Aalto University
School of Engineering

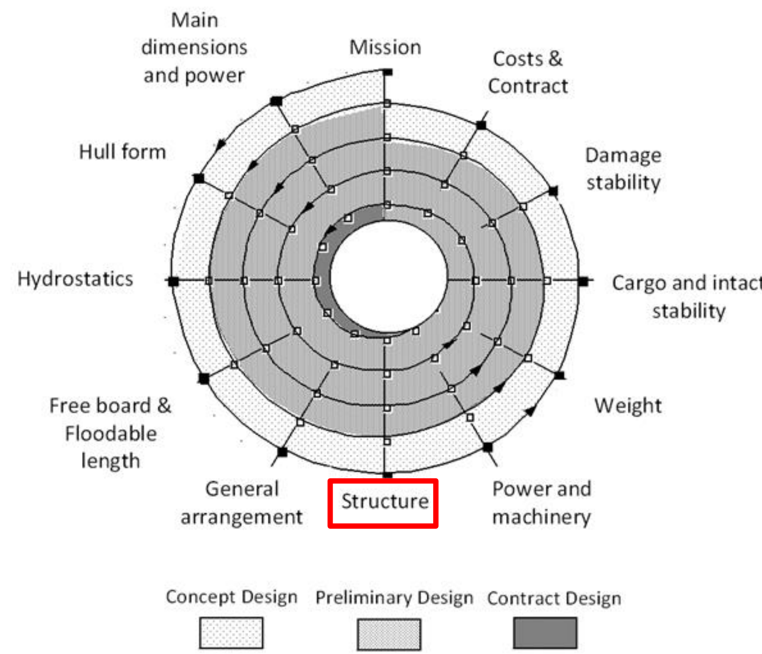
MEC-E1004 Principles of Naval Architecture

Lecture 7 – Ship Structures

Learning points !

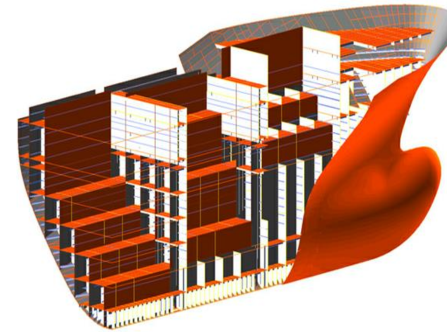
- ❑ After the lecture, you will be able to list and explain
  - ✓ The terminology related to ship structural design and the framework used
  - ✓ The general characteristics of a ship's structure

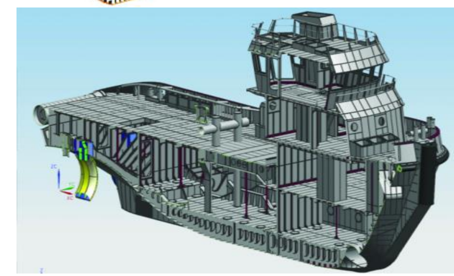
- ❑ Determine the mid-ship section, frame stiffening, ship building material etc. of your project ship

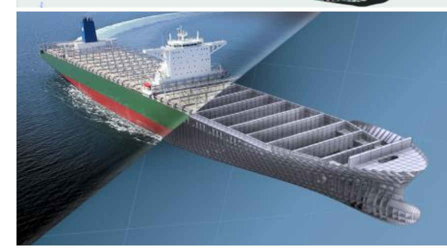


Assignment 7 – Ship Structures

- ❑ List and discuss structural requirements for your ship including
  - *Regulatory requirements*
    - ✓ Longitudinal (bending) strength
    - ✓ Shear strength
    - ✓ Hull girder ultimate strength
    - ✓ Structural continuity
  - *Ship specific challenges (e.g., structural challenges related with the GA development)*







- ❑ Considering the structural requirements, determine a schematic structural solution for your project ship including
  - *Preliminary cross section drawings namely the mid ship section and the engine room section*
  - *Specify main and forecastle deck heights, double bottom heights, framing system / spacing, ship-building materials*

Introduction

- ❑ Interconnected beams and plates
- ❑ General functional requirements
  - ✓ To form a water and weather tight body→ Buoyancy, stability
  - ✓ To provide sufficient structural strength to deal with the anticipated structural loading
- ❑ General objectives
  - ✓ High strength/weight ratio
  - ✓ Affordability
  - ✓ Producibility
  - ✓ Fire resistance
  - ✓ ...

