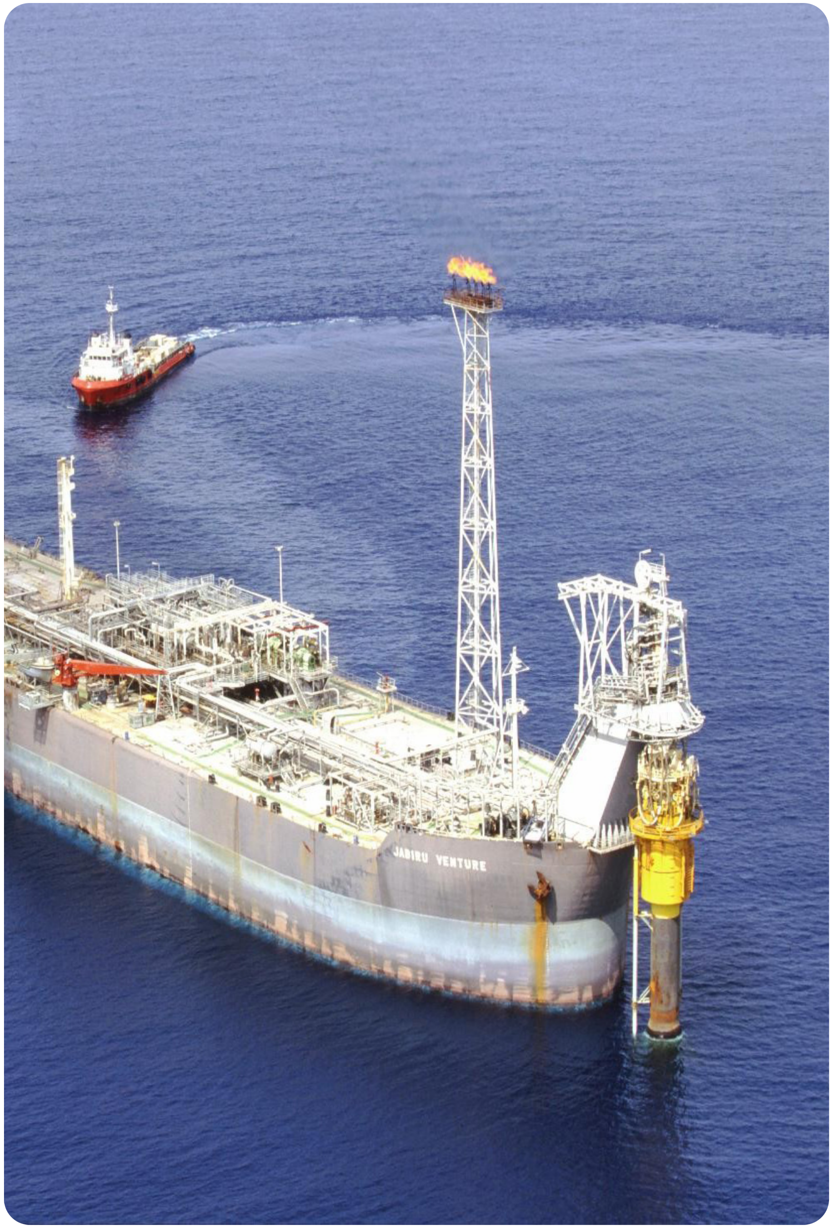


FPSO Hull Structures

Luciano Musumeci
Senior Naval Architect
Lloyd's Register EMEA

FPSO Hull Structures*

- Introduction
  - *LR and a cup of coffee…*
  - *FPSO: Which shape to use?*
- FPSO Vs. Trading tankers
- Example of different FPSOs
- Loads:
  - *Global hull loading*
  - *Other loads and model tests*
- Structural assessment:
  - *Hull strength assessment*
  - *Fatigue assessment*
  - *Corrosion*
- General advices for FPSO structural design

**Oil FPSO and LNG FPSO (FLNG)*

INTRODUCTION

It started with a cup of coffee…

…to provide merchants and underwriters recorded information on the quality of their vessels

- ❑ World's first Class Society established in 1760
- ❑ 186 countries covered with almost 250 offices
- ❑ Three business streams:
  - ✓ Marine and Offshore,
  - ✓ Energy,
  - ✓ Management Systems.

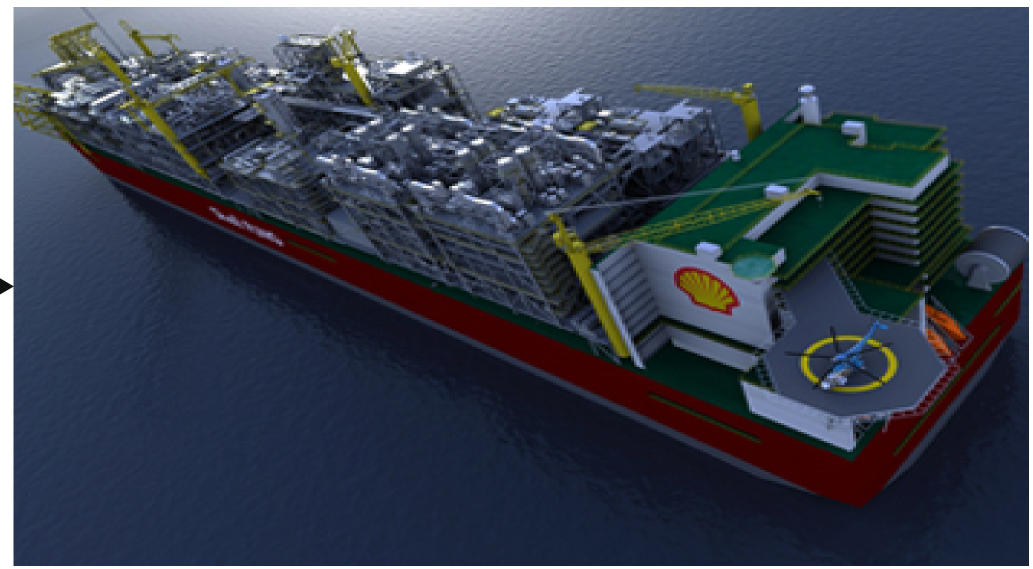
The Edward Lloyd's coffee house

LR is financially and technically independent of any government or commercial interests and has been so since the foundation

Lloyd's Register and the offshore business

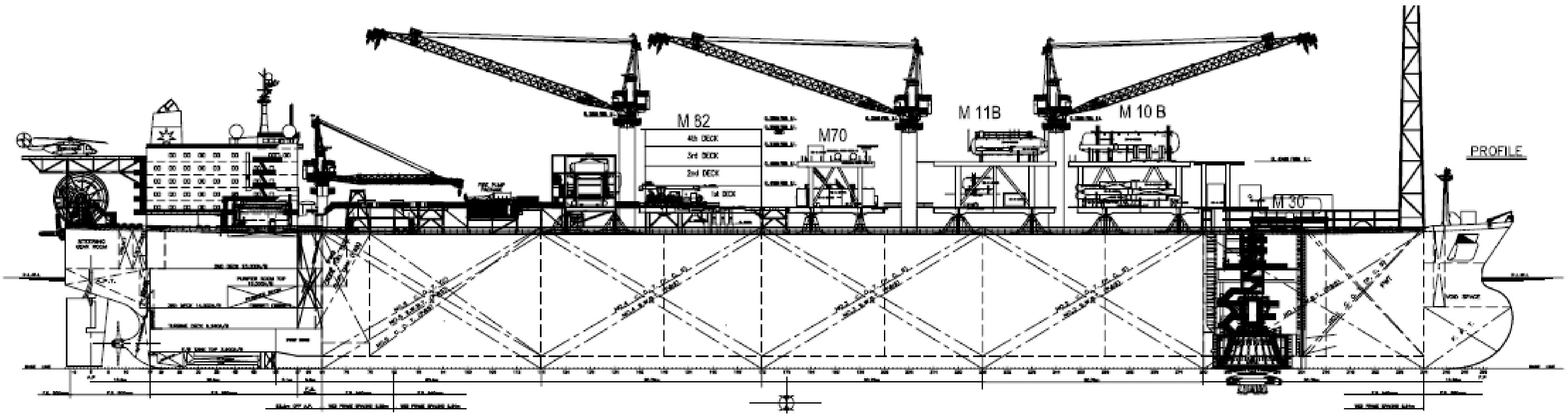
- Assigned class to the world's first FPSO: Shell Castellon

- Assigned class to the world's largest FLNG: Shell Prelude




FPSO:
Which shape to use?

Typical structural arrangement of a ship-shaped unit



- ❑ Plated steel stiffened panels
- ❑ Stiffener spacing of 800 – 900 mm
- ❑ Transverse frames every 4 - 5 m
- ❑ Transverse bulkheads every 30 - 40 m
- ❑ Full length longitudinal bulkheads

They are not all ship-shaped!!!

Concrete hull form?

Challenges to be addressed:

- Minimal design and service experience for floating units.
- Current practice (design methodologies, fabrication yards etc.) based on steel.

FPSO HULL STRUCTURE COMPARED TO TRADING TANKER

FPSO hull structure compared to trading tanker

- The majority of FPSOs are ship-shaped units

&

- Design of tankers has been standardised and harmonised
  (IACS – Common Structural Rules for Double Hull Oil Tankers)

<u>Design of ship-shaped FPSOs therefore should follow typical Ship Rules?</u>

Terminology

IACS – International Association of Classification Societies

CSR – Common Structural Rules

ROU – Rules for Offshore Units

FPSO hull structure compared to trading tanker

Most visible differences…

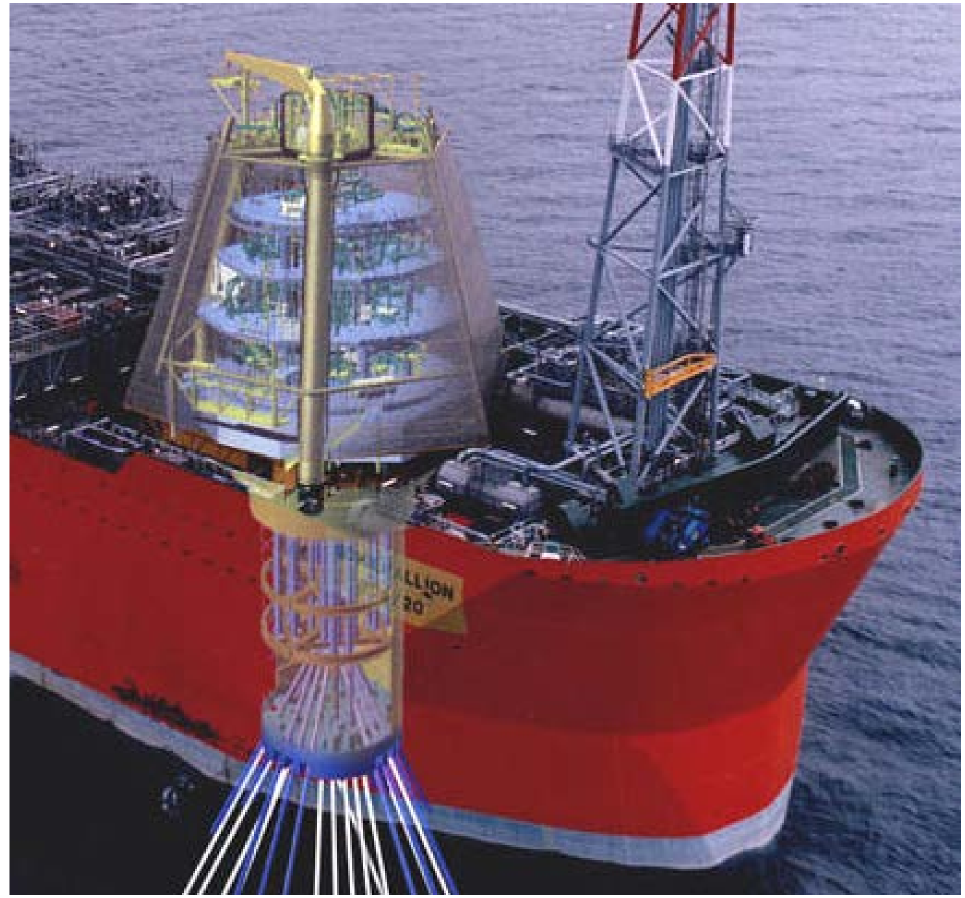
Typical topside structures:

- ❑ Process equipment;
- ❑ Cranes;
- ❑ Flares;
- ❑ Helicopter decks;
- ❑ Accommodation spaces;
- ❑ Etc.

FPSO hull structure compared to trading tanker

Less visible differences…

- Permanent mooring system
- Riser connections to sea-bed
- Designed to site specific environment
- Requirement to stay on location
- More complex legislation
- Different statistics of loads
- Etc.

