Abnormal and accidental loads on piers, dolphins and loading platforms

Martin Hovden Thuve

Multiconsult Norge AS

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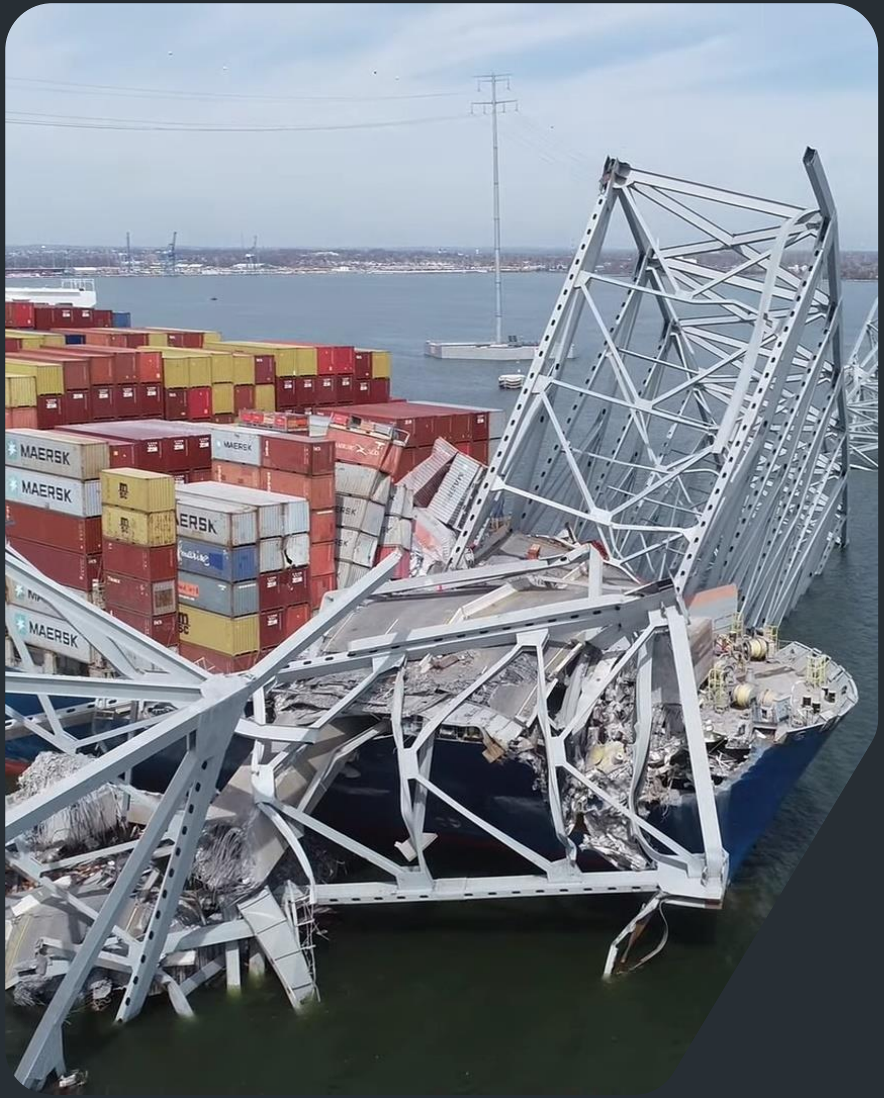
Agenda

1. The problem
2. The structures
3. The rules
4. The ~~solutions~~ strategies

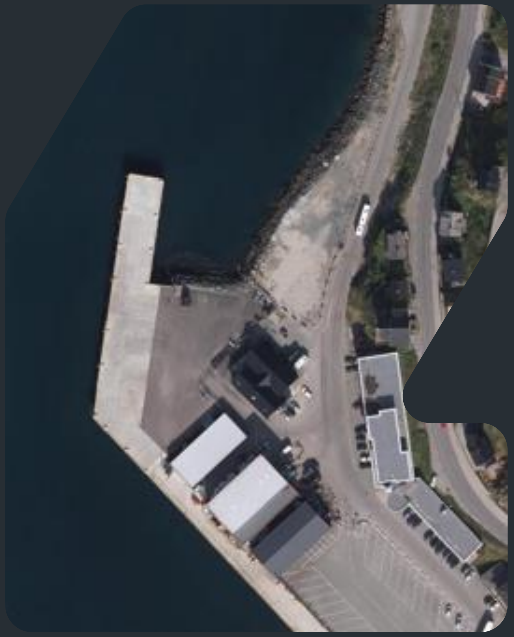
The problem

- Our assignment as engineers is easy enough – provide a platform above the water line with a given water depth directly in front
- Fender systems protect the structure from the ship – and vice versa
- Fender systems should also provide a comfortable berthing for vessels
- Despite our best engineering efforts, a vessel can easily tear down (almost) anything we design



The structures

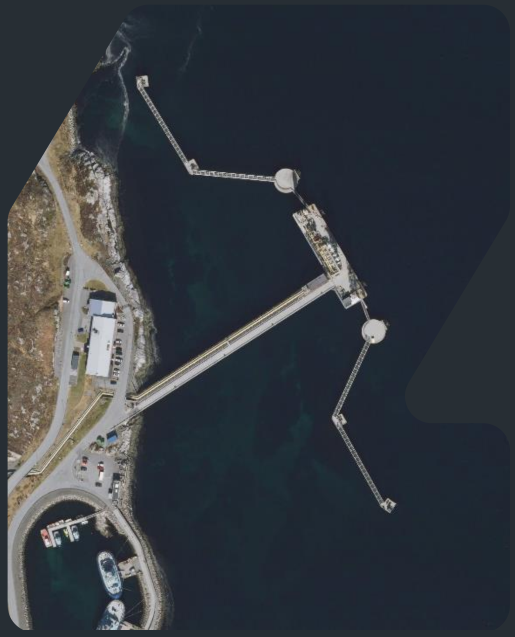
Passenger piers



Mooring dolphins

Loading piers

Loading platforms



Susceptible to collapse

Fender design

- WG211 intruduce significant changes from WG33 in finding the design berthing energy
- Consequence classes differentiate on the required reliability of the fender system
- Allows for differentiating fender cost based on criticality
- WG211 also account for multiple fender contact to a larger degree than WG33

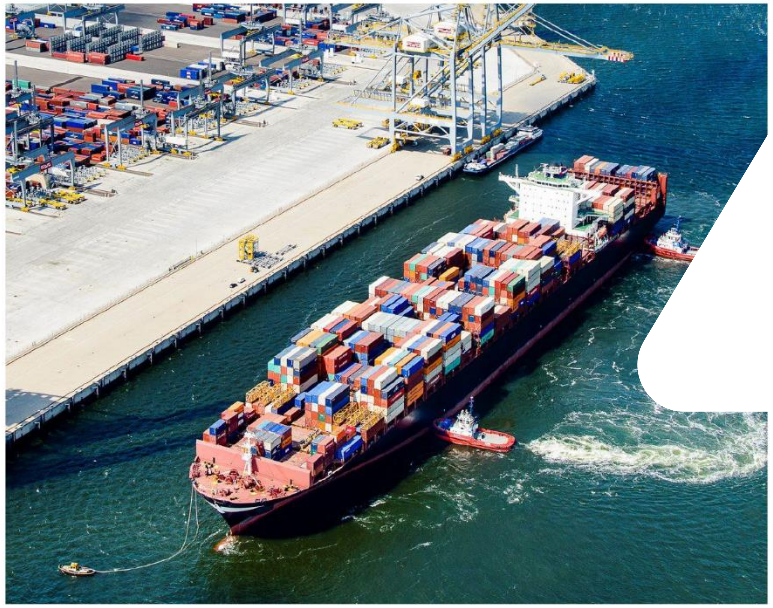
Class	Description of failure consequences	Explanation	Example of fender systems
A	Negligible/ low consequences for risk of loss of human life AND environmental damage AND economic damage.	Failure of a single fender predominantly results in insignificant to no structural damage.	Fenders installed on a marine structure that is part of a terminal or port with functional redundancy [a] and limited number of people at risk. Failure of a single fender is not likely to result in the unavailability of the berth or widespread damage to the marine facility assuming there is sufficient redundancy with additional berths. An example can be a continuous earth retaining quay wall or a dolphin berth with more than two/ redundant berthing (breasting) dolphins or marine facilities with multiple berths having similar capabilities.
B	Some consequences for risk of loss of human life OR environmental damage OR economic damage.	Material damage **and** functionality losses of significance for owners and operators **and** low or no social impact.	Fenders installed on a marine structure without functional redundancy [a]. Failure[b] of the fender system is likely to result in the unavailability of the berth with no other alternatives. An example can be a single berth with two berthing (breasting) dolphins.
C	Considerable consequences for risk of loss of human life OR environmental damage OR economic damage.	Material losses **and** functionality losses of societal significance, causing regional disruptions **and** delays in important societal services over several weeks.	Fenders installed on marine structures, positioned at locations for which failure of the fender system is likely to put public lives at risk. Fenders installed on a marine structure for which failure[b] of the fender system is likely to close the berth and cause considerable consequential economic loss. Examples can be essential floating powerplants or floating storage regassification units that are prevented from operating after fender failure[b] and sufficient backup measures are available to resume operations.
D	High risk of loss of human life OR environmental damage OR economic damage.	Disastrous events causing severe losses of societal services **and** disruptions **and** delays at national scale over periods in the order of months.	Fenders installed on marine structures for which failure[b] of the fender system is likely to lead to significant socio-economic disruptions. Examples are progressive damage or cascading effects of other types of structures, e.g. critical installations such as essential powerplants or floating storage regassification units that are prevented from operating after fender damage with no backup measures available to resume operation.
E	Very high risk for loss of human life OR environmental damage OR economic damage.	Catastrophic events causing losses of societal services **and** disruptions **and** delays beyond national scale over periods in the order of years.	Beyond the scope of this guideline. In some cases, owners may choose, for practical reasons, to add an additional berthing criterion to cover 'Extreme Events' where additional energy is absorbed by partial collapse of secondary structural elements to protect critical wharf assets.