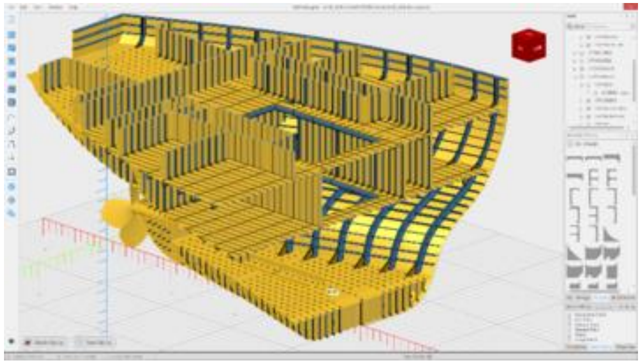
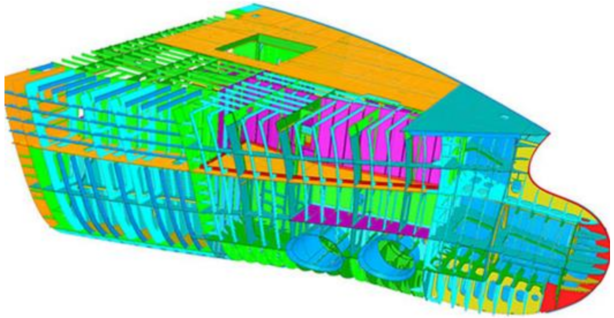


Image credit Napa



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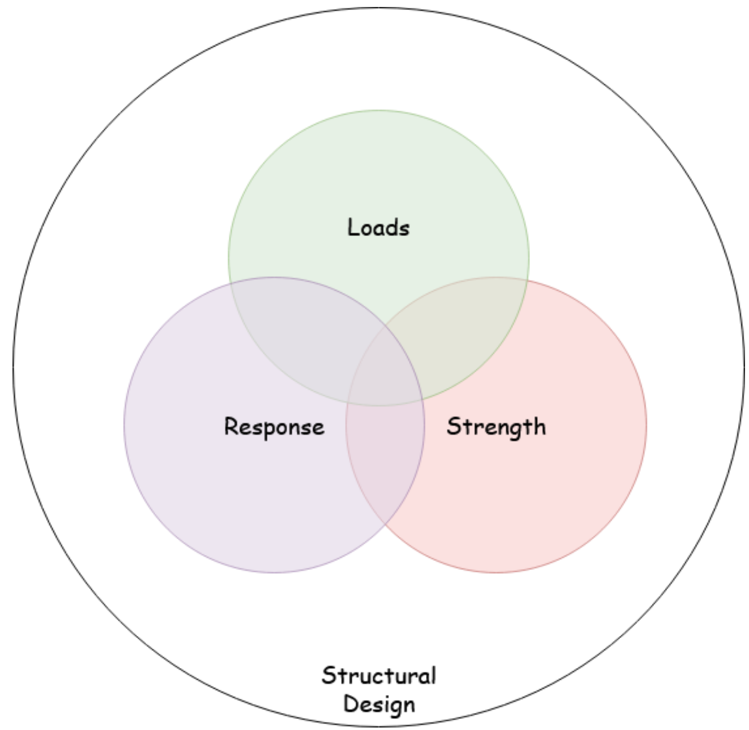
Structural Design



Structural Design – basic elements

❑Loads

- *A force applied to a structure or its components*
  - ✓ Static loads
  - ✓ Dynamic loads
- *Structural loads cause stresses, deformations, and displacements in structures*