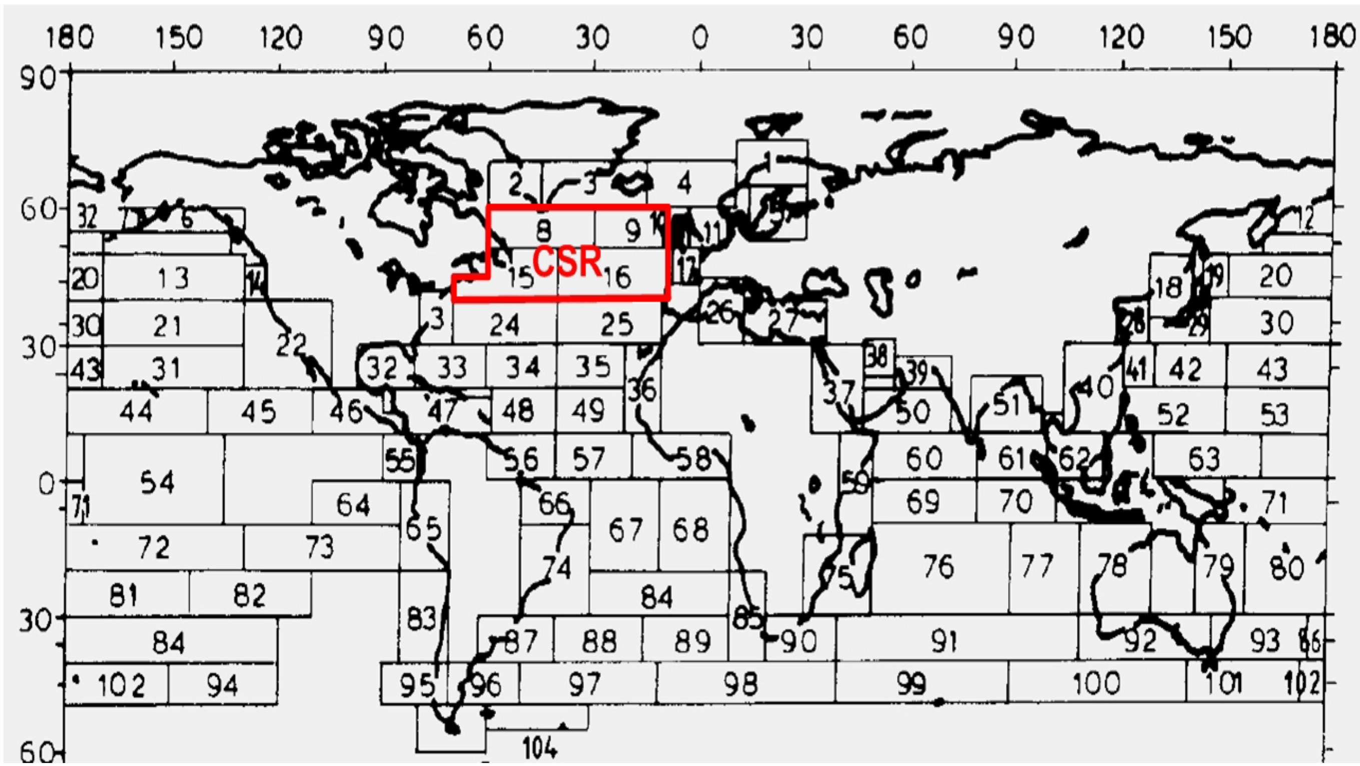


FPSO hull structure compared to trading tanker

Site-specific environment

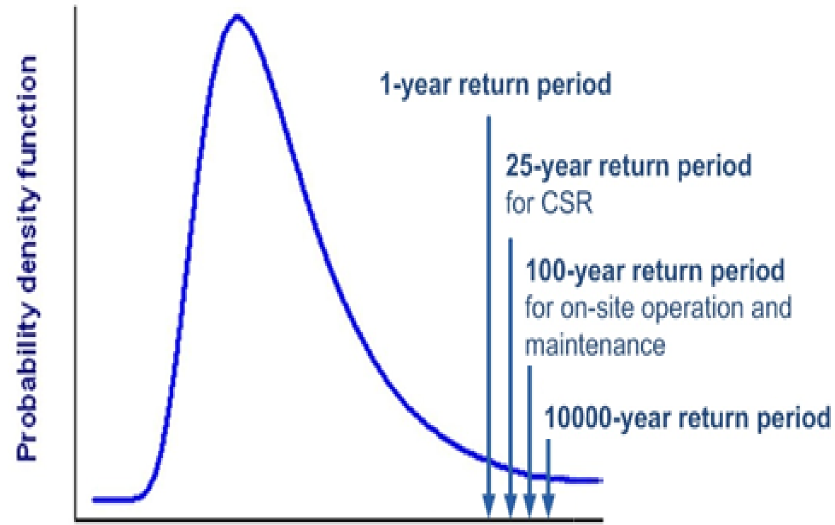
Trading tanker rules (CSR) are based on North Atlantic values.

FPSOs are designed for site specific environment (wind, waves, current, temperatures).



Statistics and nature of the loads

- different load return periods considered;
- different heading statistics.



LONDON/HEATHROW*

Extreme Annual Design Conditions							
n-Year Return Period Values of Extreme DB							
n=5 years		n=10 years		n=20 years		n=50 years	
Max	Min	Max	Min	Max	Min	Max	Min
32.5	**-7.0**	**33.7**	**-8.2**	**34.8**	**-9.3**	**36.3**	**-10.8**

*Ref. *"2005 ASHRAE Handbook - Fundamentals (SI)"*

(ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning Engineers)

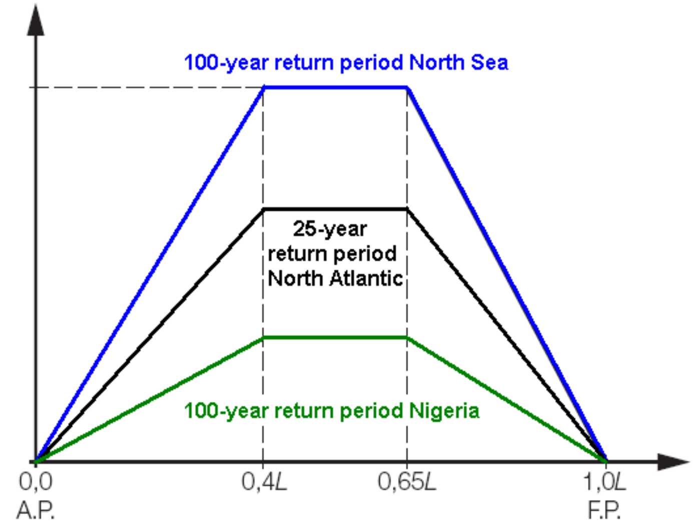
FPSO hull structure compared to trading tanker

Typical environmental criteria

Location	Hs* (metres)
Nigeria	4.0
Australia (non-cyclonic)	6.0 - 7.0
Australia (cyclonic)	10.0 -14.0
Brazil	7.0
U.K. Central	13.0
Gulf of Mexico**	14.5
Nova Scotia	16.0
West of Shetland	17.0

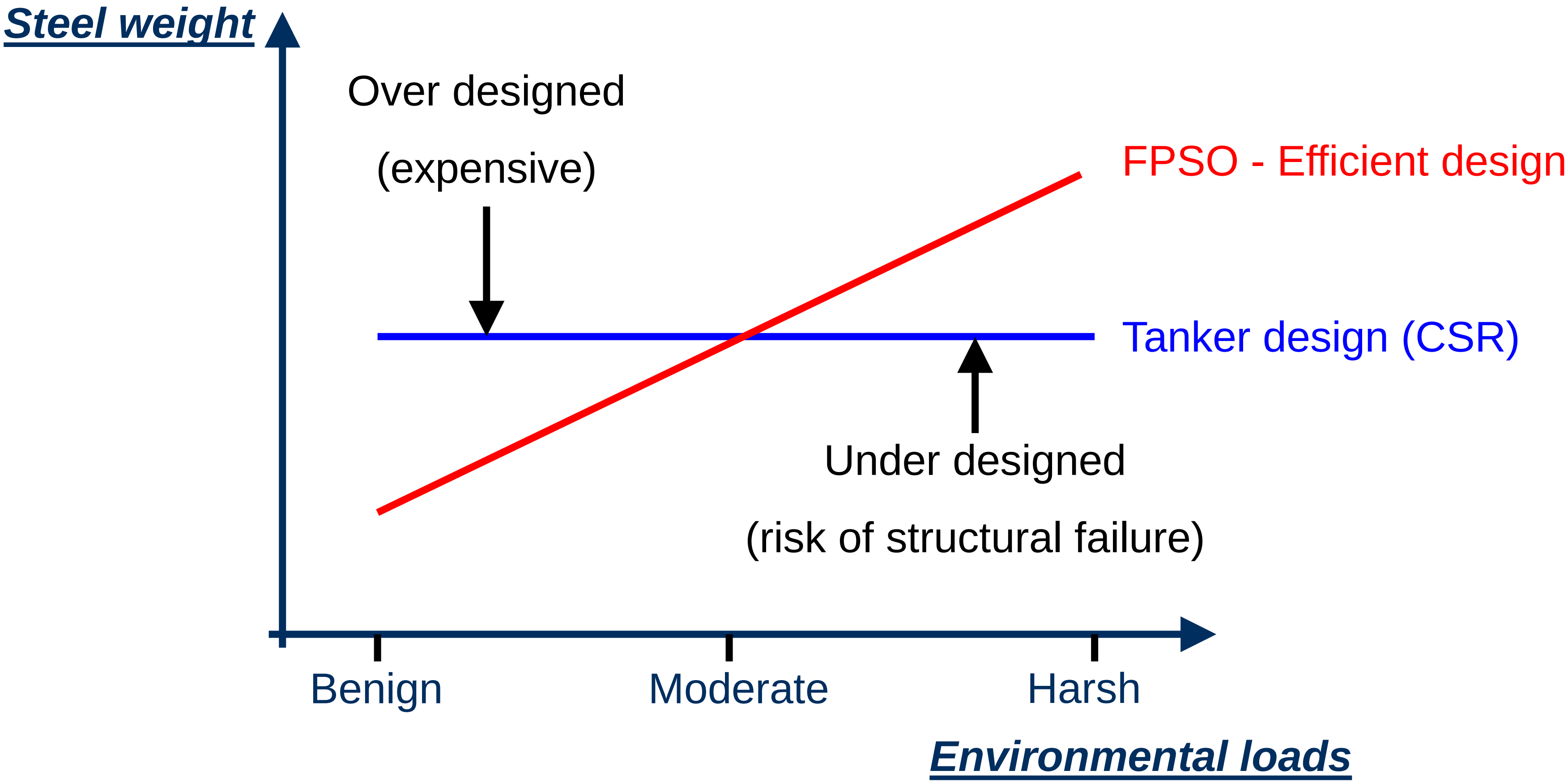
*Data relates to the "100 year" storm

**Gulf of Mexico includes hurricane waves

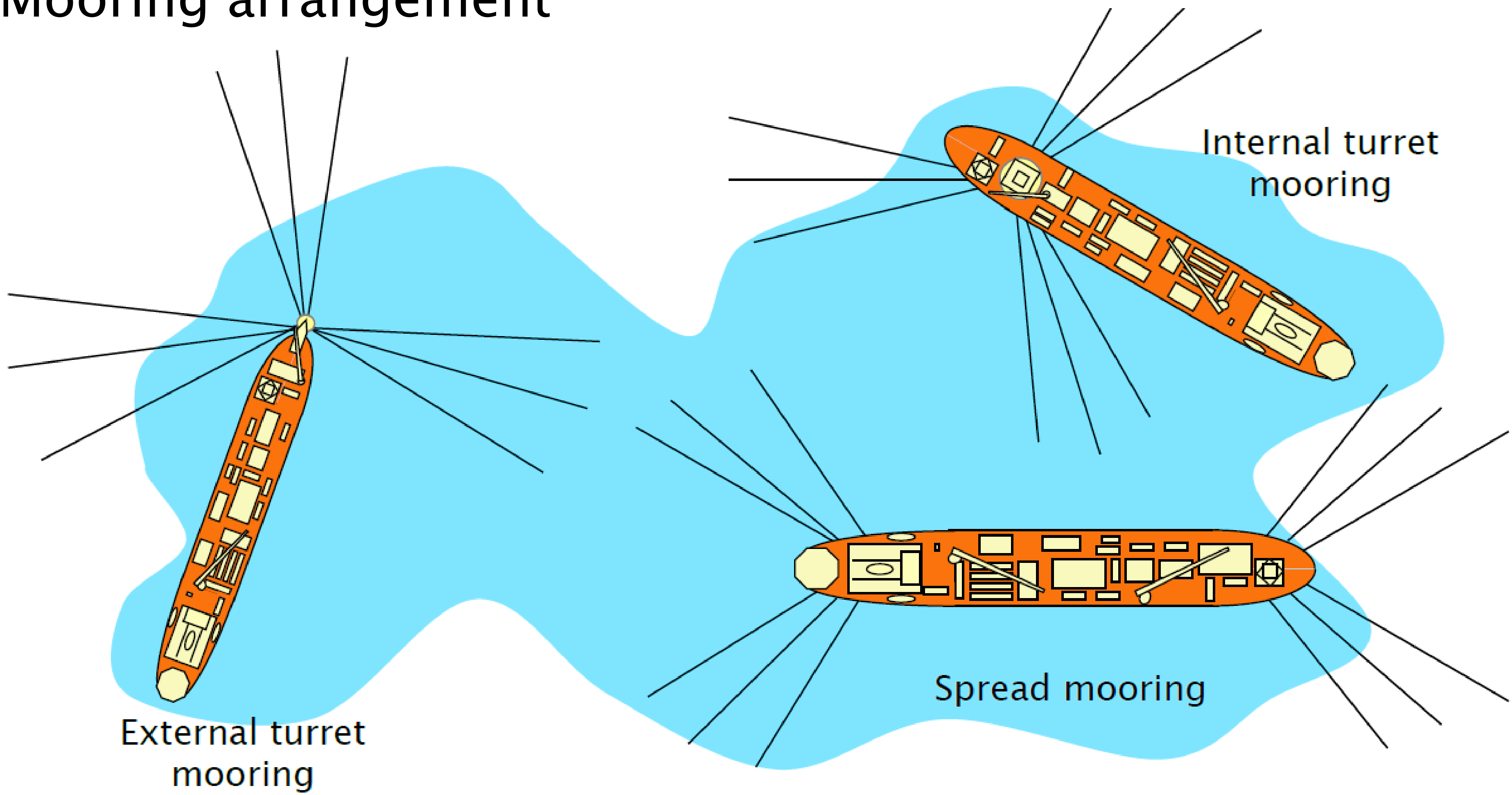


Wave bending moment distribution

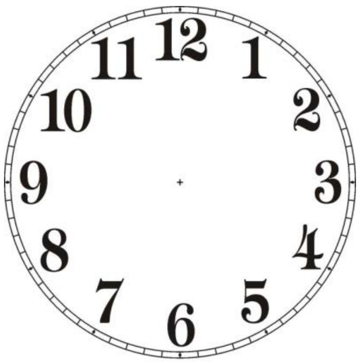
FPSO hull structure compared to trading tanker



Mooring arrangement



Heading probability

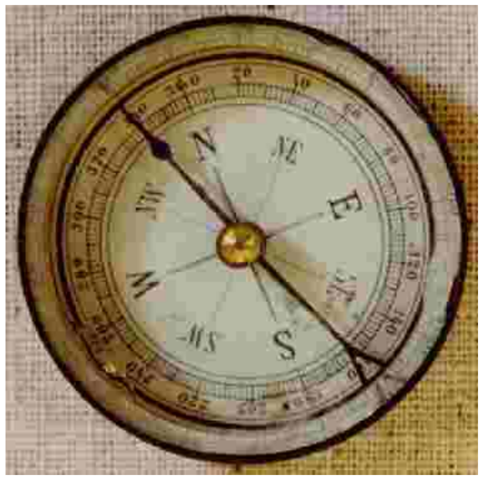


CSR considers an Omni-directional wave environment

Each wave heading relative to the ship has an equal probability of occurrence.