a) If a structural component is part of a series system (a configuration such that, if any one of the system components fails, the entire system fails) or if progression of failure is not mitigated, a higher consequence class should be considered.

b) A fender system is therefore considered to fail when it does not fulfil its function (Chapter 2.1), resulting in a high probability of exceeding the design value of the fender reaction force and/or the design value of the associated berthing impact force. Fender system failure can happen even if fender units still appear intact and undamaged for future use. Other causes of failure can be damage due to degradation or mechanical failure of the fender system itself.

PIANC
The World Association for Waterborne Transport Infrastructure

PIANC FENDER GUIDELINES 2024



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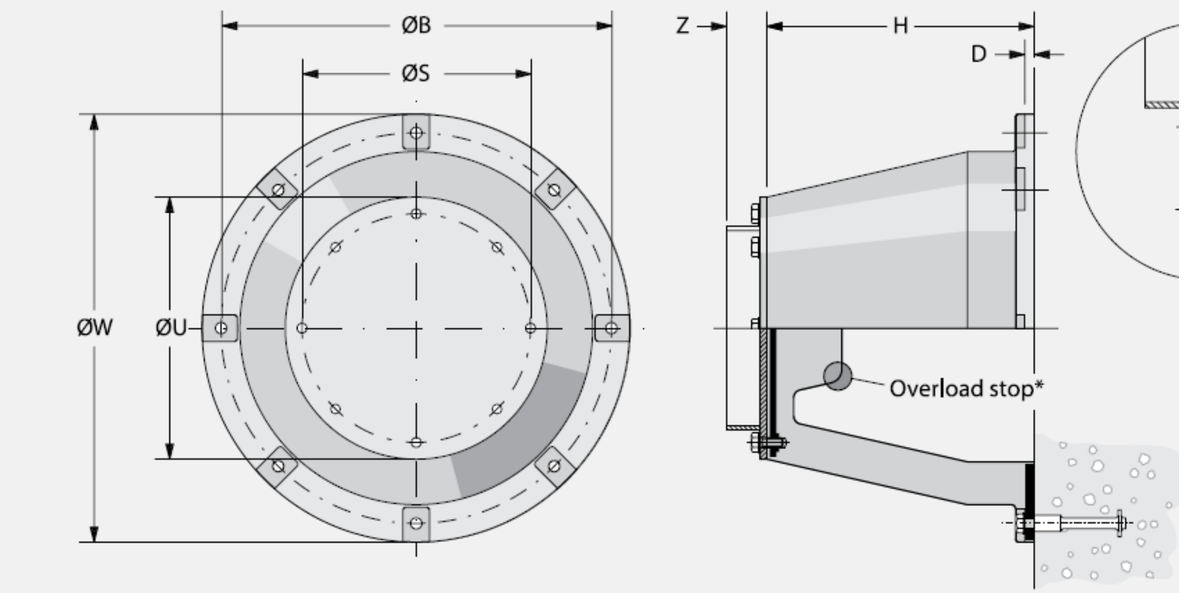
Fender design

- The structures mentioned previously can typically have brittle failure modes, and therefore high consequences of structural overloading
- Compared to WG33, WG211 gives smaller fenders for continous quay walls and larger fenders for dolphins and stand-alone structures
- Reliability of the fender system ≠ reliability of the structure

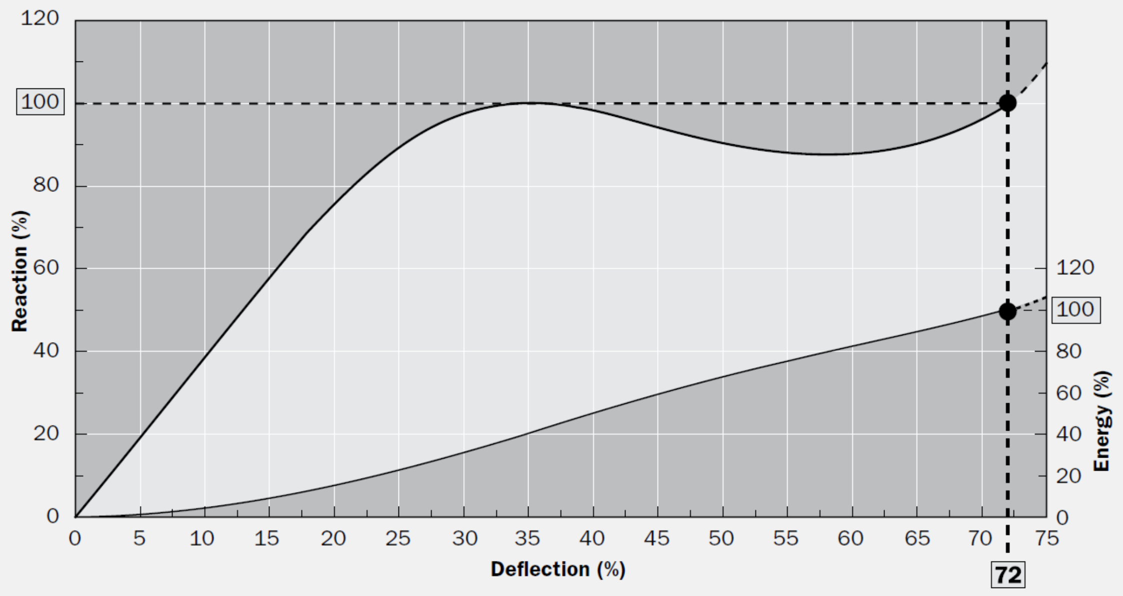
Example - cone fender

- Reaction force is known up to 75 % deflection – 106 % of rated energy
- Overload stop ensures practically direct force transfer to supporting structure
- What happens next depends on the structure