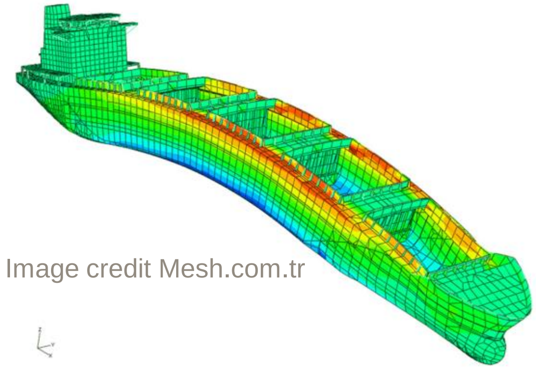


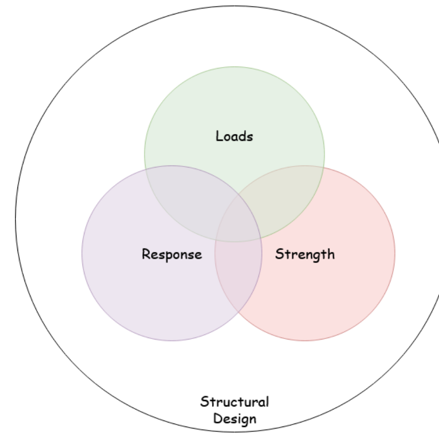
Image credit Mesh.com.tr

❑Responses

- *A load induced deformation / dynamic response*
  - ✓ Static structural response (e.g., hogging & sagging)
  - ✓ Dynamic structural response (e.g., whipping & springing)

❑Strength

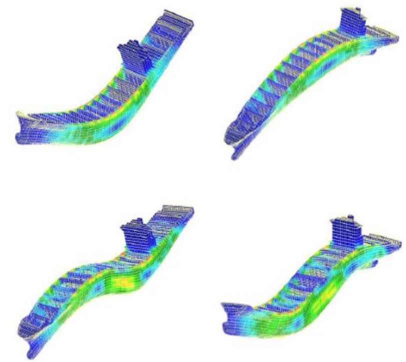
- *Strength is a measure of the capacity of a structural element to withstand/carry a structural load without failure or plastic (permanent) deformation*

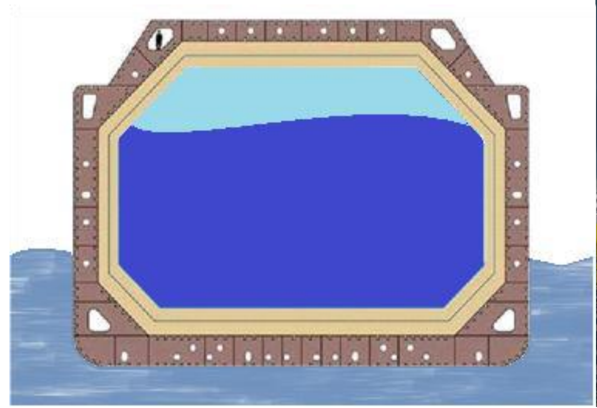


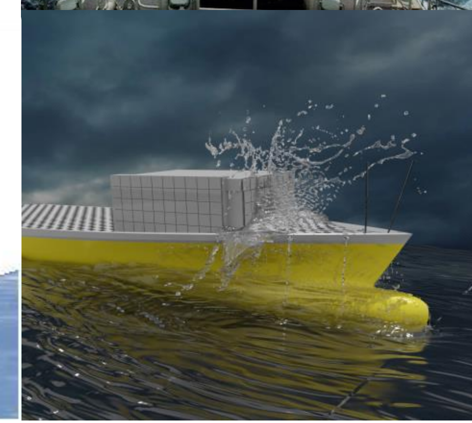
https://www.youtube.com/watch?v=j1dGF6cTSRA

Discussion

- ❑ **Static vs. Dynamic Loads**
- ❑ Global vs. local loads
- ❑ Springing
- ❑ Slamming vs Whipping
- ❑ High vs. low frequency loads
- ❑ Sloshing
- ❑ Ship collision and grounding
- ❑ Green water on decks