FPSOs do not operate in an Omni-directional wave environment:

- Weathervaning units predominately see waves between head sea and beam seas.
- Spread-moored units predominately see waves from one or two quadrants.



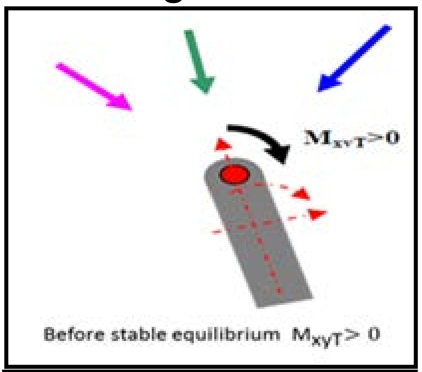
FPSO hull structure compared to trading tanker

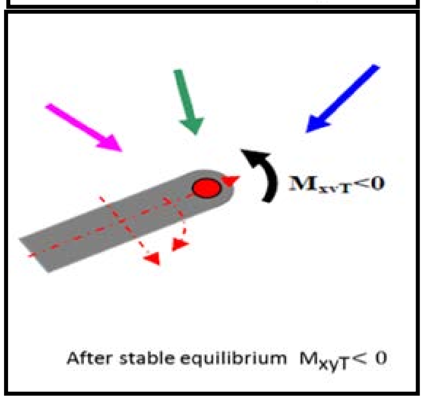
Site-specific heading analysis

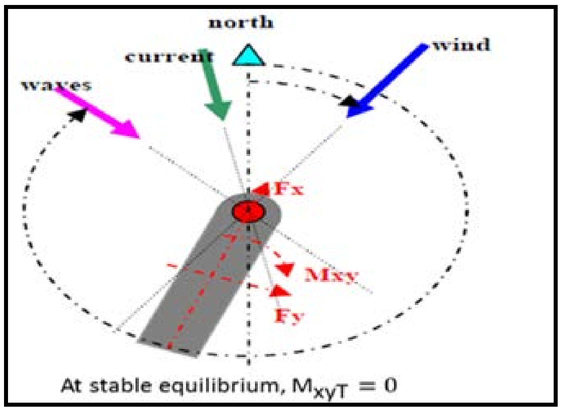
The MetOcean reports provide the input environmental data for the heading analysis;

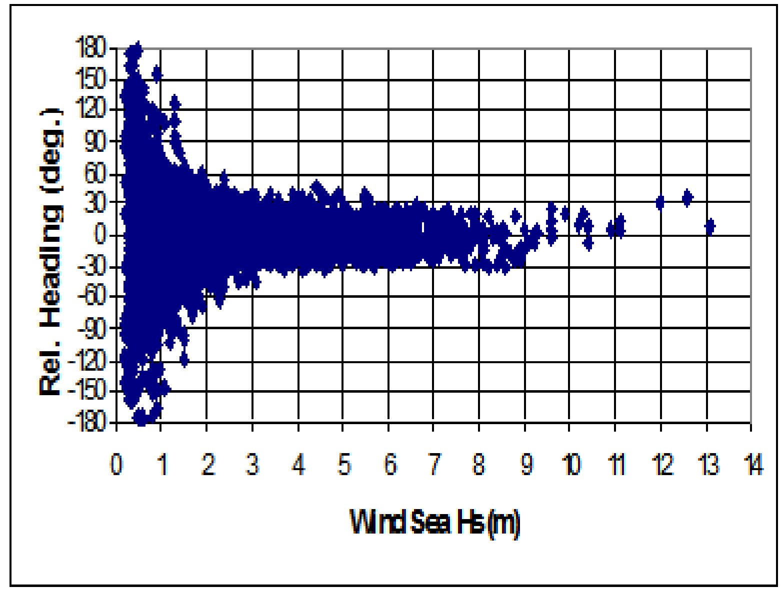
The mean vessel heading is determined for each sea state;

The long-term heading probability distribution is used to determine extreme loads.









Vessel relative heading to wind sea

FPSO hull structure compared to trading tanker

- Offshore bespoken load scenarios

Global hull girder loads								
Load component	Operation on-site		Inspection/maintenance		Transit		Flooded	
	S	S+D	S	S+D	S	S+D	S	S+D
$M_{v\text{-total}}$	$M_{sw\text{-perm-oper}}$	$M_{sw\text{-perm-oper}} + M_{wv}$	$M_{sw\text{-perm-maint}}$	$M_{sw\text{-perm-maint}} + M_{wv}$	$M_{sw\text{-perm-sea}}$	$M_{sw\text{-perm-sea}} + M_{wv}$	$M_{sw\text{-perm-flood}}$	$M_{sw\text{-perm-flood}} + M_{wv}$
$M_{h\text{-total}}$	–	M_h	–	M_h	–	M_h	–	M_h
Q	$Q_{sw\text{-perm-oper}}$	$Q_{sw\text{-perm-oper}} + Q_{wv}$	$Q_{sw\text{-perm-maint}}$	$Q_{sw\text{-perm-maint}} + Q_{wv}$	$Q_{sw\text{-perm-sea}}$	$Q_{sw\text{-perm-sea}} + Q_{wv}$	$Q_{sw\text{-perm-flood}}$	$Q_{sw\text{-perm-flood}} + Q_{WV}$

Local loads										
Load component		Space type	Operation on-site		Inspection/maintenance		Transit		Flooded	
			S	S+D	S	S+D	S	S+D	S	S+D
External sea pressure	P_{ex}	Exposed deck		P_{wdk_dyn}		$P_{wdk\text{-dyn}}$		$P_{wdk\text{-dyn}}$		$\max(P_{hys} + P_{ex\text{-dyn}}, P_{wdk\text{-dyn}})$
		Hull envelope	P_{hys}	$P_{hys} + P_{wv\text{-dyn}}$	P_{hys}	$P_{hys} + P_{wv\text{-dyn}}$	P_{hys}	$P_{hys} + P_{wv\text{-dyn}}$	P_{hys}	$P_{hys} + P_{wv\text{-dyn}}$
Liquid pressure	P_{in}	Ballast tanks	$P_{in\text{-air}} + P_{drop}$	$P_{in\text{-tk}} + P_{in\text{-dyn}}$	$P_{in\text{-test}}$	$P_{in\text{-test}} + P_{in\text{-dyn}}$	$P_{in\text{-air}} + P_{drop}$	$P_{in\text{-tk}} + P_{in\text{-dyn}}$	$P_{in\text{-flood}}$	$\max(P_{in\text{-tk}}, P_{in\text{-flood}}) + P_{in\text{-dyn}}$
		Cargo tanks/ other tanks designed for liquid filling	$P_{in\text{-tk}} + P_{valve}$	$P_{in\text{-tk}} + P_{in\text{-dyn}}$	$\max(P_{in\text{-tk}} + P_{valve}, P_{in\text{-test}})$	$P_{in\text{-test}} + P_{in\text{-dyn}}$	$P_{in\text{-tk}} + P_{valve}$	$P_{in\text{-tk}} + P_{in\text{-dyn}}$	$P_{in\text{-flood}}$	$\max(P_{in\text{-tk}}, P_{in\text{-flood}}) + P_{in\text{-dyn}}$
		Fresh water and fuel/lube oil tanks	$P_{in\text{-air}}$	$P_{in\text{-tk}} + P_{in\text{-dyn}}$	$P_{in\text{-test}}$	$P_{in\text{-test}} + P_{in\text{-dyn}}$	$P_{in\text{-air}}$	$P_{in\text{-tk}} + P_{in\text{-dyn}}$	$P_{in\text{-flood}}$	$\max(P_{in\text{-tk}}, P_{in\text{-flood}}) + P_{in\text{-dyn}}$
		Water tight boundaries/ void spaces			$P_{in\text{-test}}$	$P_{in\text{-test}} + P_{in\text{-dyn}}$			$P_{in\text{-flood}}$	$\max(P_{in\text{-tk}}, P_{in\text{-flood}}) + P_{in\text{-dyn}}$
		Dry space							$P_{in\text{-flood}}$	$P_{in\text{-flood}} + P_{in\text{-dyn}}$
Deck loads	P_{dk}	Dry space	P_{stat}	$P_{stat} + P_{dk\text{-dyn}}$	P_{stat}	$P_{stat} + P_{dk\text{-dyn}}$	P_{stat}	$P_{stat} + P_{dk\text{-dyn}}$	P_{stat}	$P_{stat} + P_{dk\text{-dyn}}$

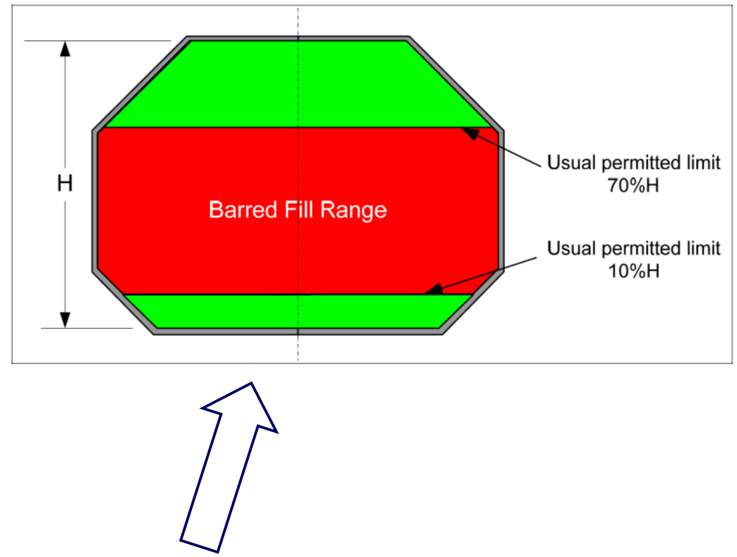
Risk Based Inspections and Offshore In-Water Survey

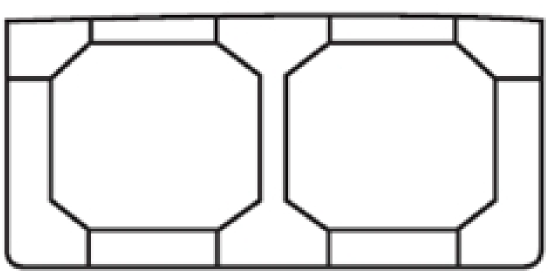
- Flexible approach in order to detect and monitor system, sub-system, equipment and component degradation.
- alternative to the traditional periodical survey regime

Important to ensure good access for inspection and maintenance at the design stage

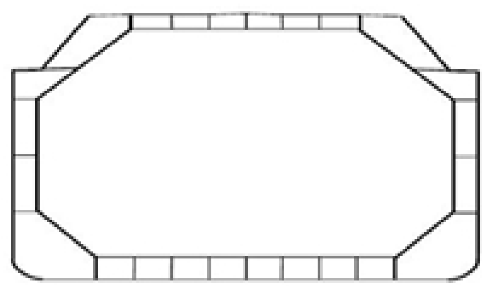
LNG FPSOs (FLNGs) hull structure Vs. Gas carriers

- Different hull types;
- No “barred fill range”;
- Site specific temperatures;
- Central cofferdam;
- “Recovery duration”;
- 10 000 year return period event;
- Etc.





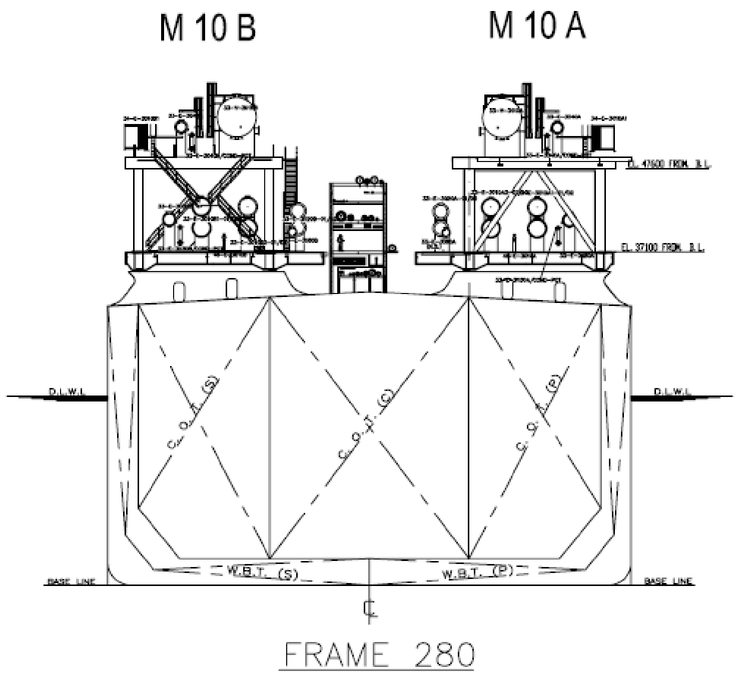
FLNG



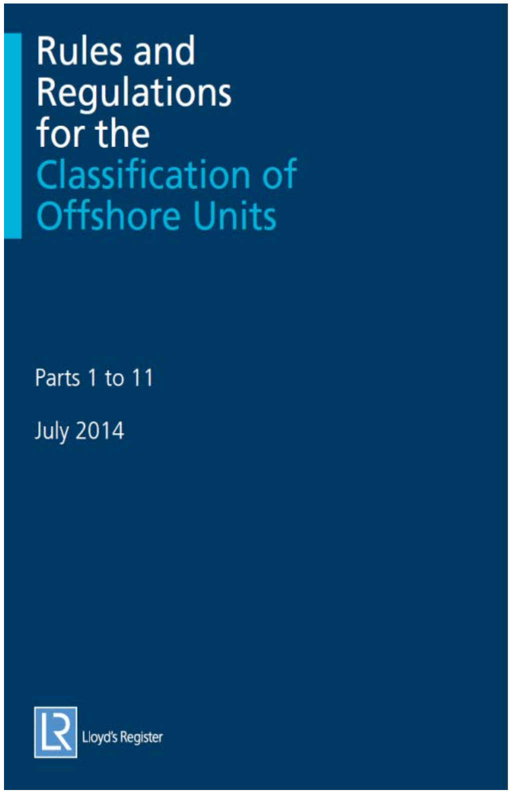
Gas carrier

Some factors affecting the hull structural arrangement:

- cargo type: oil or LNG;
- production/offloading rate and required storage capacity;
- single or double bottom;
- stability aspects;
- collision loads;
- Internal fluid motions (sloshing)
- loads from on-deck structure / equipment (topsides);
- access for inspection maintenance;
- mooring arrangement:
    - Internal or external turret
    - Spread mooring
- etc.