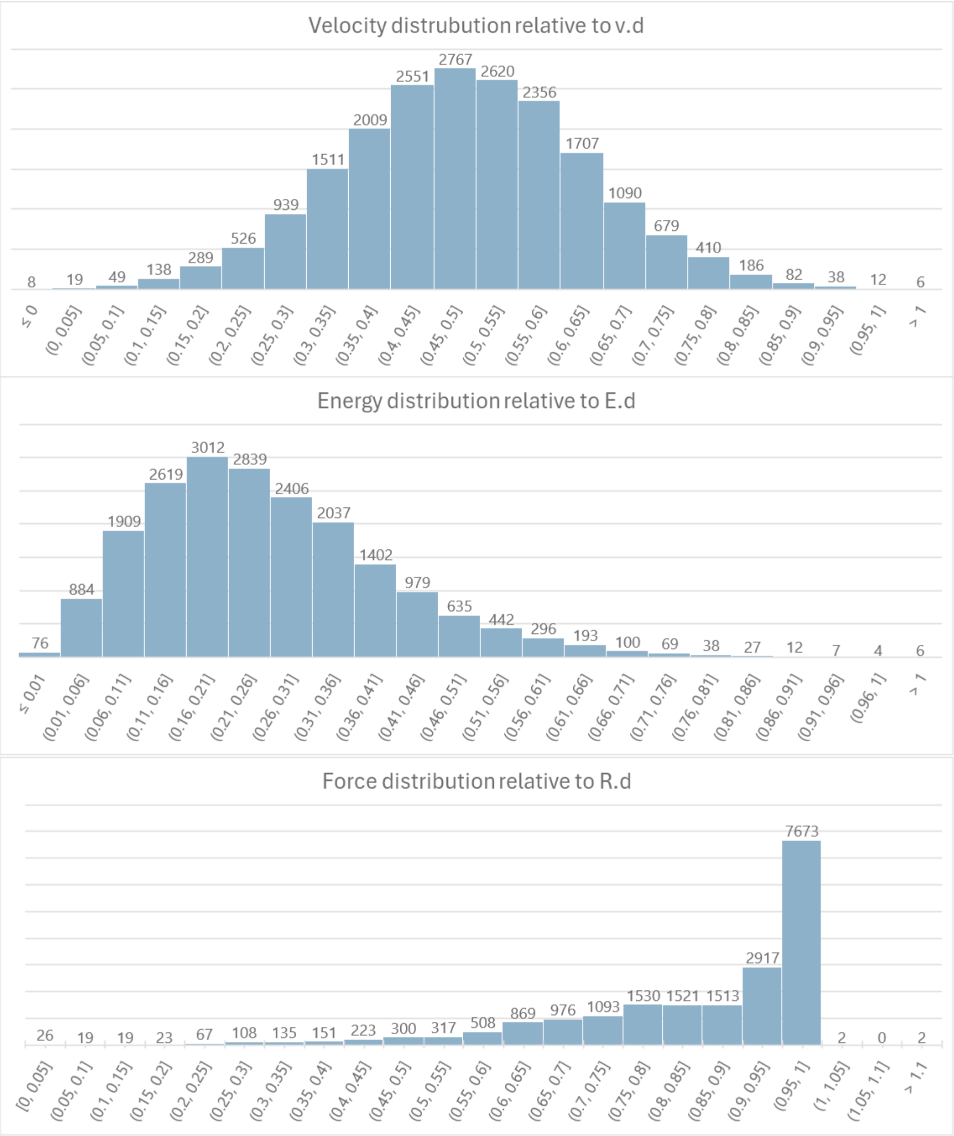


D_i (%)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	**72**	75
E_i (%)	0	1	4	8	15	22	31	40	50	59	67	75	82	89	96	**100**	106
R_i (%)	0	20	39	58	76	90	98	100	98	94	90	88	88	90	96	**100**	110

Nominal rated deflection may vary at RPD. Refer to the Performance Tolerances table in the Fender Application Design Manual.



Load distribution



- Velocity distribution from WG145 (Fitted normal distribution)
- 20,000 berthings
- $p(v>v_d)=0.0002$ (iaw. WG211)
- Distribution of variable load compared to assumption in EN1990?

C6 Target values of reliability index β

(1) Target values for the reliability index β for various design situations, and for reference periods of 1 year and 50 years, are indicated in Table C2. The values of β in Table C2 correspond to levels of safety for reliability class RC2 (see Annex B) structural members.

NOTE 1 For these evaluations of β

– Lognormal or Weibull distributions have usually been used for material and structural resistance parameters and model uncertainties ;

– Normal distributions have usually been used for self-weight ;

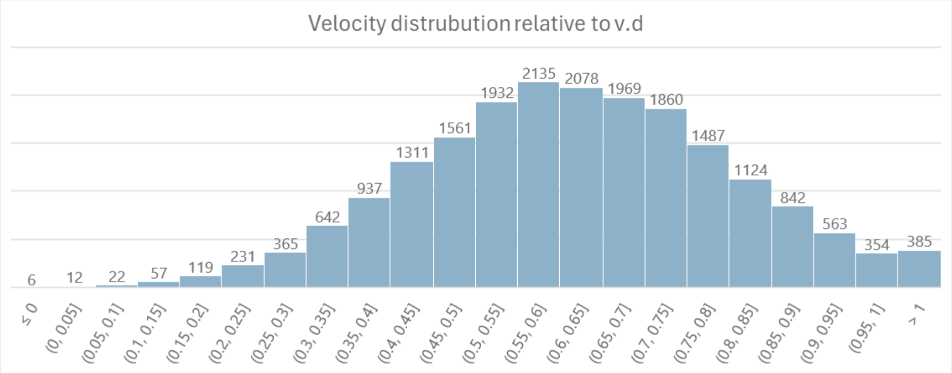
– For simplicity, when considering non-fatigue verifications, Normal distributions have been used for variable actions. Extreme value distributions would be more appropriate.

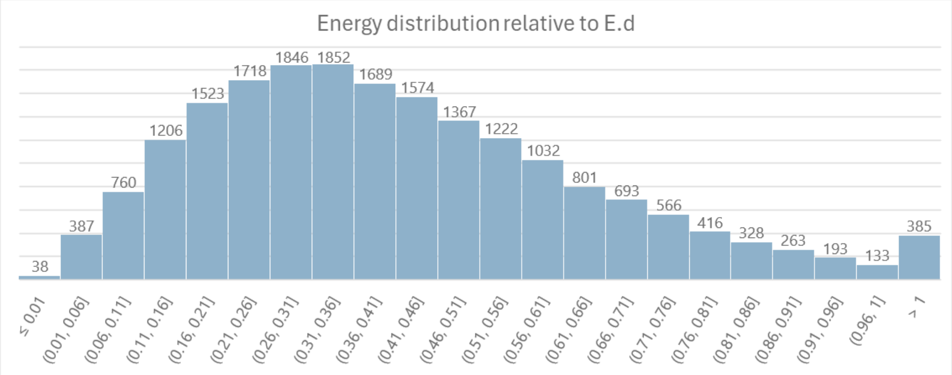
- What happens if you underestimate the berthing velocity?

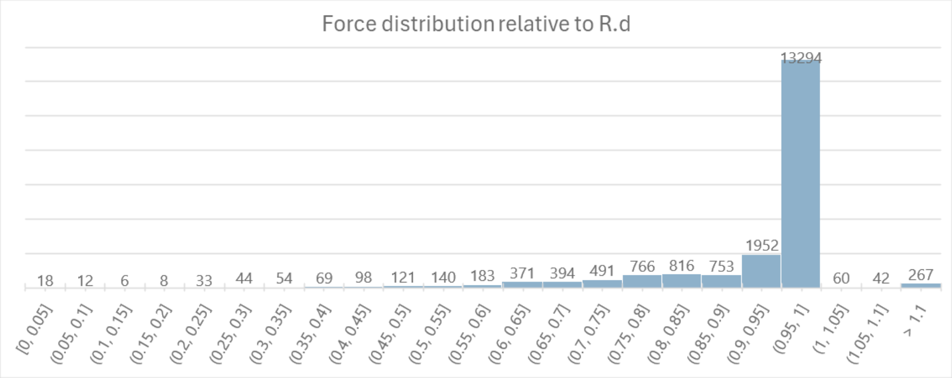
NOTE 2 When the main uncertainty comes from actions that have statistically independent maxima in each year, the values of β for a different reference period can be calculated using the following expression :

$$\Phi(\beta_n) = [\Phi(\beta_1)]^n \qquad (C.3)$$

Load distribution



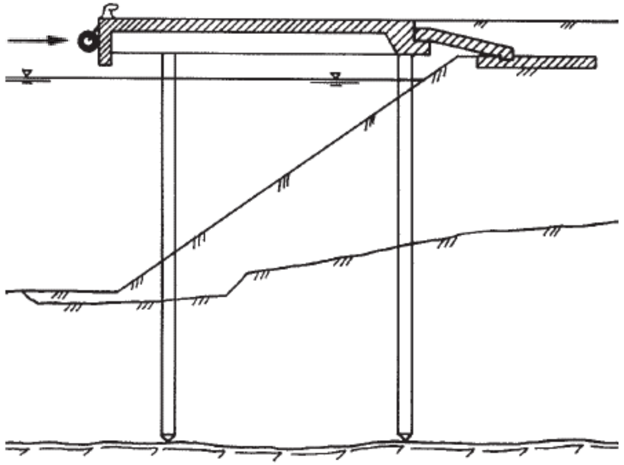




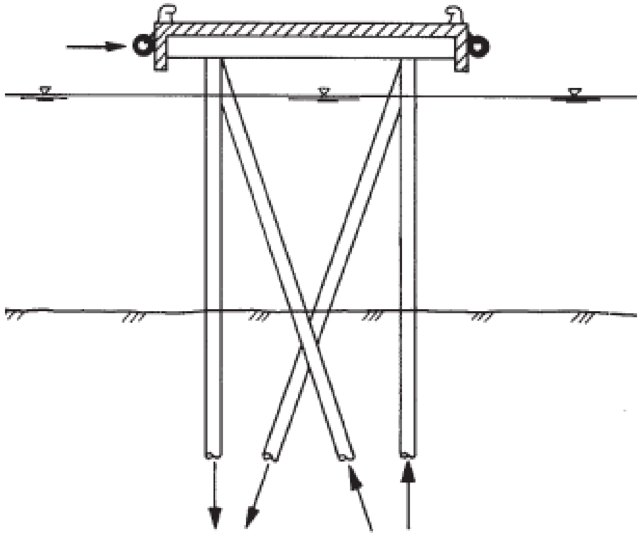
- Velocity distribution from WG145 (Fitted normal distribution)
- 20,000 berthings
- $p(v>v_d)=0.02$