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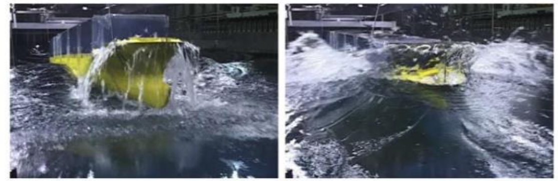

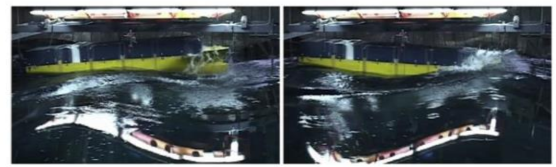

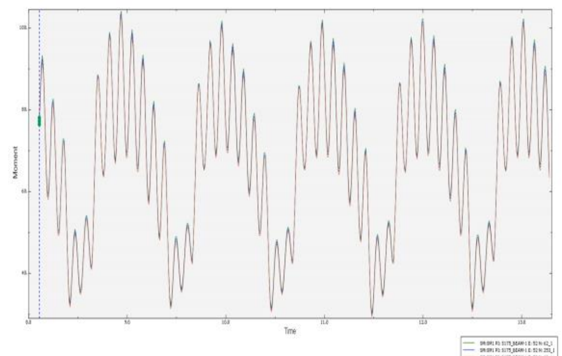

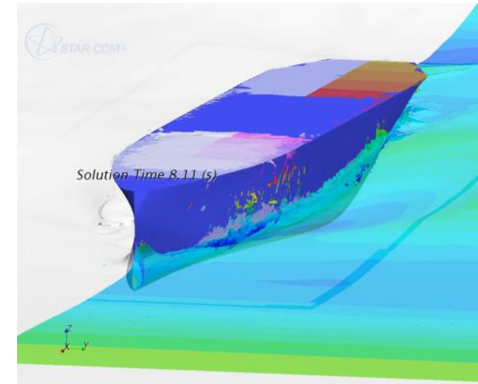

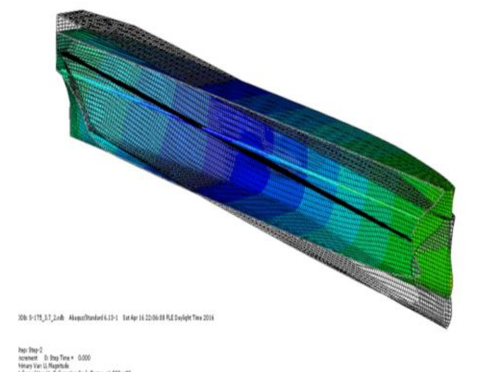

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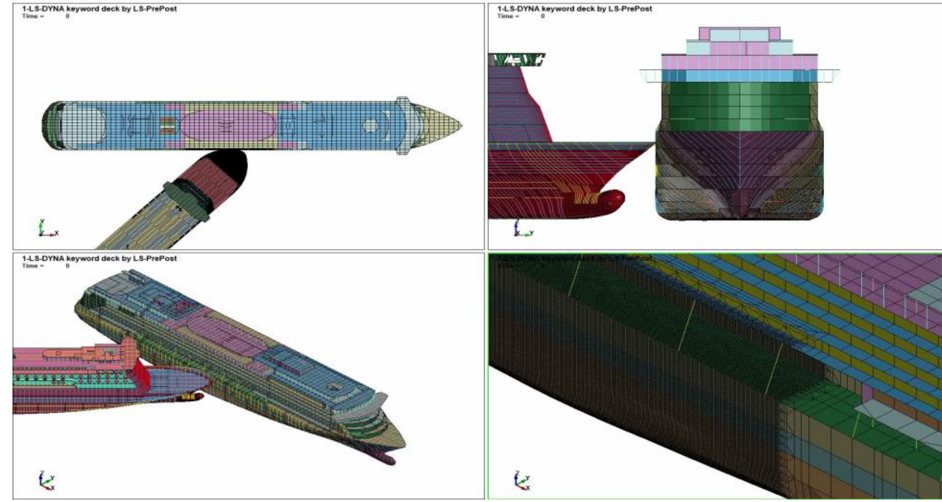
