relationship between the eccentricity coefficient & the distance "a"
- L = Length of Ship



- for larger Bulk Ships and Tankers
  K = 0.2L - 0.25L
- for Passenger Ships and Ferries
  K = 0.17L - 0.2L
- for 1/4 point Berthing a = 0.25L

Impact from Ships

Alternatively,

$$C_e = \frac{K^2}{a^2 + K^2}$$

K = radius of longitudinal gyration of the ship

a = distance between the ship's centre of gravity and the point of contact on the ship's side projected onto the longitudinal axis

Value of K is related to the block coefficient of the ship and its length.

$$K = (0.19\, C_b + 0.11) \times L$$

Block coefficient C_b

$$C_b = \frac{DT}{D \times B \times L \times Wo}$$

Where:

DT = Displacement of the ship (tonnes)

D = Draft (m)

B = Width (m)

L = Length (m)

Wo = Water Density (tonnes/M^3)

Typical Seawater Wo = 1.025 tonnes/M^3 (64 lb/ft^3)

Typical Freshwater Wo = 1.00 tonnes/M^3 (62.3 lb/ft^3)

Impact from Ships

- Formula is based on the generally accepted assumptions that at the moment of maximum fender deflection:
    - Rotation only occurs at the contact point
    - Ship's hull does not slide along the fender
    - Forces such as wind, currents tugs are negligible compared to the fender reaction.
- The approach angle is usually taken as 7° ~ 10°. If the ship is berthing properly under control at the moment of contact with the fender then the direction of travel will be at right angles to the berthing face.

Impact from Ships

Examples:

- The minimum C_e is reached when the centre of gravity of the large ship falls halfway between the two dolphins (dolphins are 1/3 L distance apart) on contact with the fenders.

- When a = 1/6 L

$$C_e = \frac{(.25L)^2}{(1/6L)^2 + (.25L)^2} = 0.692$$

- The maximum in this case would occur when the ship's center of gravity falls in line with the point of contact with the fender or a = 0; thus $C_e = 1$

Impact from Ships

- In the case of a continuous fender system and a large oil tanker, a = 0.3 L

- Therefore,

$$C_e = \frac{(0.25L)^2}{(0.3L)^2 + (0.25L)^2} = 0.41$$

- Generally C_e ranged between 0.4 and 0.8

Impact from Ships

Virtual Mass Coefficient – C_m

When the ship is in motion and contact the fender, the mass of the ship has to be decelerated as well as a certain mass of water surrounding and moving with the ship. This additional mass is counted for in the virtual mass coefficient – C_m which is a function of the block coefficient of the vessel, its draft and its width.

$$C_m = 1 + \frac{\pi}{4\,C_b} \times \frac{D}{B}$$

OR

$$C_m = 1 + \frac{2D}{B}$$

C_b = Block Coefficient

D = Draft

B = Width

Use both ways, take the higher value

Impact from Ships

Softness Coefficient – C_s

This factor accounts for the relationship between the rigidity of the ship and that of the fender. It expresses that proportion of impact energy absorbed by the fender.

For a soft fender $C_s = 1.0$ as deflection of the ship's hull will be negligible and therefore all the energy will be absorbed by the fender.

In the instance of hard fenders, it is assumed that the ship's hull will absorb 2 to 7 percent of the impact energy so C_s is taken as 0.98 to 0.93

Impact from Ships

Berth Configuration Coefficient – C_c

This factor attempts to quantify the difference between an open pile supported pier and a solid sheet pile or concrete crib structure.

Open pile supported pier – the water being pushed by the berthing ship is easily able to displaced around the pier. $C_c = 1.0$

Solid sheet pile – the moving water is squeezed in between the structure wall and the ship causing a cushion effect. A reduction factor has to account for this effect. $C_c = 0.8$

Impact from Ships

Vessel Dimensions & Typical Energy Requirements

Berthing energy based on standard conditions:

- Velocity = 0.15 m/s
- Eccentricity Coefficient = 0.5 (for ¼ point berthing)
- Softness Coefficient = 1.0
- Berth Configuration Coefficient = 1.0

Impact from Ships

General Cargo

Tonnage (D.W.T.)	Length (m)	Width (m)	Height (m)	Loaded Draft (m)	Displacement Tonnage (DT)	Virtual Mass Coefficient	Berthing Energy (Tonne-M)*
800	56	9.0	4.0	3.8	1,115	1.6	1.02
1,000	58	9.4	4.6	4.2	1,390	1.59	1.27
2,500	83	12.4	6.7	5.5	3,470	1.58	3.15
5,000	109	15.0	8.4	6.7	6,930	1.57	6.23
7,500	129	18.0	10.2	7.7	10,375	1.59	9.48
10,000	142	19.1	11.1	8.2	13,800	1.56	12.32
12,000	150	20.1	11.9	8.7	16,500	1.55	14.73
15,000	162	21.6	12.7	9.1	20,630	1.52	18.02
20,000	180	23.5	14.0	10.1	27,400	1.54	24.19
25,000	195	25.0	14.5	10.3	34,120	1.50	29.35
30,000	200	26.0	15.7	11.0	40,790	1.48	34.62
35,000	210	27.2	16.2	11.7	47,400	1.49	40.50
40,000	217	28.3	17.3	12.0	54,000	1.47	45.52
45,000	225	29.2	17.9	12.4	60,480	1.46	50.65