- Several load cases beyond overload protection of fender

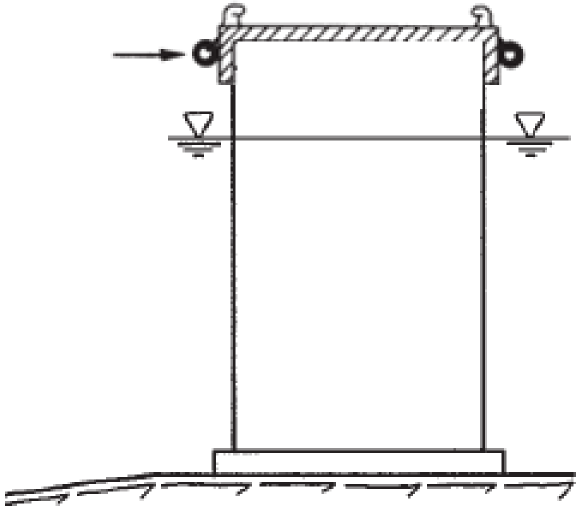
Force-displacement and failure modes



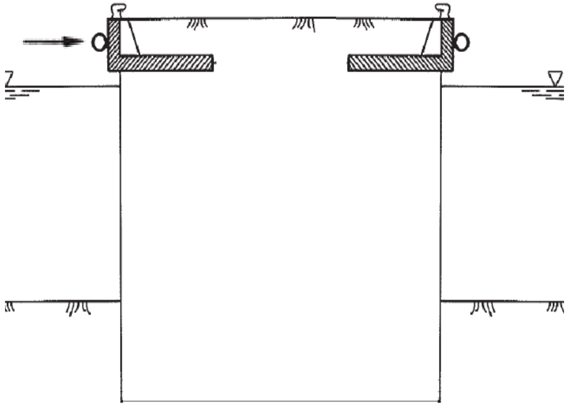
- Mobilisation of passive pressure
- Extremely high resistance
- Failure mode not clear
- High energy absorption in vessel



- Capacity approx. 2x design force
- Some additional mobilisation in slanted piles
- Rapid reduction of resistance with small displacement
- Low energy absorption in vessel



- Tipping force 3x design force at low displacement
- Sine-shaped force reduction over B/2
- Additional energy absorption through deformation
- Low-medium energy absorption in vessel



- High restance in displacement of coping beam
- Probably failure in locks and pile sheets before tilting
- Large energy absoption in deformation of fill masses
- Low-medium absorption in vessel

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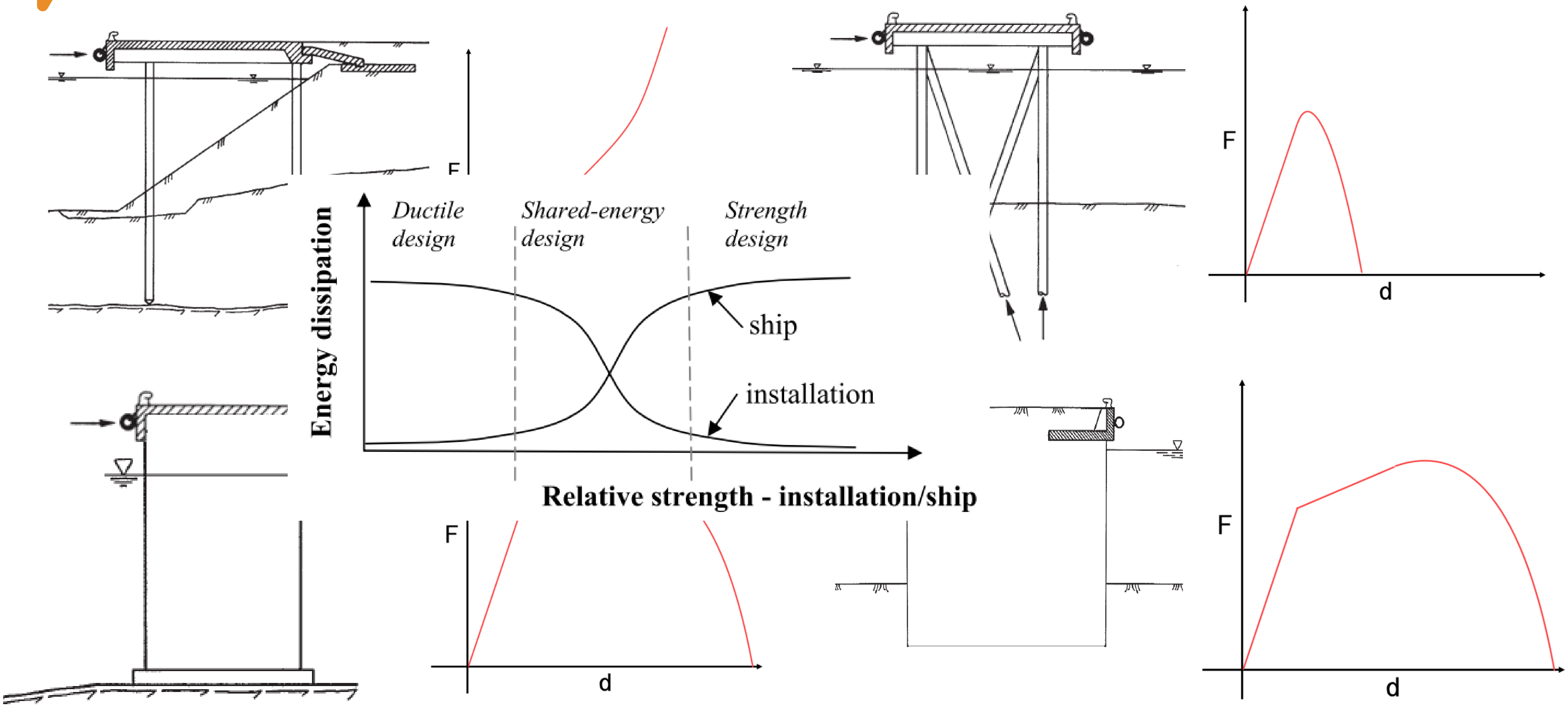
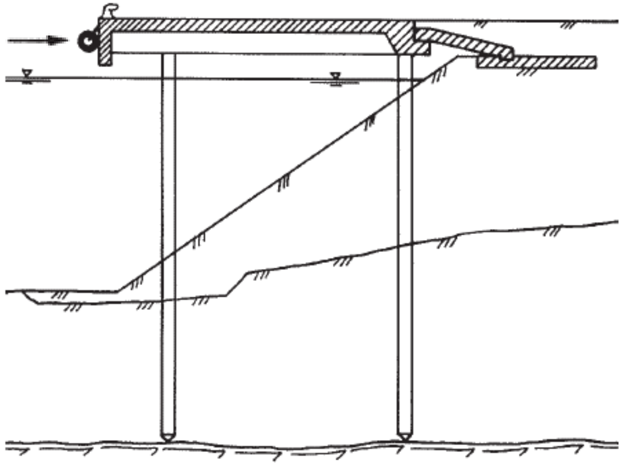
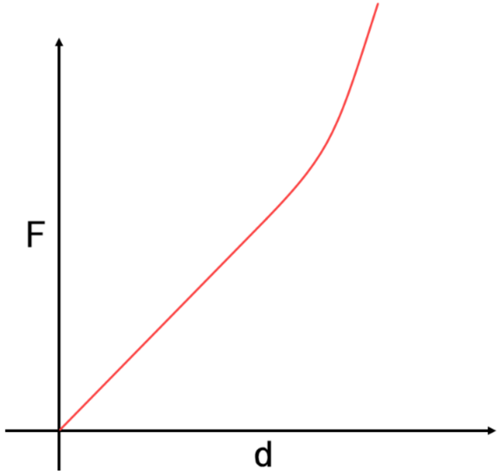
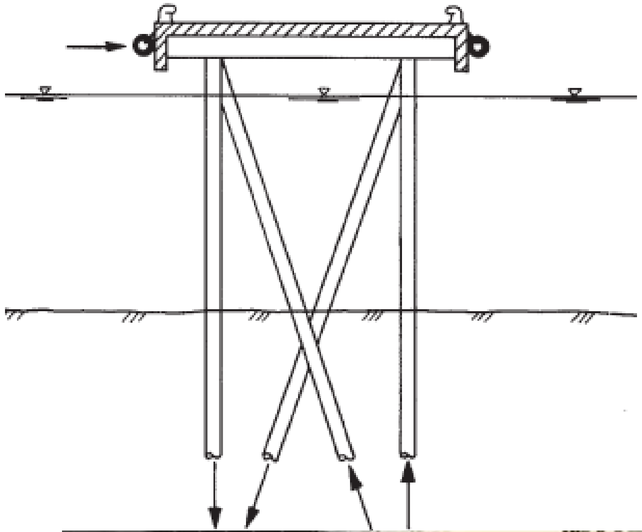
Force-displacement and failure modes