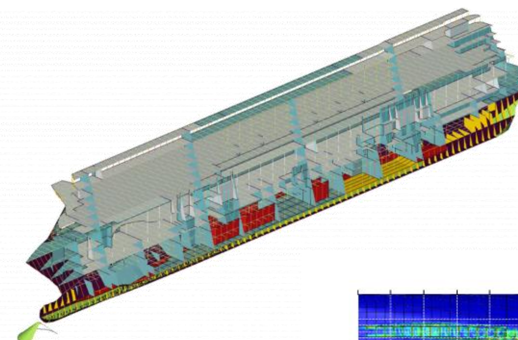
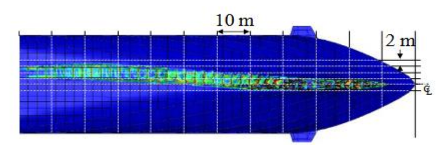
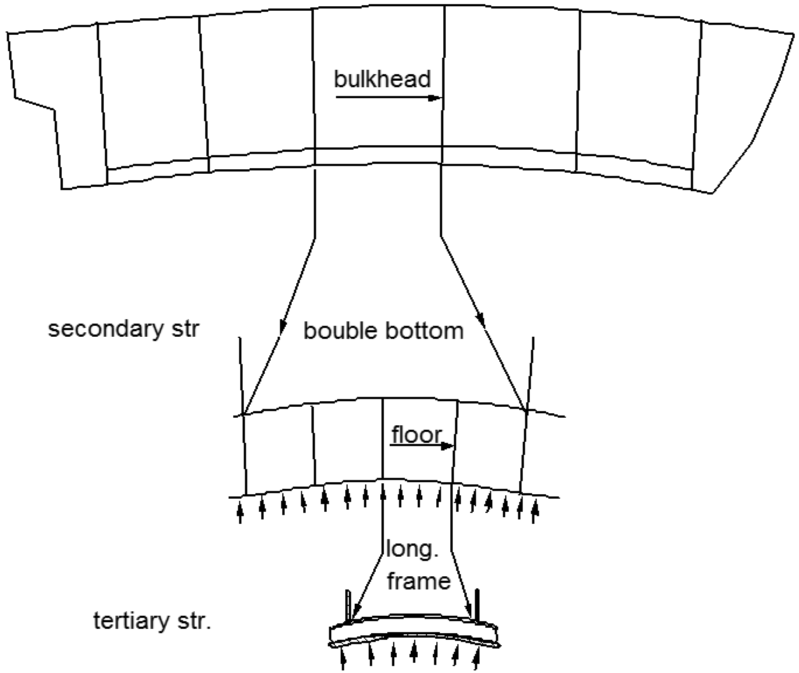






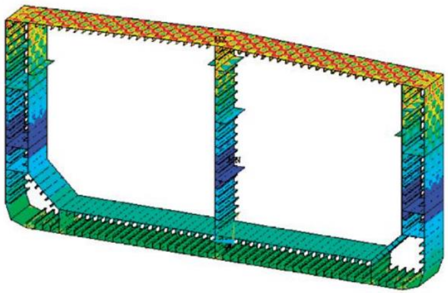
Hierarchy levels

- ❑ Primary level, s1
  - e.g., ship beam, longitudinal strength
- ❑ Secondary level, s2
  - e.g., double bottom structure
- ❑ Tertiary level, s3
  - e.g., plate frames