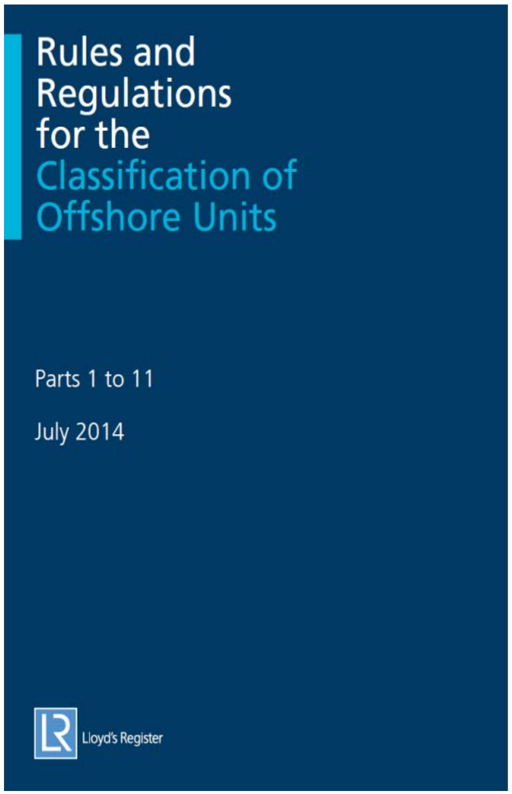
Lloyd's Register Rules



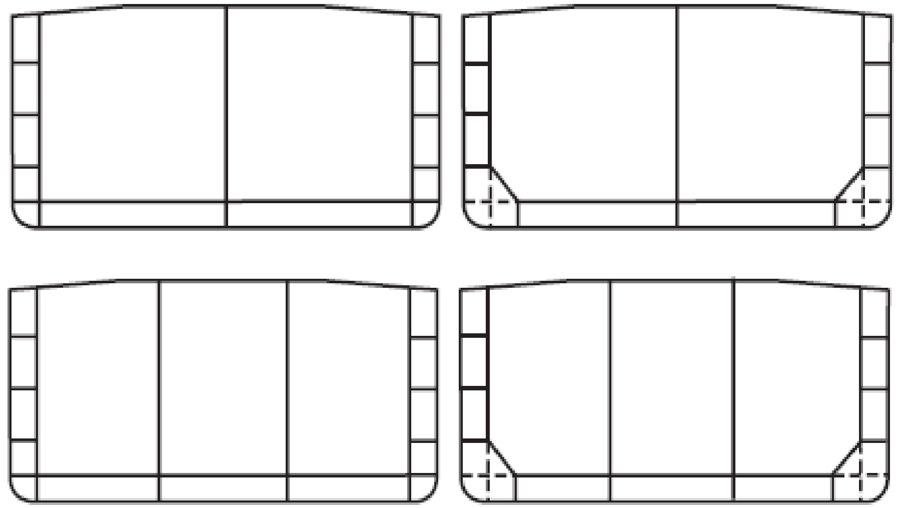
The Rules for Offshore Units address the differences between FPSOs and Tankers:

- ❑ Transparent methods based on sound engineering principles;
- ❑ Flexible to suit field development requirements (owner defined corrosion margins, load cases, etc.);
- ❑ Address all types of offshore structures (Semi-submersibles, TLP, Barges, Buoys, etc.).
- ❑ Not only structural issues – also Moorings / Electrical / Machinery / Safety systems.

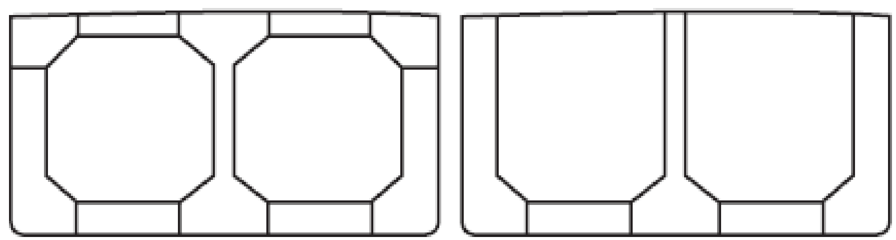
Lloyd's Register Rules – Some structural arrangements



OIL FPSO



LNG FPSO



EXAMPLES OF DIFFERENT FPSOs

Examples of different FPSOs

Terra Nova FPSO

Terra Nova FPSO

- Newfoundland
- Extremely harsh environment (100 year Hs ~ 17m)
- 90-100m water depth
- New build hull
- Lbp=277m, B=45.5m, Δ = 196,000 tons
- Turret moored
- Ice loading considered in design
- Design air temperature -18°C
- Disconnectable (due to iceberg and sea ice)
- Hull is twice the strength of typical tanker
- Capable of withstanding limited iceberg collision

Bonga FPSO

Examples of different FPSOs

Bonga FPSO

- Nigeria
- Benign environment (100 year Hs ~ 4m)
- 1000m water depth
- New build hull
- Lbp=295m, B=58m, Δ = 392,000 tons
- Spread moored
- First oil in 2005

Examples of different FPSOs

Peregrino FPSO

- Brazil
- Moderate (100 year Hs ~ 9.0m)
- 100m water depth
- Converted hull
- Lbp=320m, B=58m, Δ = 322,600 tons
- Turret moored
- First Oil 2011
- Disconnectable (allows flexibility with regard to installation)
- Hull almost new at time of conversion (year of build 2008)

Prelude FLNG (LNG FPSO)

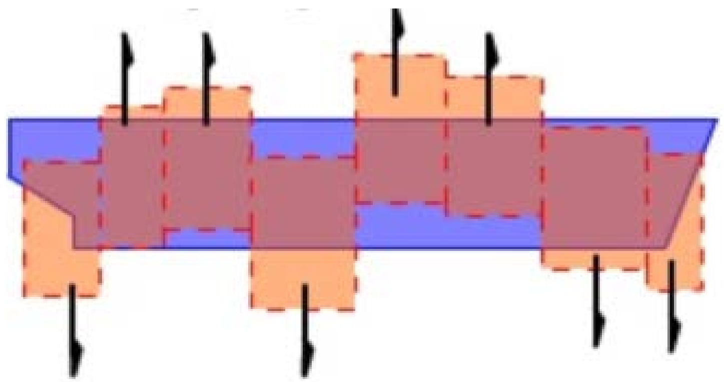
- Western Australia (Cyclonic)
- New build hull
- Largest floating unit ever built
- Lbp = 488 m, B = 74 m, Δ > 600,000 tons
- Turret moored
- LNG stored at −163 °C

GLOBAL HULL LOADING

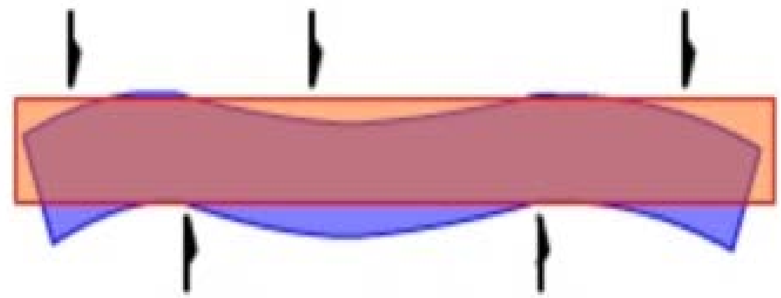
When vessel loading goes wrong

Global hull loading

Global shear



Global bending

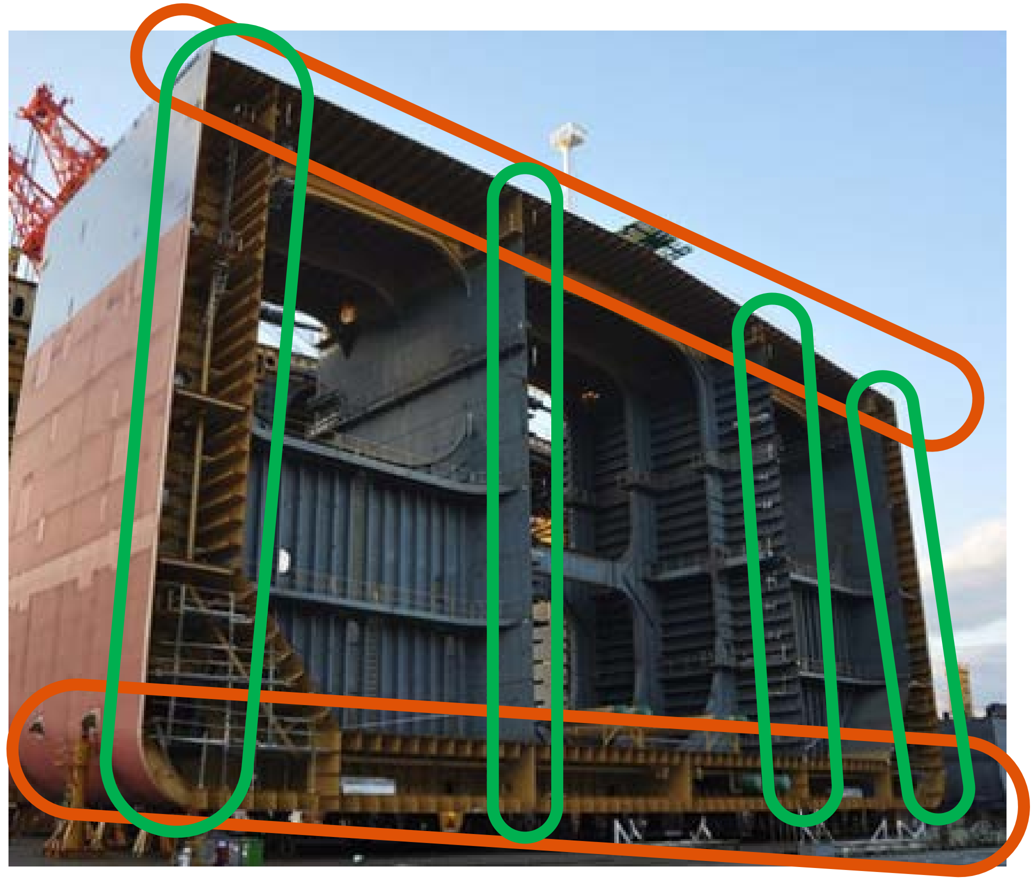


- Loads comprise: still water loads + wave loads;
- Must be evaluated at every point along vessel;
- Must remain below capacity of hull structure;
- Operation On-site, Maintenance, Transit/Disconnected and Flooded conditions to be considered.

Global hull loading

Global bending loads determine (mostly) longitudinal material in deck and bottom

Global shear loads determine (mostly) material in vertical longitudinal bulkheads



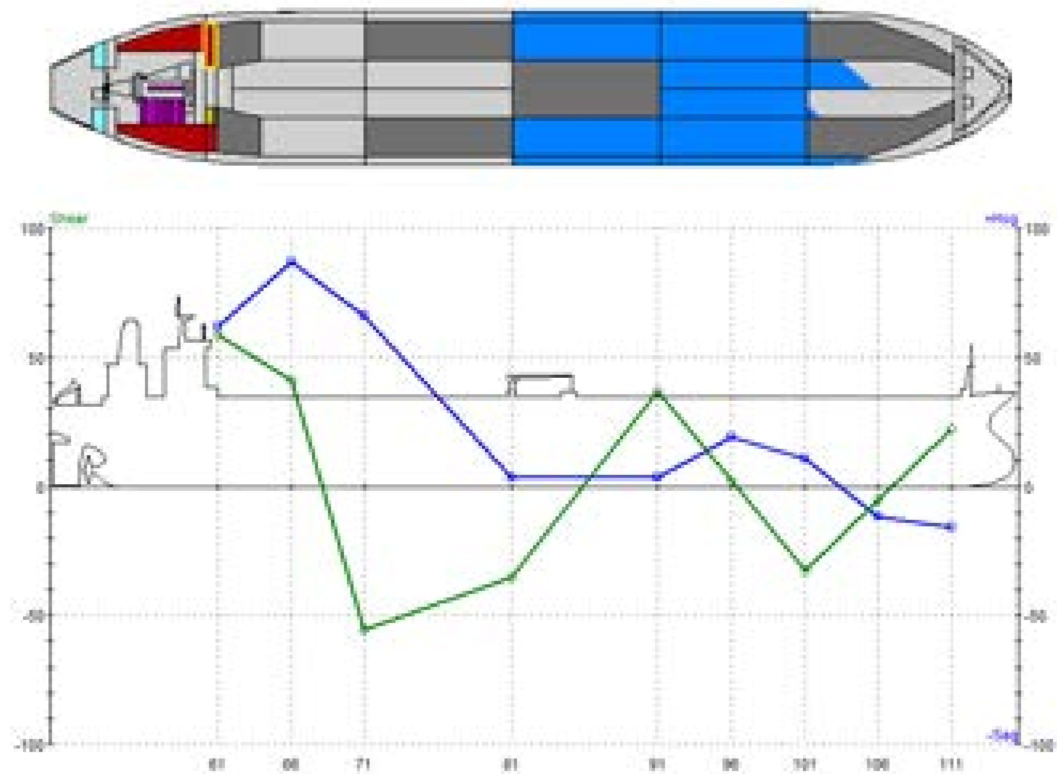
Still water global loads

Still water global loads comprise:

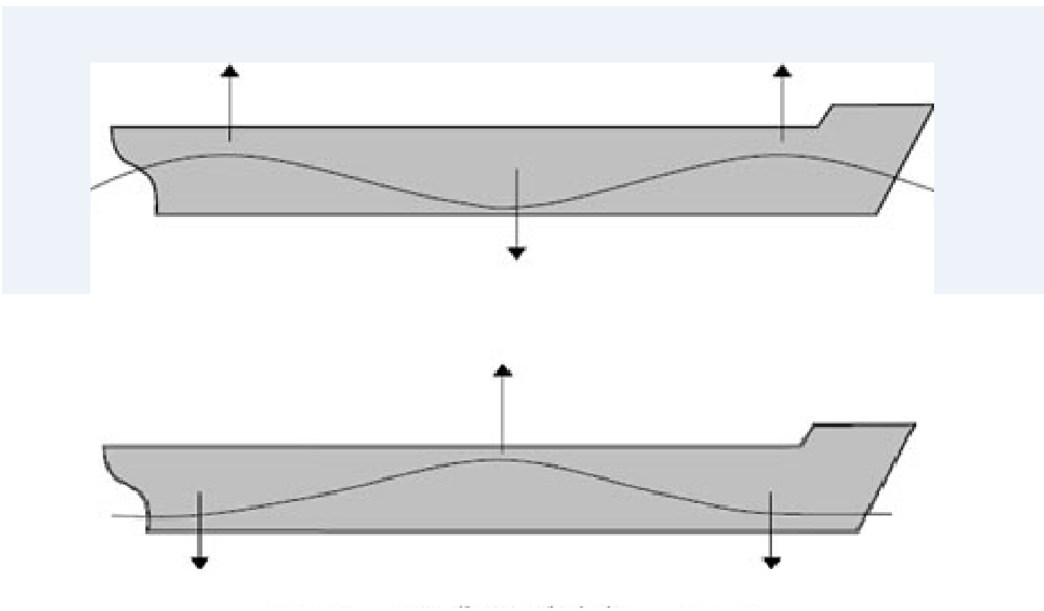
- ❑ Cargo loads;
- ❑ Empty hull weight;
- ❑ Buoyancy loads.

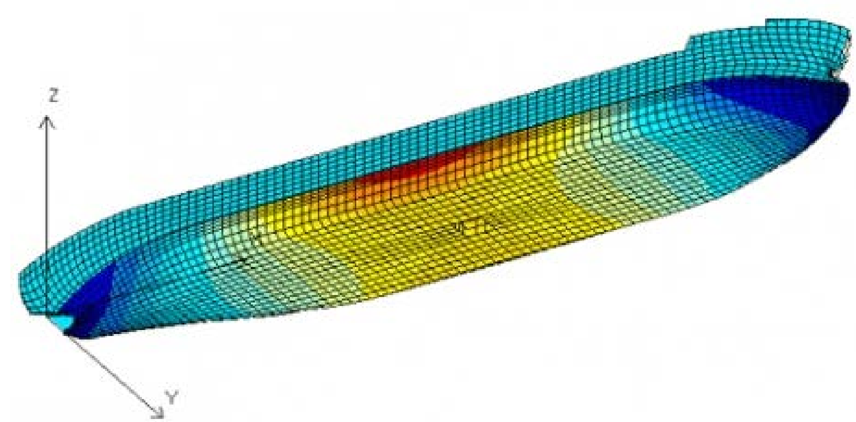
Still water loads of FPSO to consider:

- ❑ Maintenance conditions;
- ❑ All cargo arrangements;
- ❑ Inspection conditions;
- ❑ Weight of turret / mooring / risers etc.



Global wave loads on FPSO hull



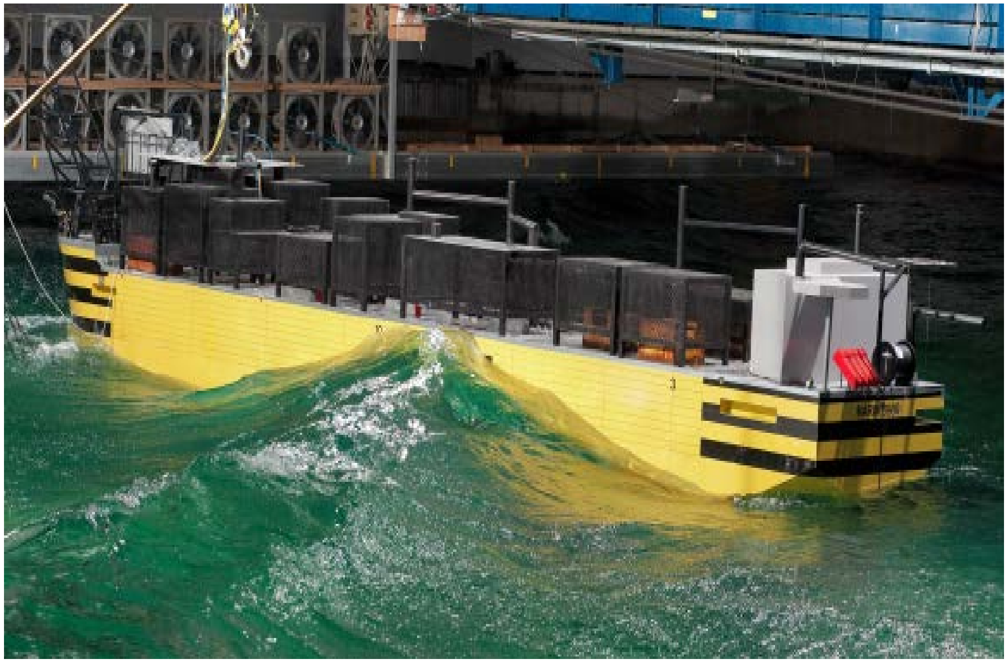


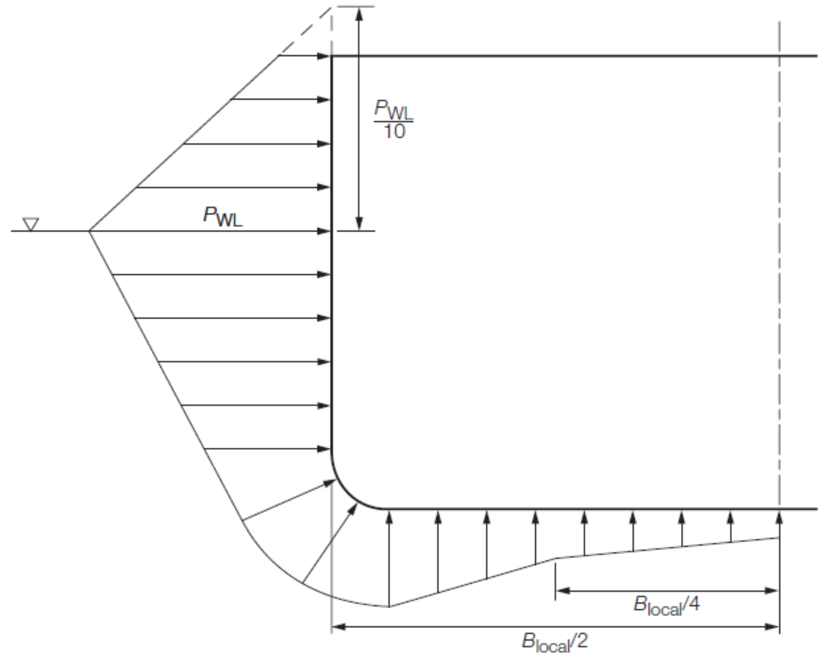
Wave loads are:

- ❑ site specific (require detailed knowledge of wave environment);
- ❑ complex to evaluate (compared to loads on ships).

OTHER LOADS AND MODEL TESTS

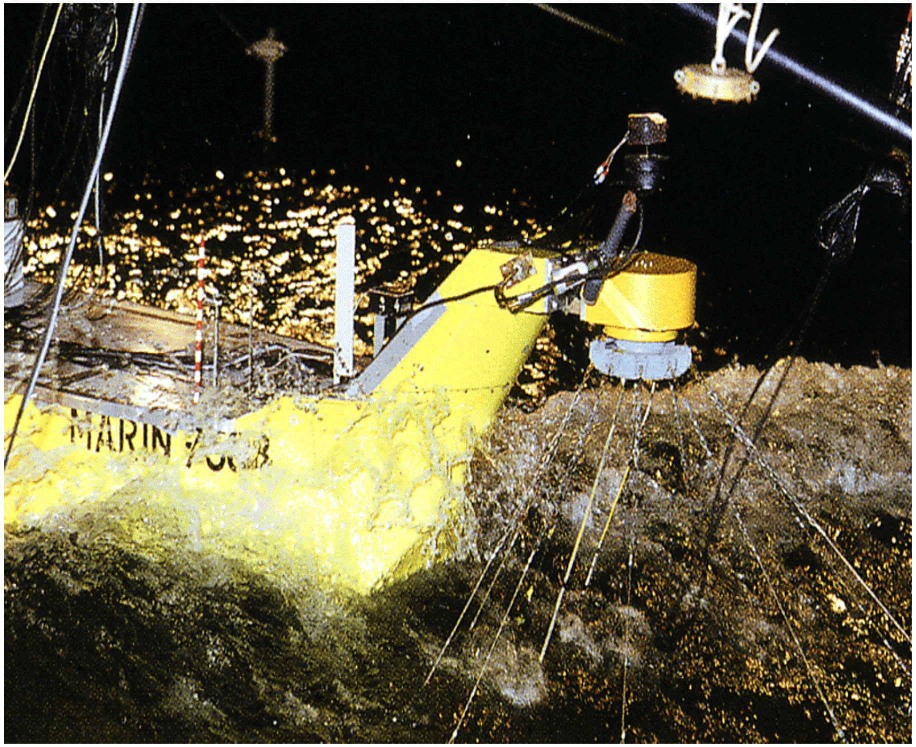
External wave pressure





Other loads and model tests

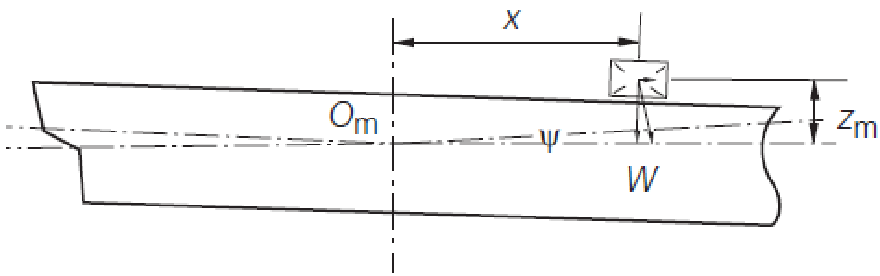
Wave impact loads both on-site and in transit



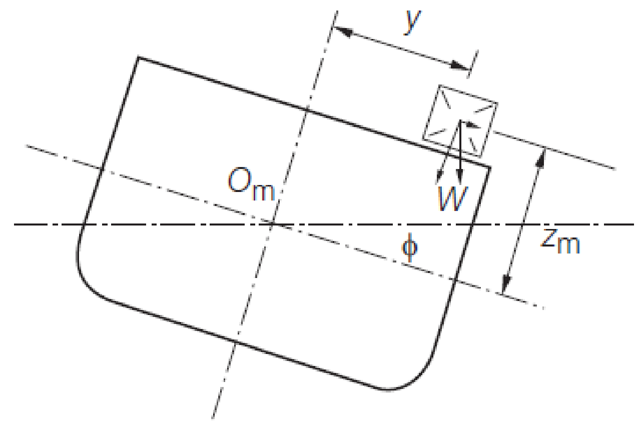
Inertia loads

Harsh location typical values of acceleration:

- ❑ transverse: 0.5g
- ❑ vertical: 0.5g
- ❑ longitudinal: 0.2g



Pitching

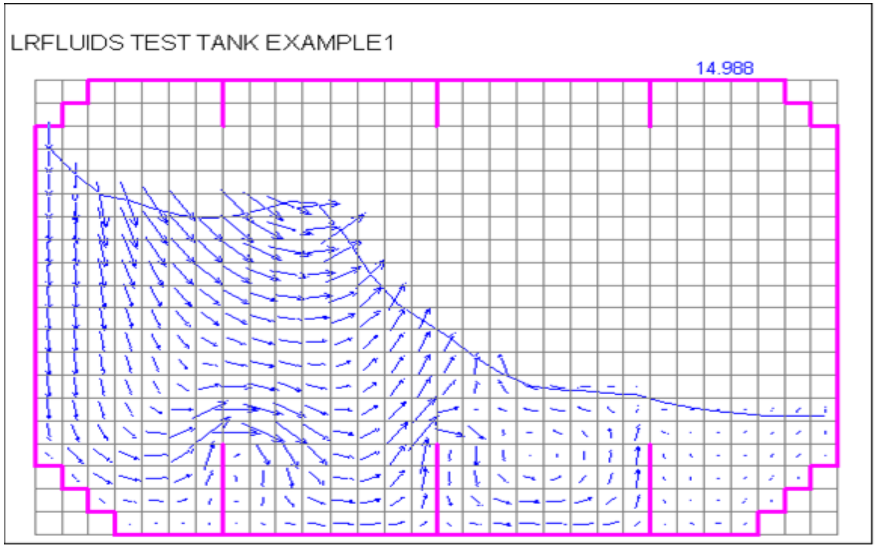


Rolling

Sloshing

Sloshing is the dynamic magnification of pressures within cargo/ballast tanks.
Partial fillings the norm for FLNGs (NOT so for trading LNG tankers)

- ❑ Influencing Factors:
  - ➢ Tank size
  - ➢ Hull form
  - ➢ Natural periods of both vessel and fluid
  - ➢ Tank fill levels



Ice Loading

- Additional weight on deck and significant loads at waterline;
- Terra Nova FPSO designed for 1.5 m thick sea ice and 2000 tonnes weight on deck;
- Minimum design temperature.