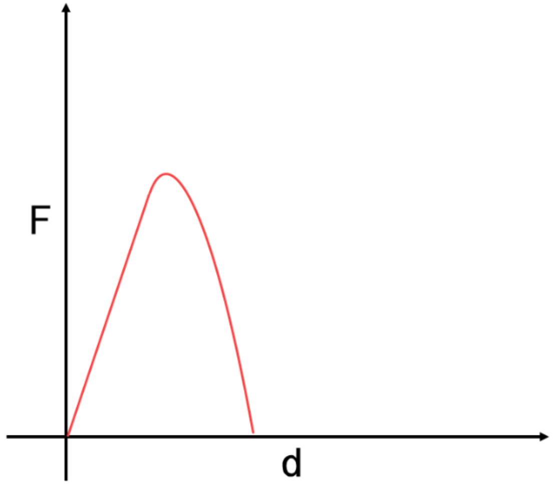


Force-displacement and failure modes





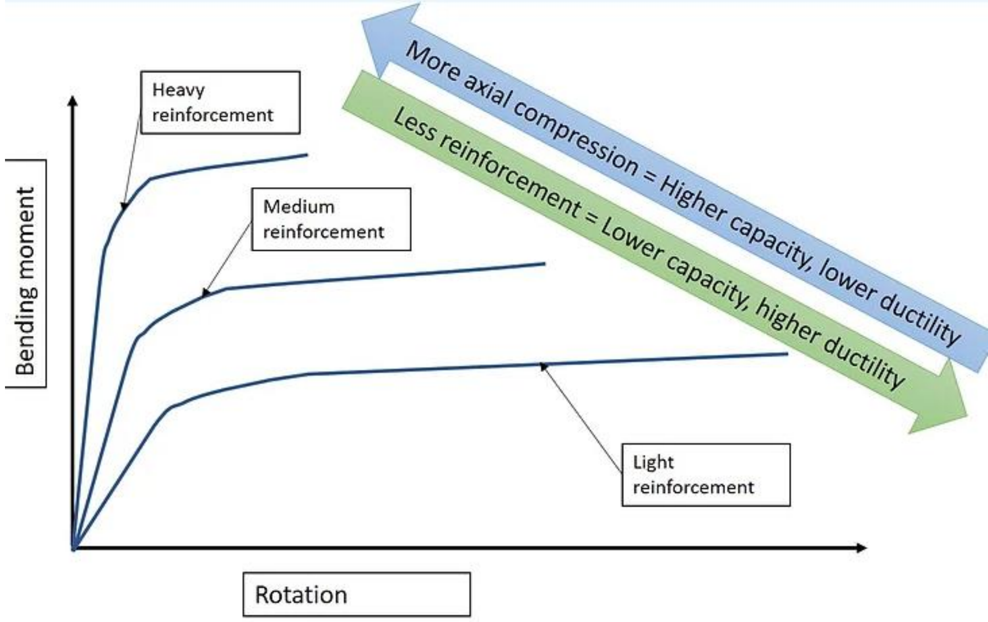




General Directorate of Maritime Affairs

Energy absorption in concrete failure

- Energy absorbtion is dependent on deformation
- Concrete has brittle behaviour in failure
    - No plastic hinges
- Steel rebar gives some ductile behaviour, but high rebar density and high strength concrete reduces the effect
- Higher bonding strength -> Lower anchorage length -> Lower failure length of anchorage -> Lower elongation in rebar before failure -> Lower energy absorption per bar
- Bundled bars give better energy absorption due to longer failure zones around the bar



Moment-curvature diagram

Concrete and piles alone cannot stop a ship

The rules

- Planning and building code
- EN1990-1999
- Major accident regulations


NORWEGIAN BUILDING AUTHORITY

Regulations on technical requirements for construction works

An unofficial English translation of the regulation "Forskrift om tekniske krav til byggverk (Byggteknisk forskrift - TEK17)" for information purposes. Any disputes shall be decided on the basis of the formal regulation in Norwegian.

July 2017

Required reliability

Section 10-1 Life and material safety

Construction works shall be sited, designed and constructed to ensure the attainment of an adequate level of safety for people and domestic animals and to ensure that any collapse or accident does not result in unacceptably great material damage or loss to society.

Section 10-2 Structural safety

(1) The properties of materials and products in construction works shall ensure compliance with the fundamental requirements for the construction work's mechanical resistance and stability.

(2) Construction works shall be designed and constructed to ensure the attainment of an adequate level of safety against failure and sufficient rigidity and stability for loads that may occur during their intended use. This requirement applies to construction works under construction and completed construction works.

(3) The fundamental requirements relating to the construction works' mechanical resistance and stability, including ground conditions and safety measures during construction and upon completion, can be complied with by designing construction works in accordance with Norwegian Standard NS-EN 1990 Eurocode: Basis of structural design, and underlying standards in the series NS-EN 1991 to NS-EN 1999, with associated national additions.

Section 2 Requirements

2.1 Basic requirements

(1)P A structure shall be designed and executed in such a way that it will, during its intended life, with appropriate degrees of reliability and in an economical way
- sustain all actions and influences likely to occur during execution and use, and
- remain fit for the use for which it is required.

(2)P A structure shall be designed to have adequate :
- structural resistance,
- serviceability, and
- durability.

(3)P In the case of fire, the structural resistance shall be adequate for the required period of time.

NOTE See also EN 1991-1-2

(4)P A structure shall be designed and executed in such a way that it will not be damaged by events such as :
- explosion,
- impact, and
- the consequences of human errors,

to an extent disproportionate to the original cause.

NOTE 1 The events to be taken into account are those agreed for an individual project with the client and the relevant authority.

NOTE 2 Further information is given in EN 1991-1-7.

(5)P Potential damage shall be avoided or limited by appropriate choice of one or more of the following :
- avoiding, eliminating or reducing the hazards to which the structure can be subjected;
- selecting a structural form which has low sensitivity to the hazards considered ;
- selecting a structural form and design that can survive adequately the accidental removal of an individual member or a limited part of the structure, or the occurrence of acceptable localised damage ;
- avoiding as far as possible structural systems that can collapse without warning ;
- tying the structural members together.

Table B2 - Recommended minimum values for reliability index β (ultimate limit states)

Reliability Class	Minimum values for β	
	1 year reference period	50 years reference period
RC3	5,2	4,3
RC2	4,7	3,8
RC1	4,2	3,3

NOTE A design using EN 1990 with the partial factors given in annex A1 and EN 1991 to EN 1999 is considered generally to lead to a structure with a β value greater than 3,8 for a 50 year reference period. Reliability classes for members of the structure above RC3 are not further considered in this Annex, since these structures each require individual consideration.

Table C1 - Relation between β and P_f

P_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
β	1,28	2,32	3,09	3,72	4,27	4,75	5,20

Required reliability

NS-EN 1990:2002+A1+AC+NA

EN 1990:2002 (E)

$P_f = \text{Prob}(g \leq 0)$ (C.2a)

If R is the resistance and E the effect of actions, the performance function g is :

$g = R - E$ (C.2b)

with R, E and g random variables.

(3) If g is Normally distributed, β is taken as :

$$\beta = \frac{\mu_g}{\sigma_g} \quad \text{(C.2c)}$$

where :

μ_g is the mean value of g, and
σ_g is its standard deviation,

so that :

$$\mu_g - \beta\sigma_g = 0 \quad \text{(C.2d)}$$

and

$$P_f = \text{Prob}(g \leq 0) = \text{Prob}(g \leq \mu_g - \beta\sigma_g) \quad \text{(C.2e)}$$

For other distributions of g, β is only a conventional measure of the reliability $P_s = (1 - P_f)$.

- Characteristic load values have a yearly probability of exceedence of 0.02 for climatic loads. Similar for other variable loads.
- Partial factors on
  Resistance
  Effect of actions
  ensure reliability in accordance with EN1990 for loads defines in EN1991
- Fender reaction force taken as characteristic variable load
- Load factor taken as variable load in ULS
  - What reliability level is achieved?

Accidental actions

4.6 Accidental actions caused by ship traffic

4.6.1 General

(1) Accidental actions due to collisions from ships should be determined taking account of, amongst other things, the following:

- the type of waterway,
- the flood conditions,
- the type and draught of vessels and their impact behaviour, and
- the type of the structures and their energy dissipation characteristics.

(2) The types of ships on inland waterways to be taken into account in the case of ship impact on structures should be classified according to the CEMT classification system.

NOTE The CEMT classification is given in Table C.3 in Annex C.

(3) The characteristics of ships on sea waterways to be taken into account in the case of ship impact on structures should be defined.

NOTE 1 The National Annex may define a classification system for ships on sea waterways. Table C Annex C gives an indicative classification for such ships.

NOTE 2 For information on the probabilistic modelling of ship collision, see Annex B.