This division is commonly applied in Classification Society Rules, For example,

https://www.lr.org/en/rules-regulations/

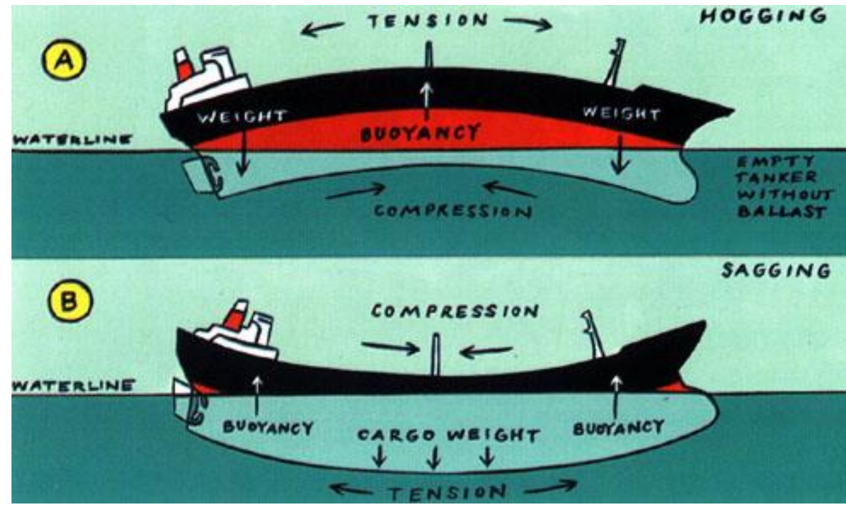


Primary Hierarchy Level – S1

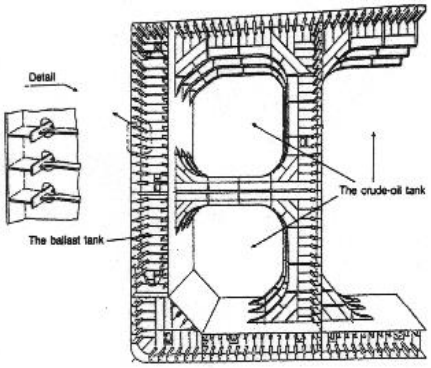
- ❑ Main (hull girder) elements forming closed compartments
  - *Deck*
  - *Bottom shell*
  - *Side shell*
  - *Longitudinal bulkhead*
  - *Transverse bulkhead*
  - *Bilge*

- ❑ These primary level (s1) elements carry much of the hull girder bending, shear and torsion loads

- ❑ There are ship types that lack some of the main elements
  - *Ro-Ro ships: no transverse bulkheads*
  - *Container ships: no main deck*

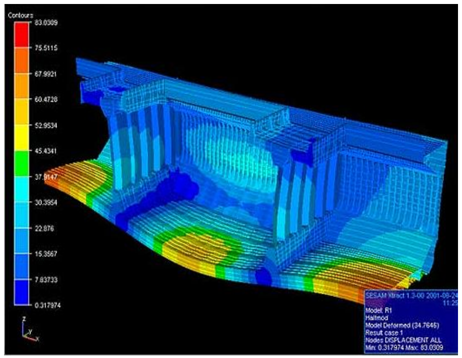


Secondary Hierarchy Level – S2



- Elements that may experience significant deformations
  - *Double bottom*
  - *Double side*
  - *Web frames*
  - *Longitudinal girder*
  - *Grillages*

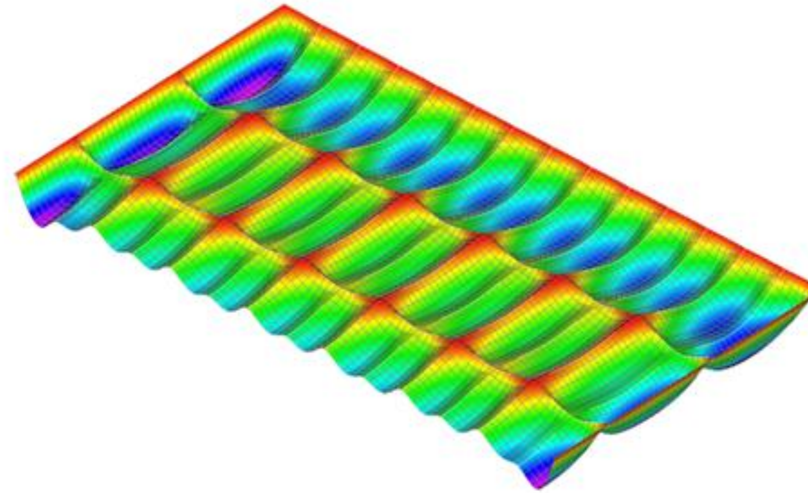
- These elements transfer loads between primary (s1) and tertiary (s3) hierarchy level elements
  - *Acts as boundary condition for level 3 response evaluation*
  - *Acts as internal load for level 1 response evaluation*