Impact from Ships

Container Ships

Tonnage (D.W.T.)	Length (m)	Width (m)	Height (m)	Loaded Draft (m)	Displacement Tonnage (DT)	Virtual Mass Coefficient	Berthing Energy (Tonne-M)*
10,000	175	25.6	15.8	9.8	14,030	1.96	15.77
20,000	200	27.3	16.8	10.4	27,940	1.62	25.95
25,000	213	30.1	16.3	10.5	34,860	1.54	30.78
30,000	290	32.0	19.8	10.3	41,740	1.60	38.29
35,000	265	32.8	20.5	11.6	48,600	1.59	44.31
40,000	279	32.5	22.8	11.0	55,430	1.49	47.36
50,000	290	32.4	24.2	11.3	69,000	1.43	56.58

Impact from Ships

Tankers

Tonnage (D.W.T.)	Length (m)	Width (m)	Height (m)	Loaded Draft (m)	Displacement Tonnage (DT)	Virtual Mass Coefficient	Berthing Energy (Tonne-M)*
1,000	58	9.4	4.5	4.2	1,360	1.60	1.25
2,500	82	12.0	6.1	5.5	3,400	1.59	3.10
5,000	102	15.0	7.7	6.5	6,790	1.51	5.88
8,000	126	15.7	9.0	7.4	10,600	1.52	9.24
10,000	140	19.0	9.8	7.9	13,540	1.52	11.80
15,000	163	20.0	11.2	8.6	20,250	1.48	17.19
20,000	175	23.5	12.3	9.6	26,930	1.48	22.85
30,000	195	27.0	14.1	10.7	40,190	1.45	33.41
40,000	213	29.6	15.2	11.8	53,300	1.45	44.31
50,000	224	32.0	16.6	12.3	66,270	1.41	53.58
60,000	236	34.0	17.7	12.7	79,100	1.39	63.04
70,000	248	35.8	18.6	13.5	91,790	1.40	73.69
85,000	260	38.1	18.7	14.0	110,550	1.37	86.84
100,000	285	40.1	21.1	14.8	129,000	1.39	102.82
150,000	300	46.1	24.3	17.0	188,200	1.37	147.84

Fenders

Fenders

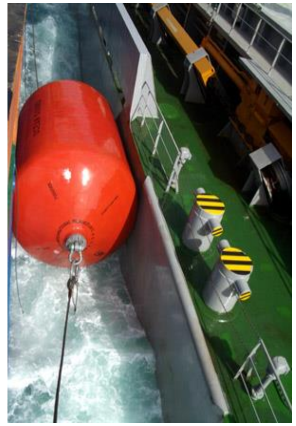
- The purpose of installing fenders on the pier is to protect the vessel and the pier from damage when the vessel berths alongside the pier.
- The fenders absorb the berthing energy of the vessel and soften the berthing impact on the pier. Fenders can be classified into timber fenders, rubber fenders and plastic fenders, according to the type of materials used.

TYPES OF FENDERS

Ship to quay (STQ)	Ship-to-ship (STS)	Boat
✓Cylindrical fender ✓Arch fender ✓Cell fender ✓Cone fender ✓Pneumatic fender ✓Foam elastomer	For bunkering operations between two vessels, floating fenders such as pneumatic or foam elastomer fenders are typically used.	✓D fenders ✓Square fenders ✓Wing fenders ✓Keyhole fenders ✓Tug boat fenders ✓Lightweight foam elastomer fenders

Fenders

Foam Filled



Cruise Ship Fenders

Cylindrical Fenders

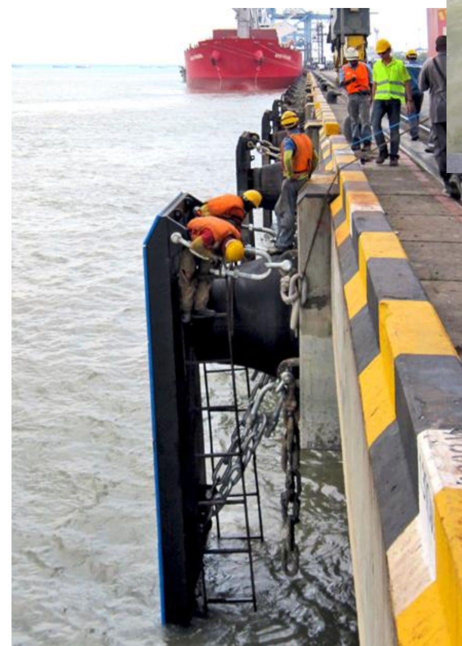
Pneumatic Fenders

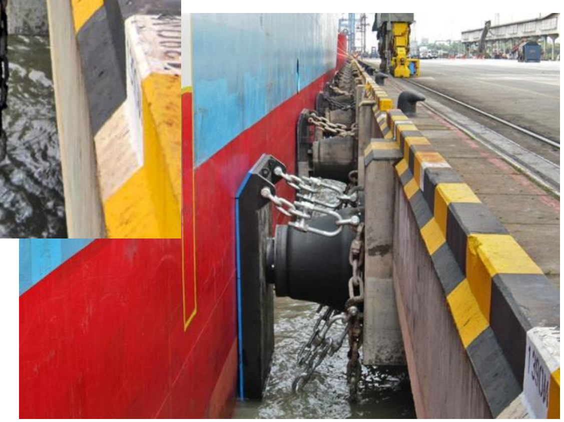
Fenders

Arch Fenders

D Fenders

Cell Fenders






THANK YOU
pic by : MSJ