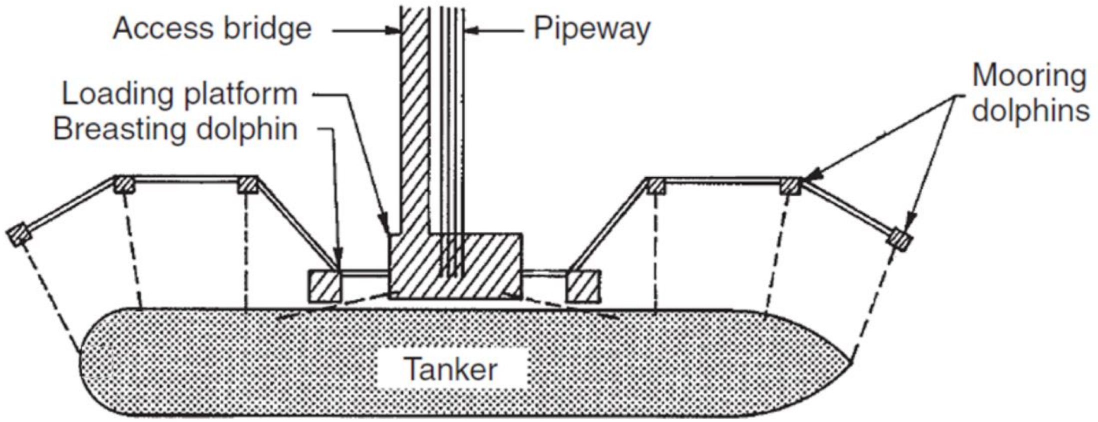
(4) Where the design values for actions due to ship impact are determined by advanced methods effects of hydrodynamic added mass should be taken into account.

(5) The action due to impact should be represented by two mutually exclusive forces:

- a frontal force F_{dx};
- a lateral force with a component F_{dy} acting perpendicularly to the frontal impact force and a fri component F_R parallel to F_{dx}.

(6) Structures designed to accept ship impact in normal operating conditions (e.g. quay walls breasting dolphins) are out of the scope of this part of EN 1991.

- Quay walls and breasting dolphins are «out of the scope»
- Does this mean they are exempt from the reliability requirements?
    - Probably yes…
- Does this apply to other components?



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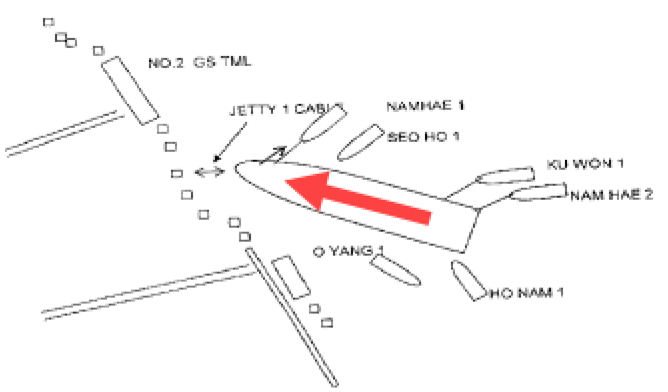
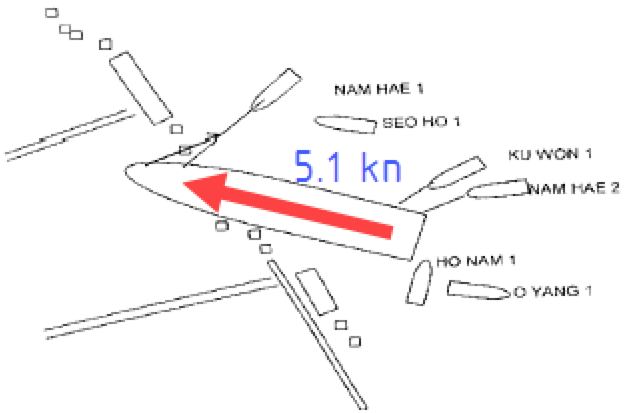
Wu Yi San allision, Yeosu, South Korea, 2014-01-31

Wu Yi San allision, Yeosu, South Korea, 2014-01-31



<Tug situation prior to collision with Pier>

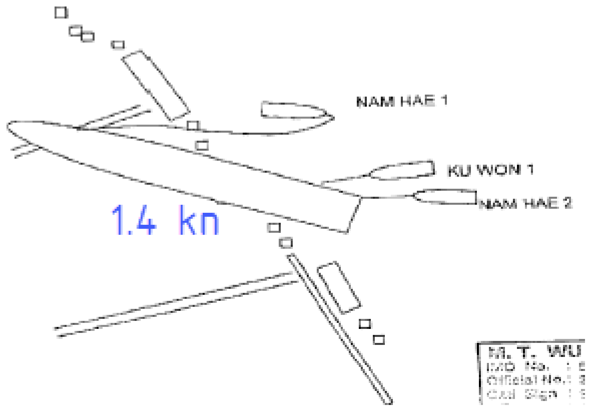


<Tug situation after first contact with Dolphin>

* O Yang 1 at port bow escaped to avoid collision with pier (upper left)

* Seo Ho 1 on starboard was unable to do its job and waited outside (upper right)

* Nam Hae 1's towing rope climbed onto the dolphin, making Nam Hae 1 unable to do its job (lower left)



<Tug situation after secondary collision with

- Ship under pilot control
- Assisted by six tugs

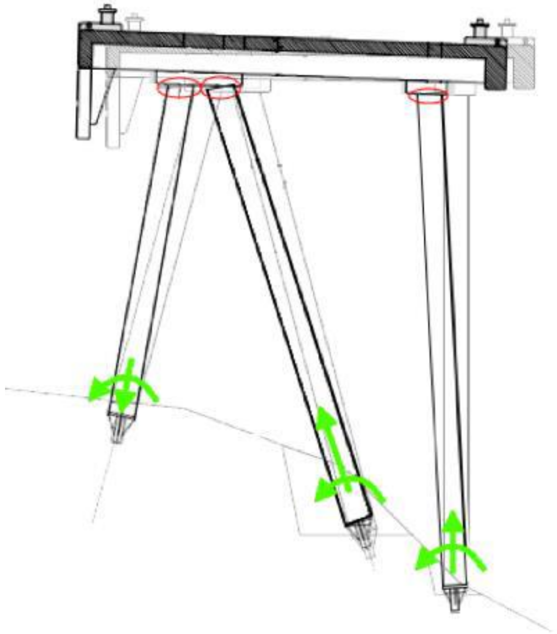
- Incident happened under intended use
- Adequate assistance
- No mechanical errors

- No human error apart from miscalculation
- Breach of port protocol

- ULS or ALS?

MSC Preziosa, Honningsvåg, 2017

- Fall winds during berthing
- Dropped bow starboard anchor
- Quarter point impact
- Unknown impact energy
- Pier close to collapse
- ULS or ALS?



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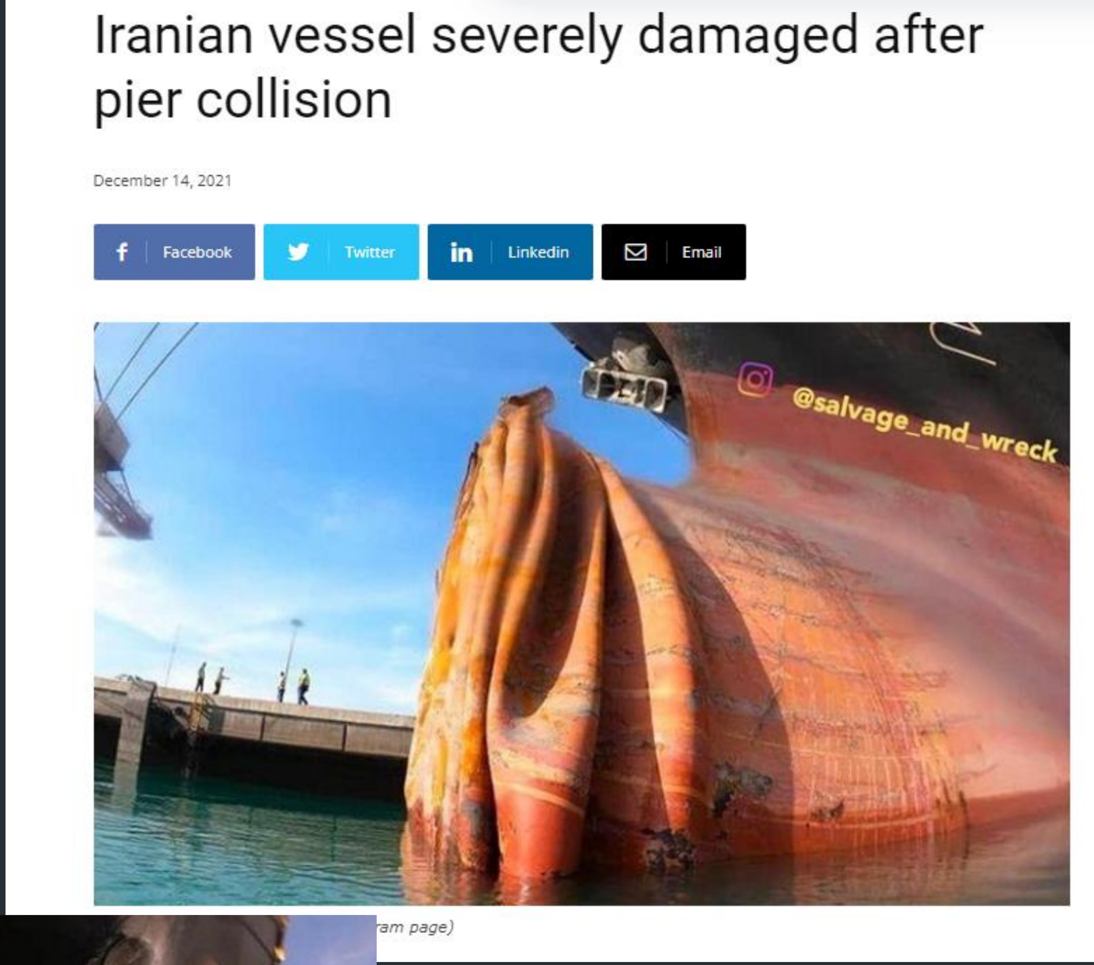
Strategies