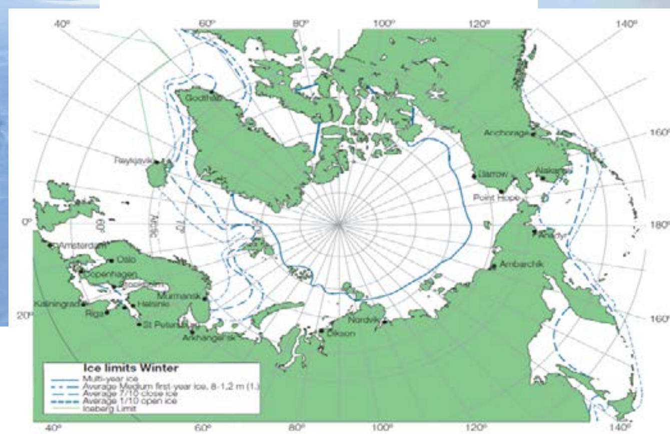


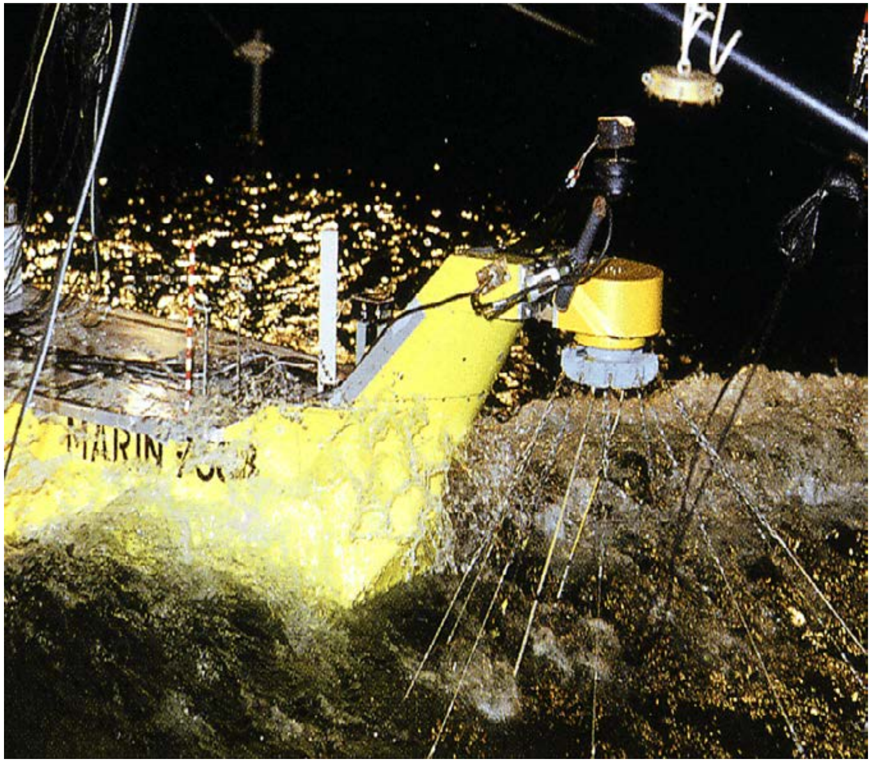
Fig. 6.2.1 Ice Limits for the Arctic Winter

Other loads and accidental loads

- ❑ Collision due to supply vessel / shuttle tanker / iceberg;
- ❑ Dropped object;
- ❑ Explosion / blast;
- ❑ Largest wave in 10,000 years;
- ❑ Emergency helicopter landings;
- ❑ Etc.

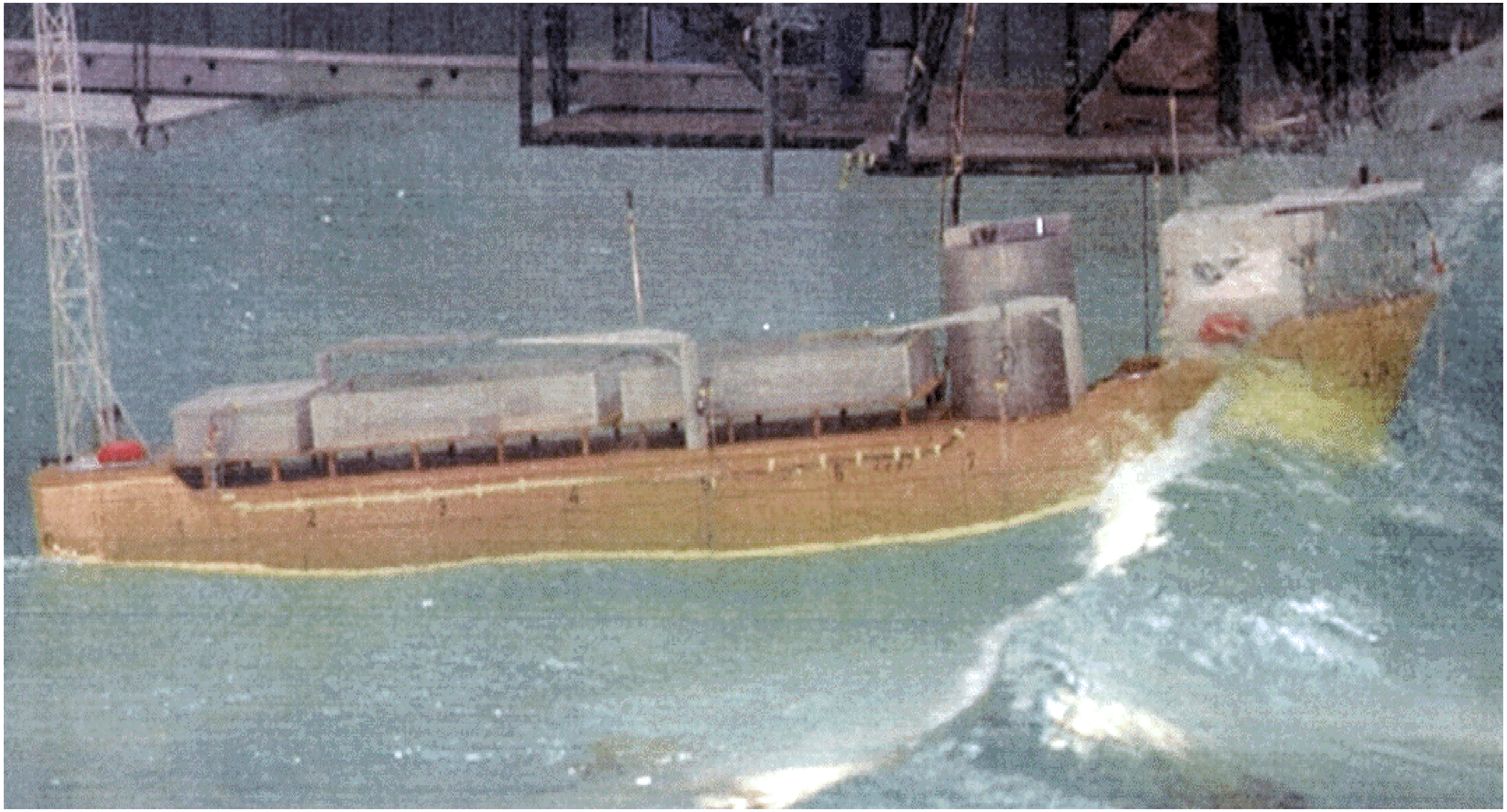
Why model tests?

- Highlight unusual or unpredictable phenomena;
- Prediction of green sea, slamming loads and other loads not readily calculated from analyses;
- Verification of mooring system analysis;
- Verification of roll damping values;
- Wind tunnel testing for wind/current coefficients;
- Sloshing model testing (particularly for LNG membrane tanks).

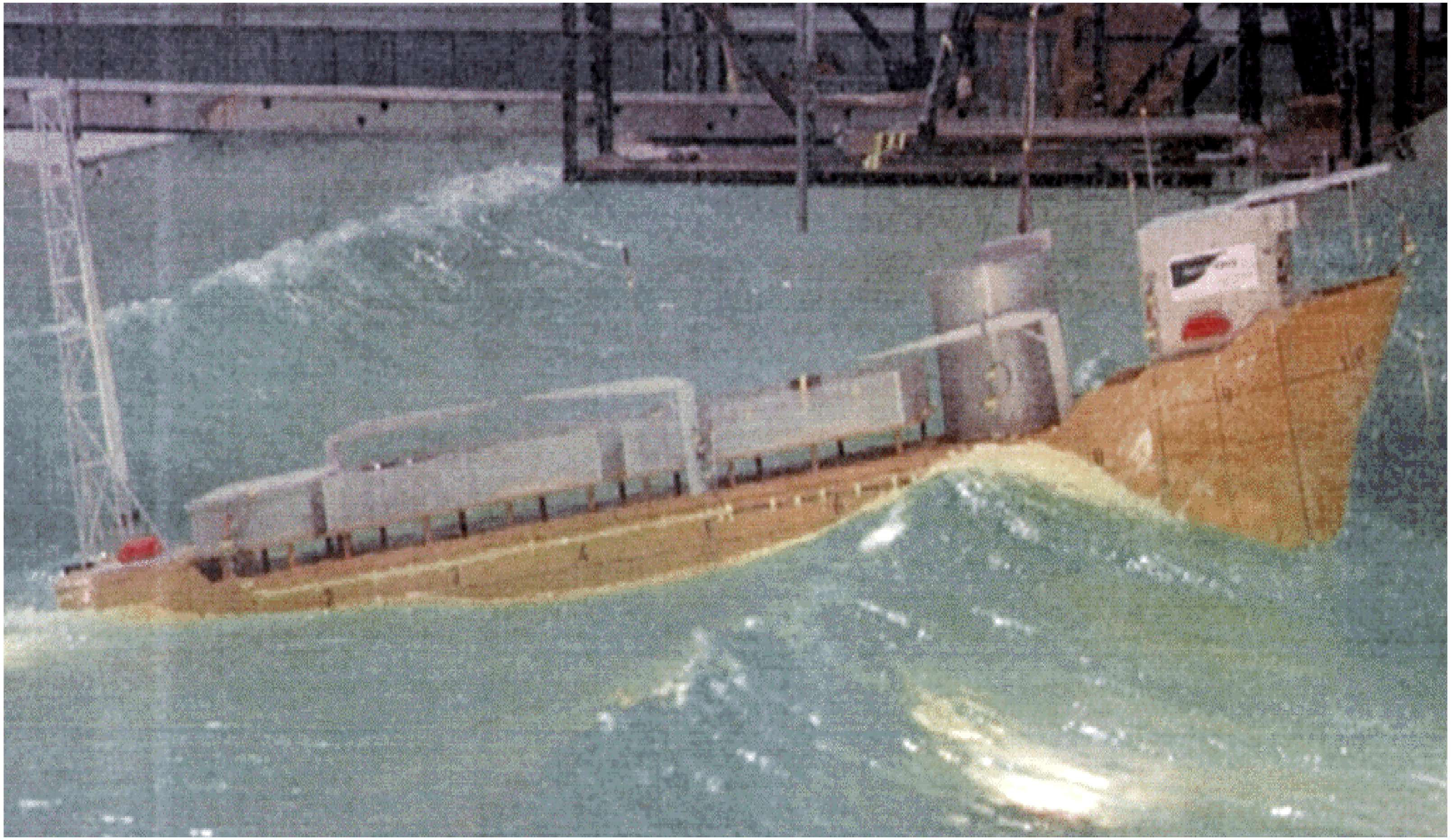


It is strongly recommended that the testing is considered following and in conjunction with the analyses.