- Just build strong enough?!
- Redundancies
- Partial failure mechanisms
- Risk/consequence mitigation


Iranian vessel severely damaged after pier collision

December 14, 2021

Facebook Twitter Linkedin Email

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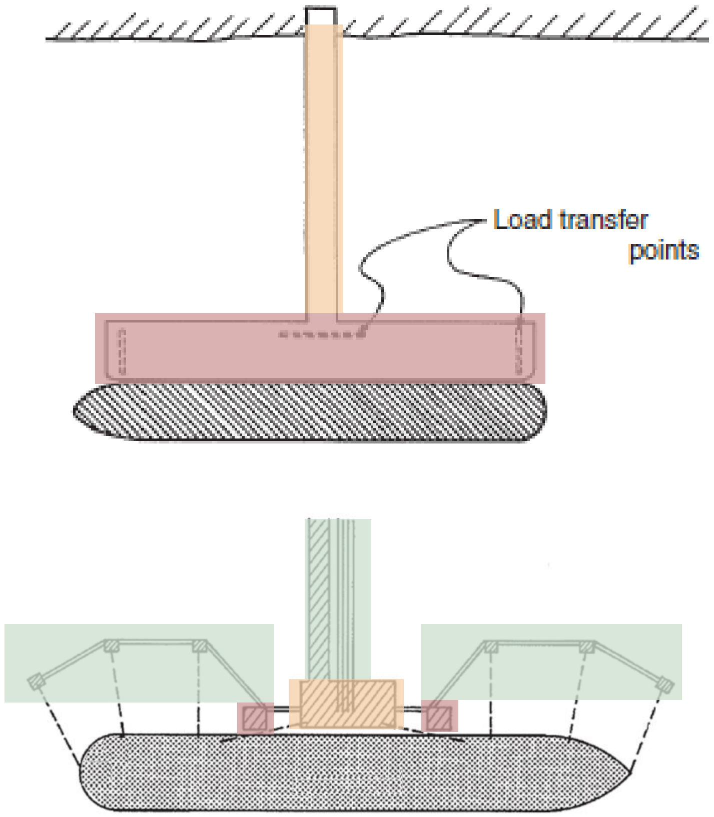
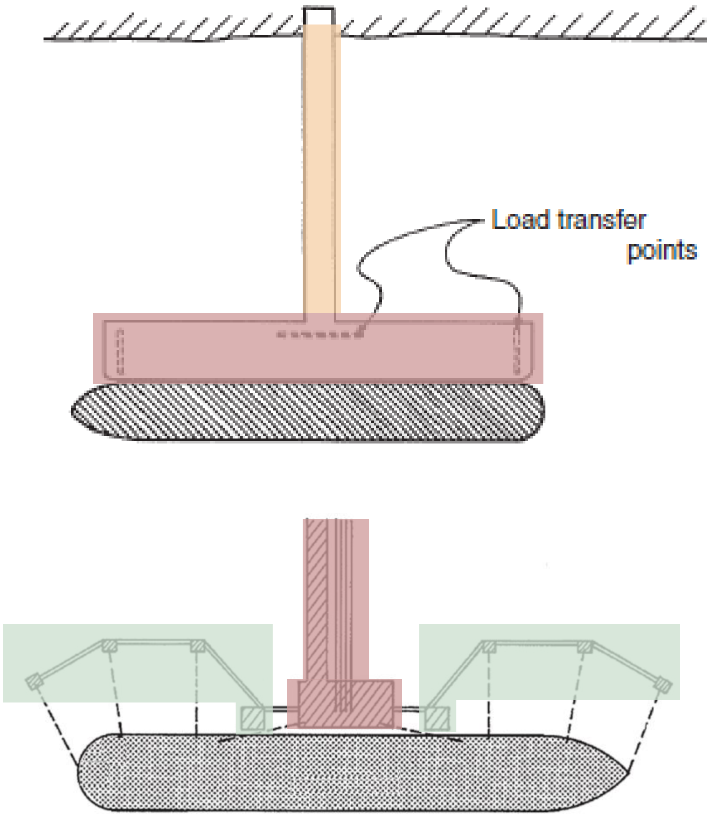
Structural strategies

Probability of failure



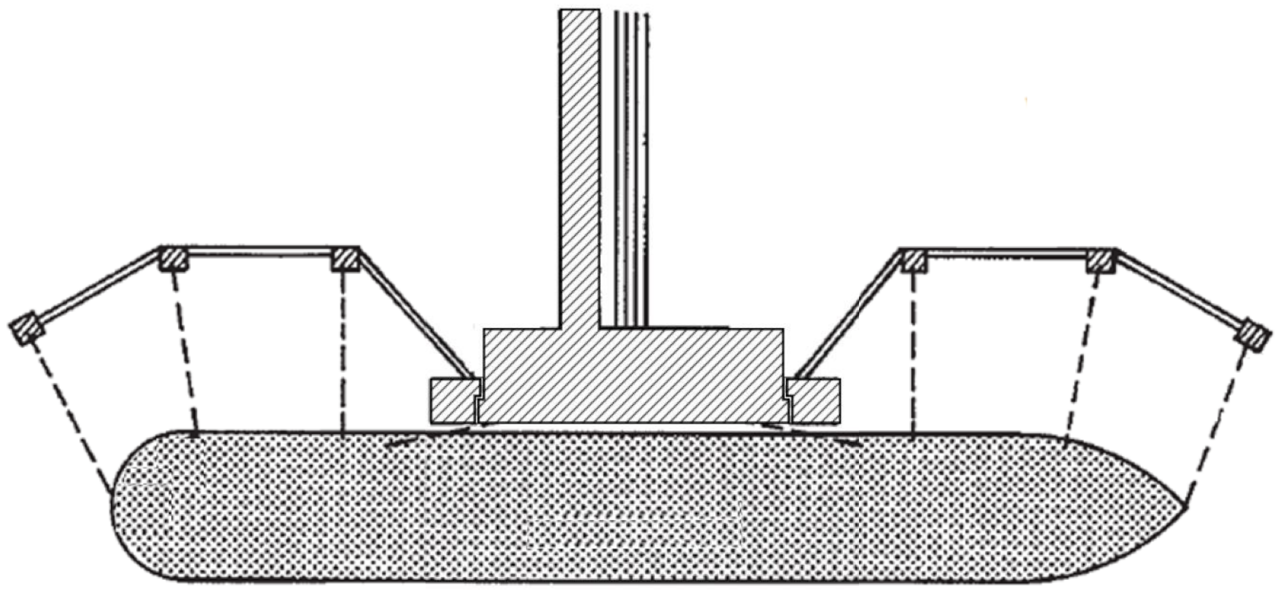
Consequence of failure



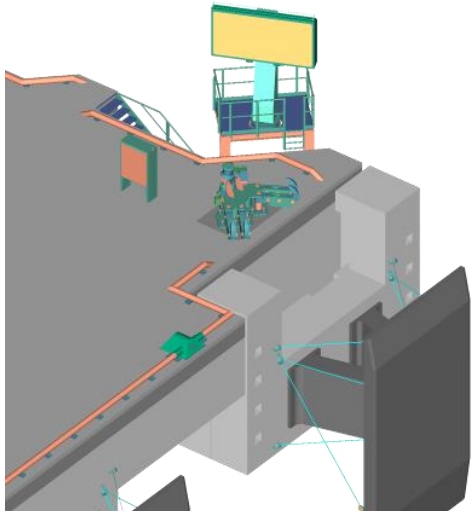
Structural strategies

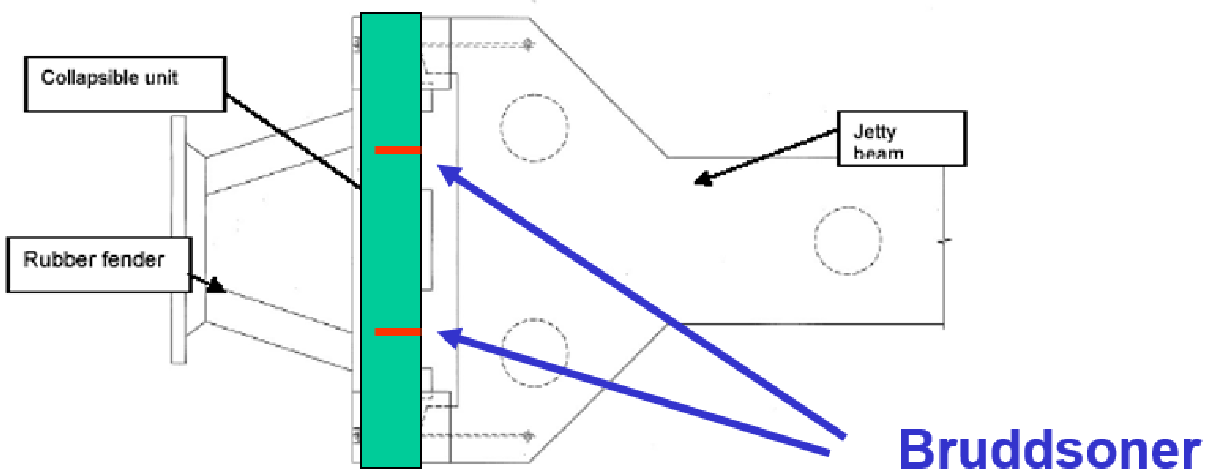
Can the design be improved upon?

Figure 3.12 Typical berth for tankers



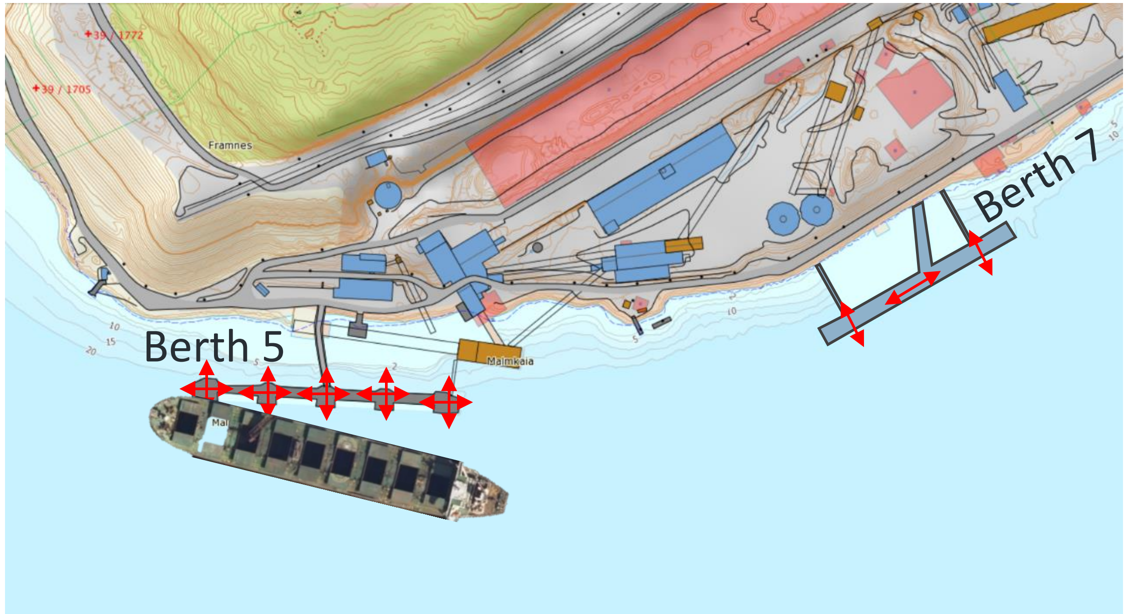
Partial failure – additional energy absorption





- Collapsible fender units in use at Hammerfest LNG and Nyhamna
- Can handle minor accidental cases – 100-400 % of normal berthing energy
- Design must ensure ductile behaviour in failure – give the steel room to deform

LKAB Narvik – different strategies



- Partially independent load bearing structures => the loading platform can be used (with care) after a collission
- The new pier have no redundancies, and will be closed after an incident

Mitigating risk/concequences

- Piers closed to public access (or access minimised) apart from embarking or disembarking
- Independent failure modes
- Operational requirements
  - Minimise personel at risk
- Emissions due to ship collisions handled through terminal design
  - *Storulykkeforskriften* (Major accident regulation) – risk contours

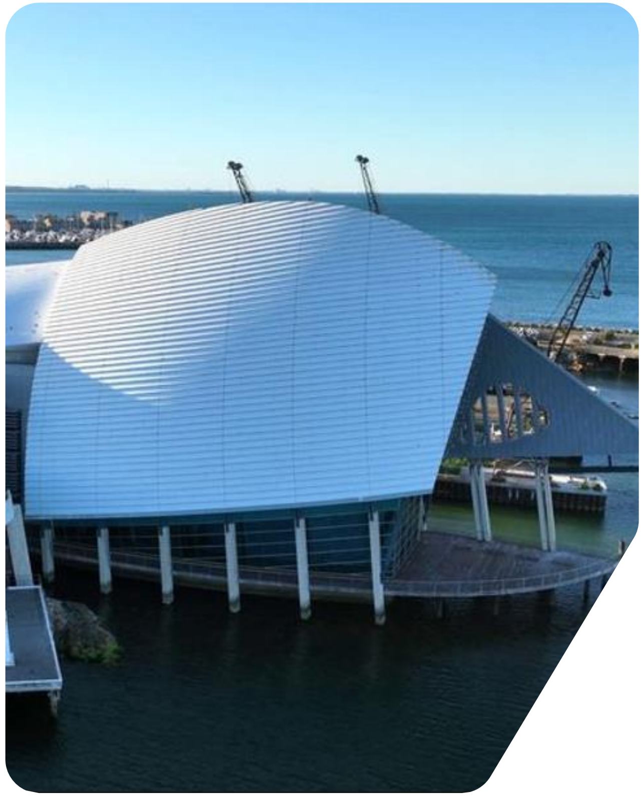
Final words

- Structures that are exposed to ship impact can fail
- Failure of these structures must be acceptible to society
- Structures where failure is unaccaptable must not be exposed to ship impact

Be vigilant

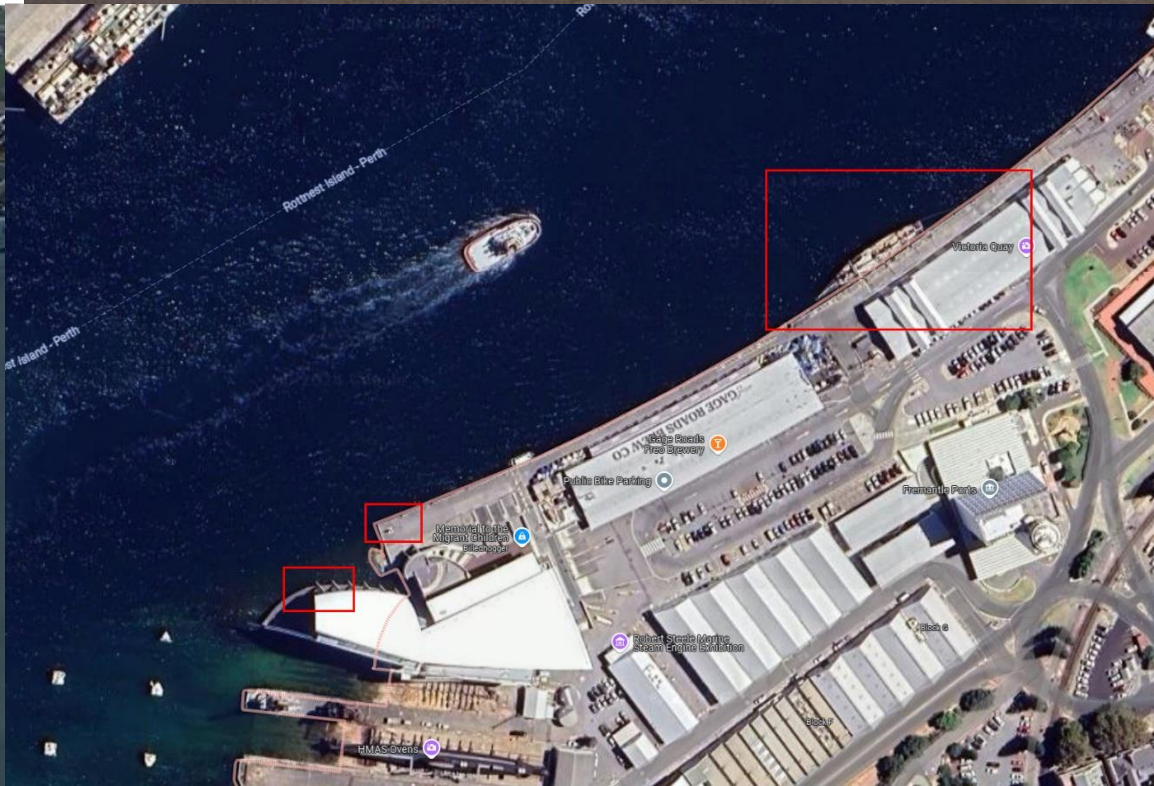
Tromsø

Perth



Maersk Shekou, Perth, 2024-08-30

- 332 m LOA | DWT 108,000 | TEU 8,800
- Collision during channel entrance assisted by four tugs
- Hit museum roof, pier and historic ship (STS Leeuwin II)

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