Response to waves: 1 – Wave impact event

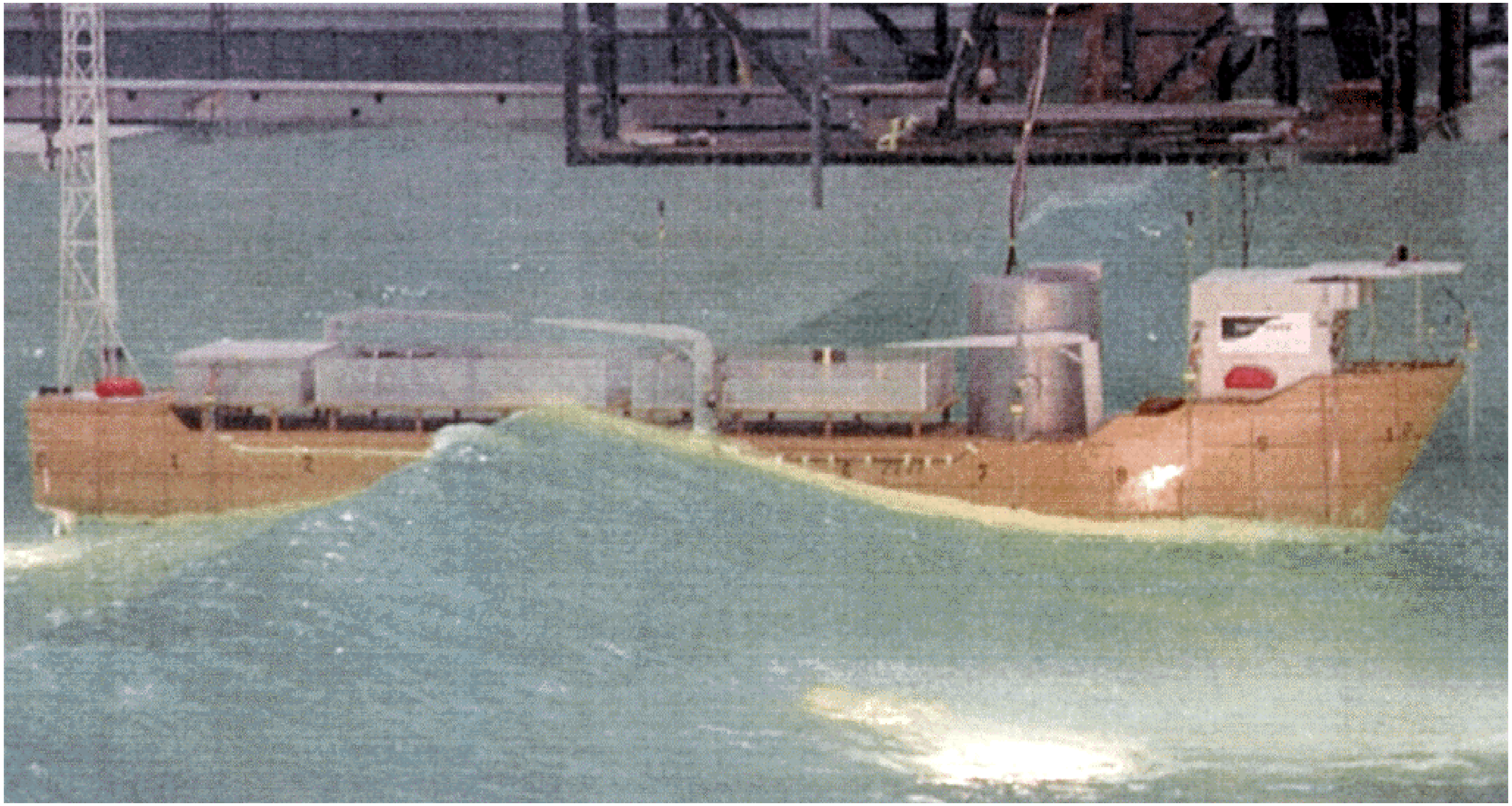


Response to waves: 2



Response to waves: 3

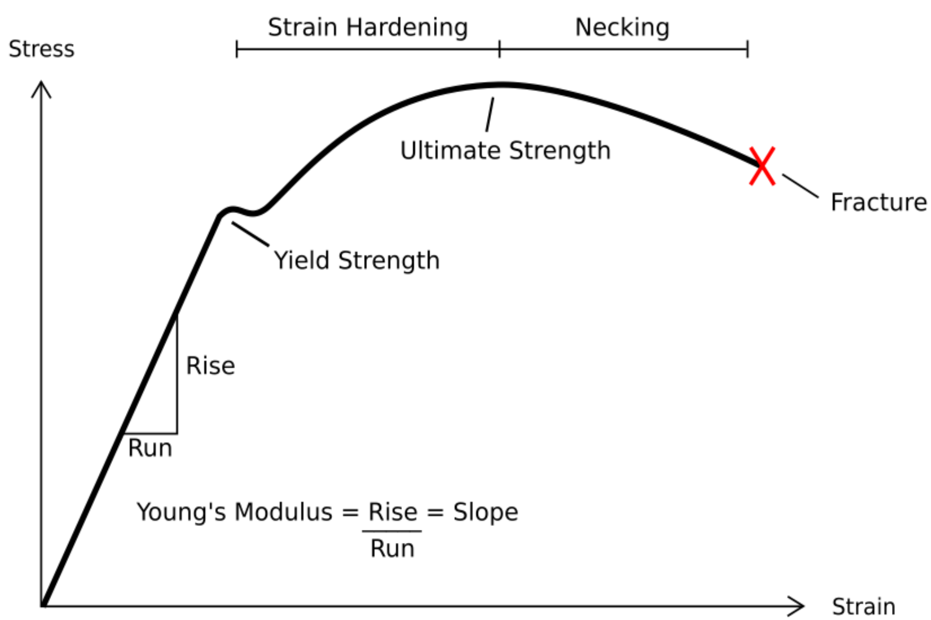
Response to waves: 4 – Green water event

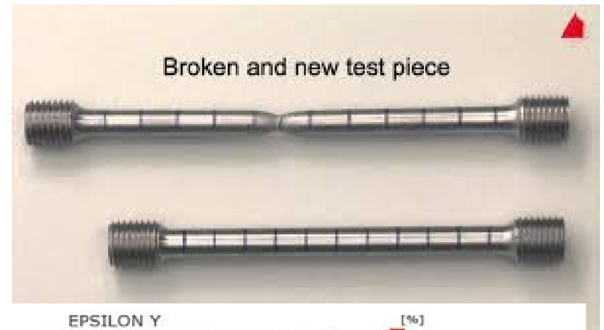


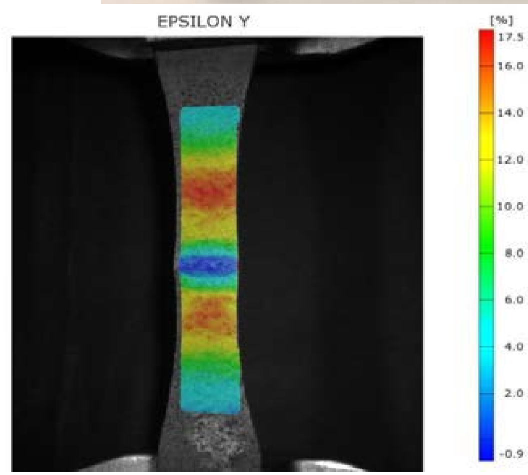
HULL STRENGTH ASSESSMENT

Structural failure mechanism

- Yielding
- Under operational loads, gross stress levels in hull should remain below yield

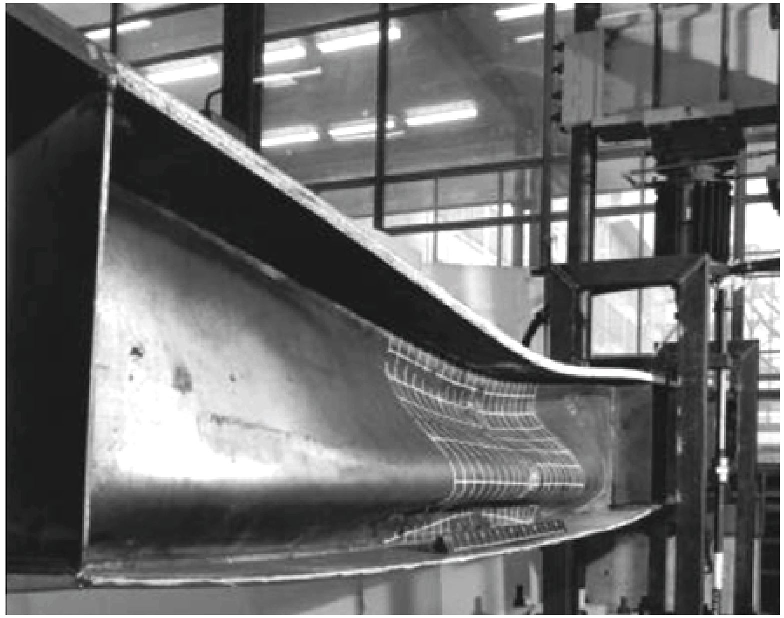


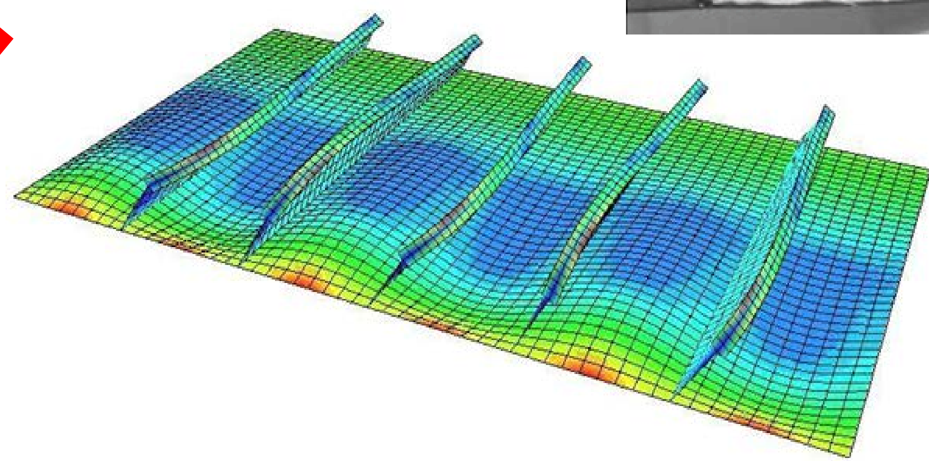




Structural failure mechanism

- Buckling
- Loads should remain below buckling load





First level considers the hull structure using a minimum scantling approach

The minimum net section modulus, Z_{net}, is to be taken as the greatest value calculated for all applicable design load sets, as given in Table 3.2.7, and given by:

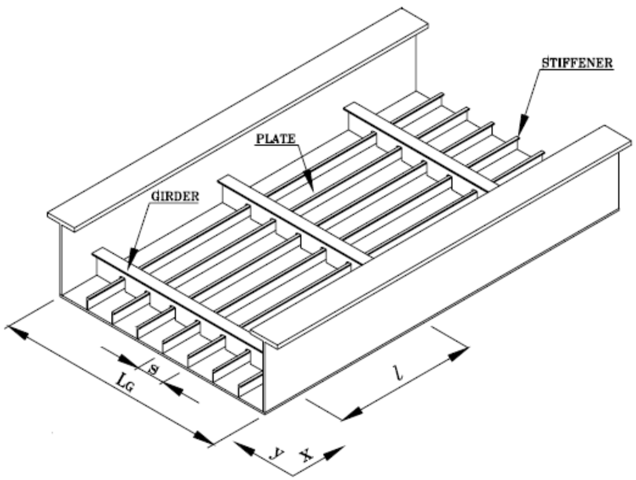
$$Z_{net} = \frac{|P| \, s l_{bdg}^2}{f_{bdg} \, C_s \, \sigma_{yd}} \quad cm^3$$

where

f_{bdg} = bending moment factor:
for continuous stiffeners and where end connections are fitted consistent with idealisation of the stiffener as having as fixed ends:
= 12 for horizontal stiffeners
= 10 for vertical stiffeners
for stiffeners with reduced end fixity, *see* Table 3.7.2

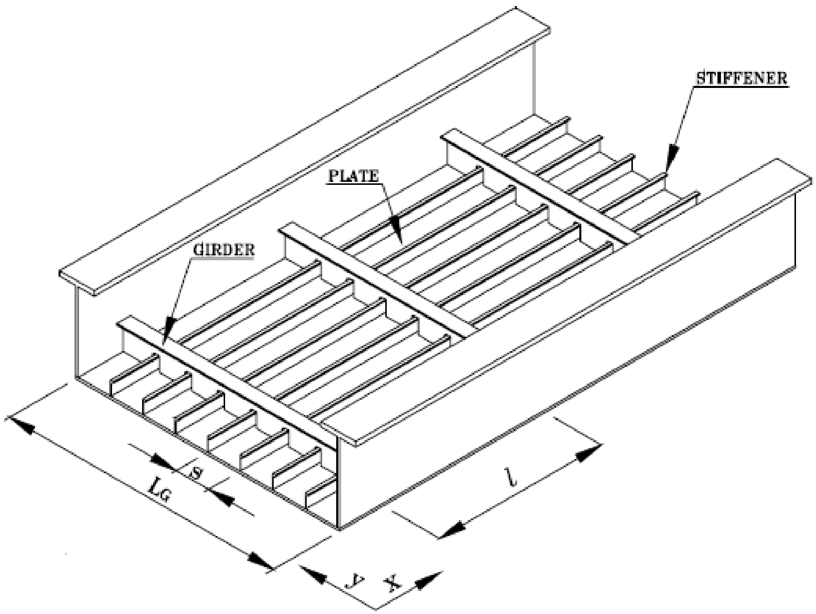
l_{bdg} = effective bending span, in metres

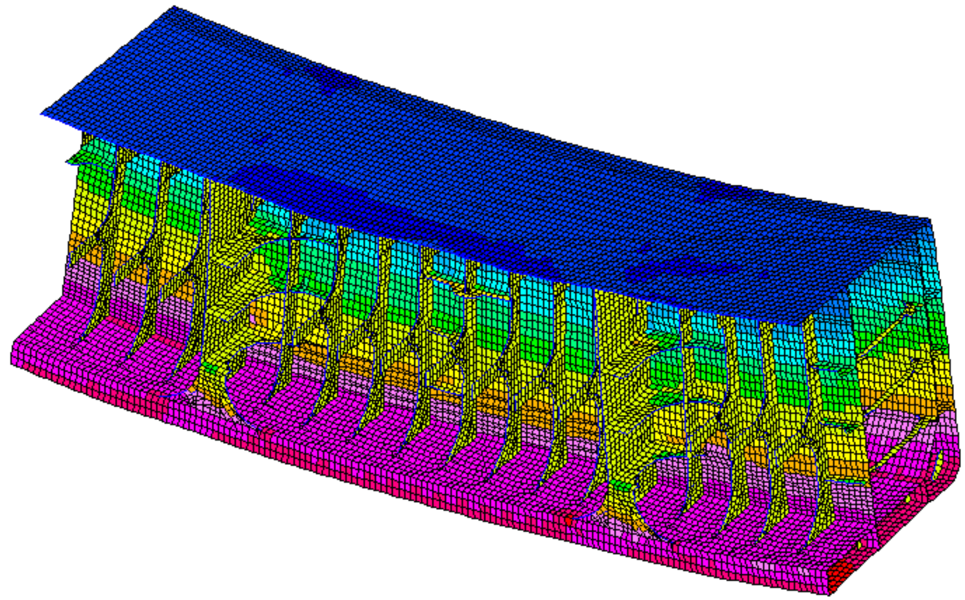
C_s = permissible bending stress coefficient for the design load set being considered, to be taken as:



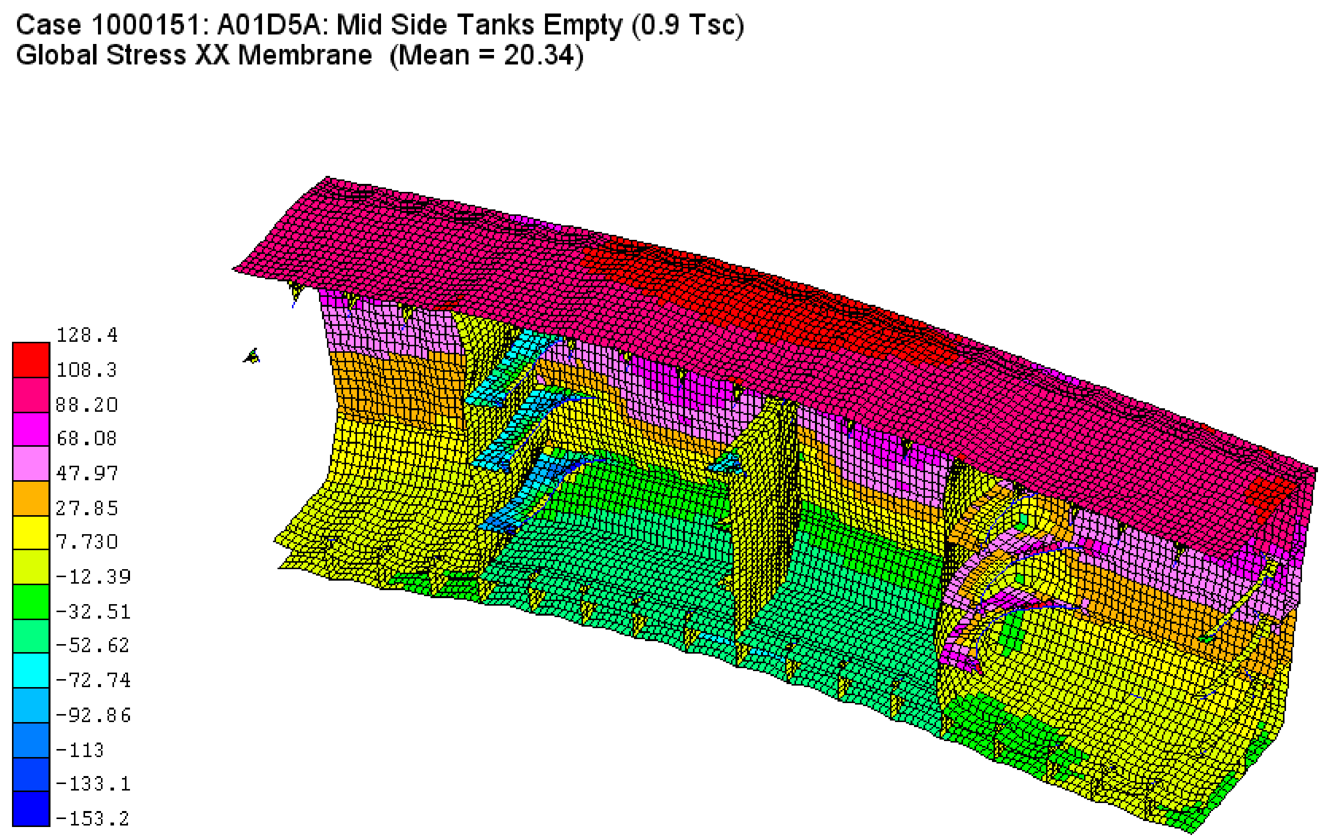
Hull structure design – two levels approach

Second level considers the hull structure using Finite Element (FE) methods

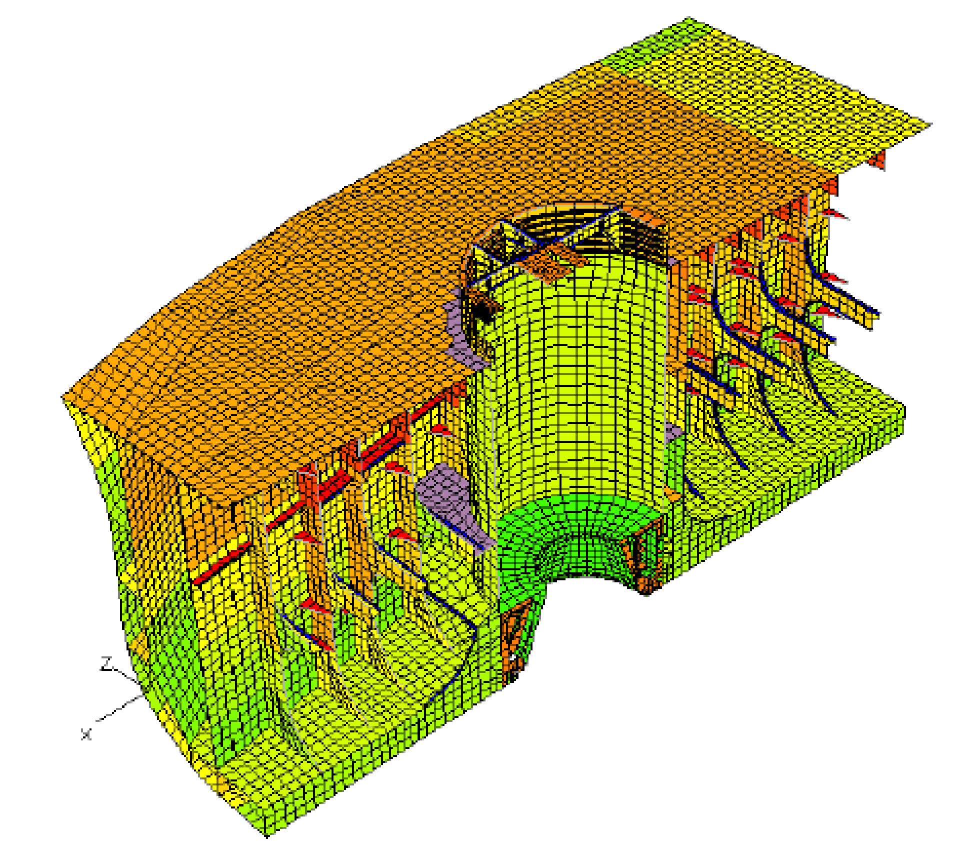




FE Example: Global assessment – Cargo Area



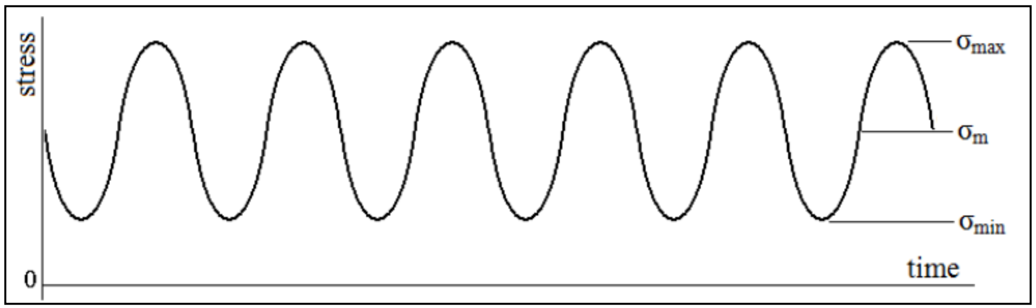
FE Example: Global assessment – Turret integration



FATIGUE ASSESSMENT

Fatigue assessment - Introduction

- Due to cyclical loads (not a strength issue)
- Influenced by:
  - size, shape and design of the component/connection;
  - condition of the surface or operating environment;
- The output of a fatigue analysis is life (in years).



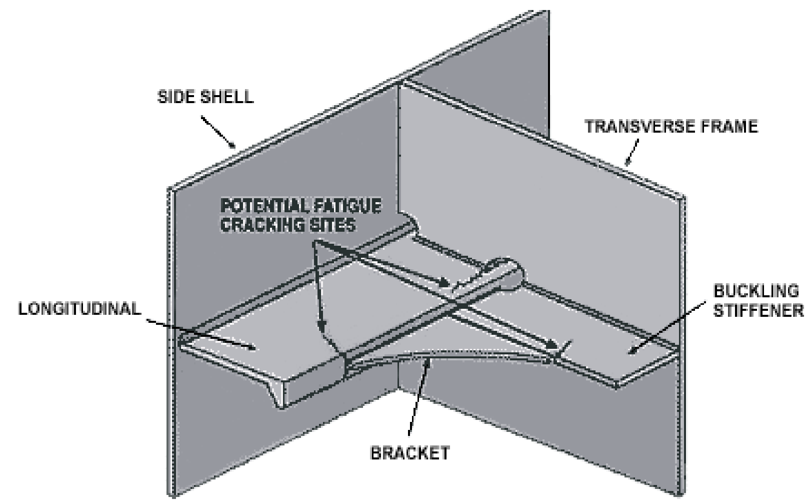
Fatigue assessment - Issues

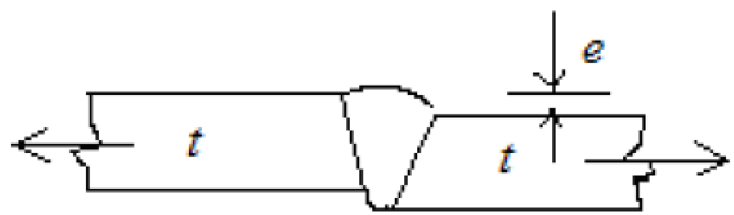
- No obvious warning:

  a crack forms without appreciable deformation of structure making it difficult to detect the presence of growing cracks.

- Fractures usually start from weld connections due to a localised concentration of stress.

- Attention must be given to:
  - Structural detailing;
  - Fabrication and construction tolerances;
  - Corrosion protection and coatings;
  - Inspection regime and inspectability.





Fatigue assessment - typical safety factors

Inspectable / Repairable	Consequence of Failure	
	*Non – substantial**	*Substantial**
Yes, dry	1	2
Yes, wet	2	4
No	3	10

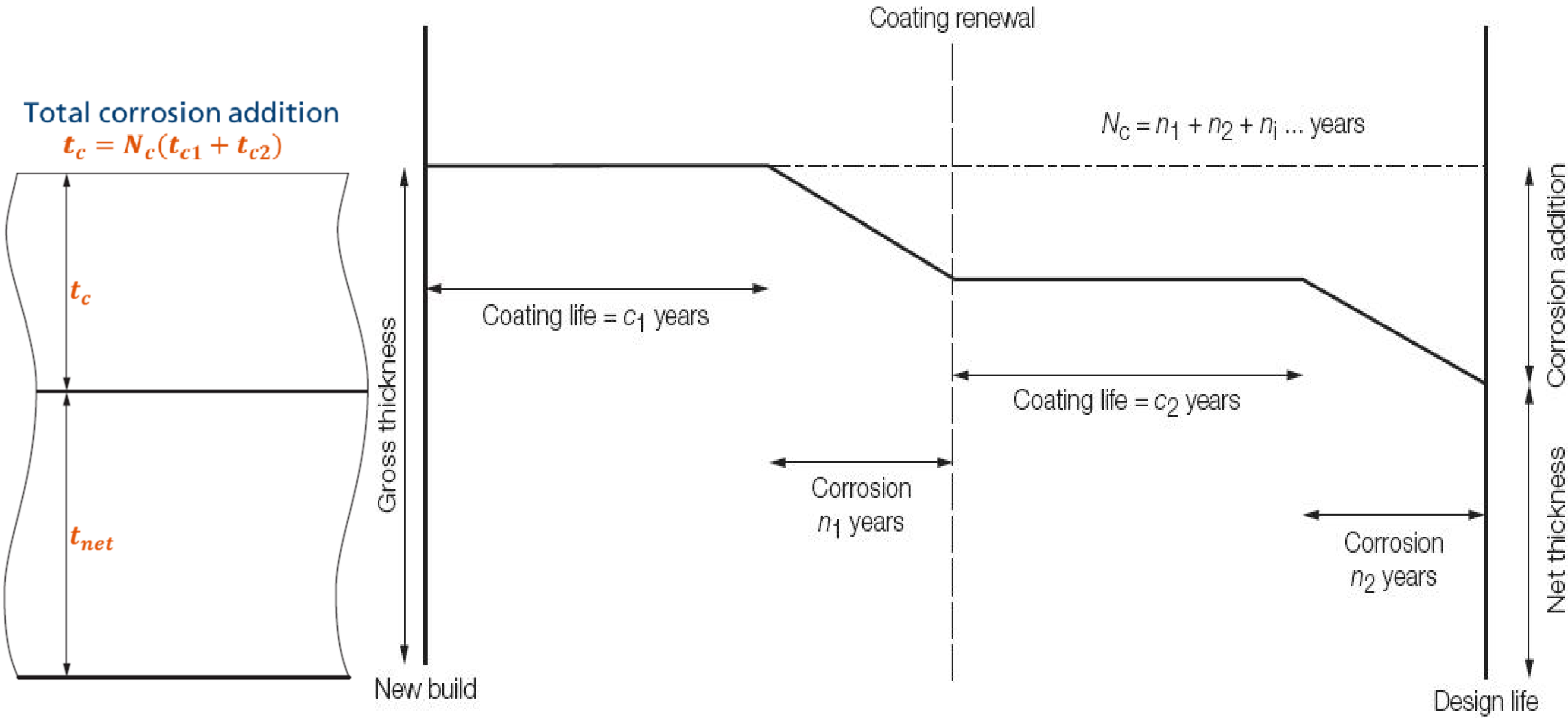
$$\boldsymbol{Required\ life\ (years) \geq Safety\ factor\ \times design\ life\ (years)}$$

*Substantial consequences of failure are defined as loss of life, uncontrolled outflow of hazardous products, collision or sinking and should include for progressive failure scenarios.

CORROSION

Last but not least: corrosion

Corrosion – a flexible approach



General advice for FPSO structural design

"Holistic" approach for good integrated solution

Good interface design between structural elements
(hull / topside structure / mooring)

Design for accidental loads
(wave impact, dropped objects, vessel collision)

Design to minimize fatigue

Ensure good access for inspection and maintenance

Offshore maintenance philosophy
instead of
ship maintenance philosophy

Thank you for your attention

For more information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