- The share of load carried by a specific type of element depends on the ship type
  - *Ro-Ro ships: web frame carries much load*
  - *Bulk carriers: double bottom carries much load*

Tertiary Hierarchy Level – S3

❑Consist of local parts such as

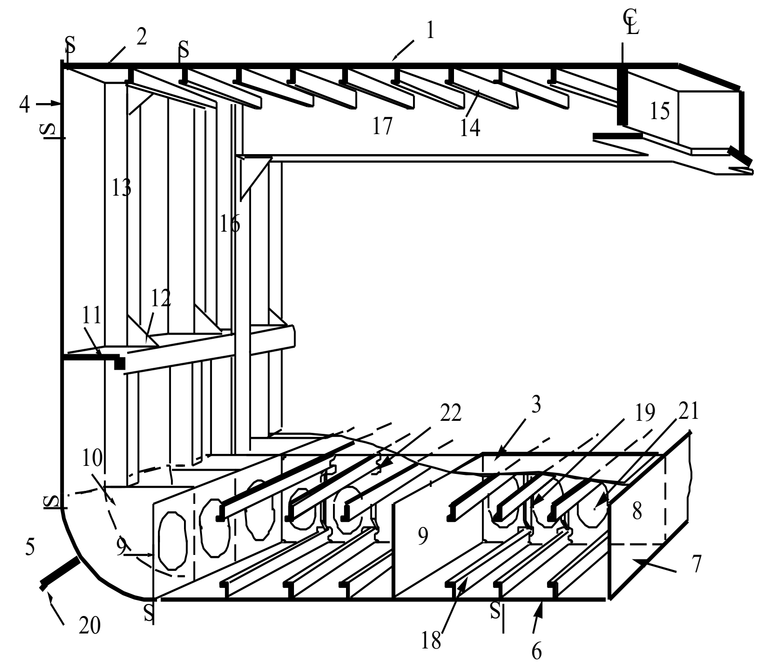


- *Plating*
- *Longitudinals*
- *Transversals*

❑Can be assessed using basic beam and plate theory

Main hull girder components

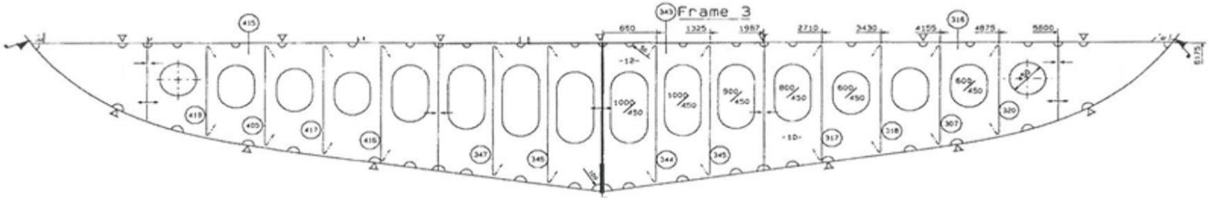
1. deck plating
2. deck stringer
3. tank top
4. sheer strake
5. bilge strake
6. keel plate
7. center girder
8. floor
9. side girder
10. side bracket
11. side stringer
12. bracket
13. frame
14. deck beam
15. longitudinal deck girder
16. web frame
17. transverse deck girder
18. bottom frame
19. stiffener
20. bilge keel
21. manhole
22. notch



Openings (Man-holes)

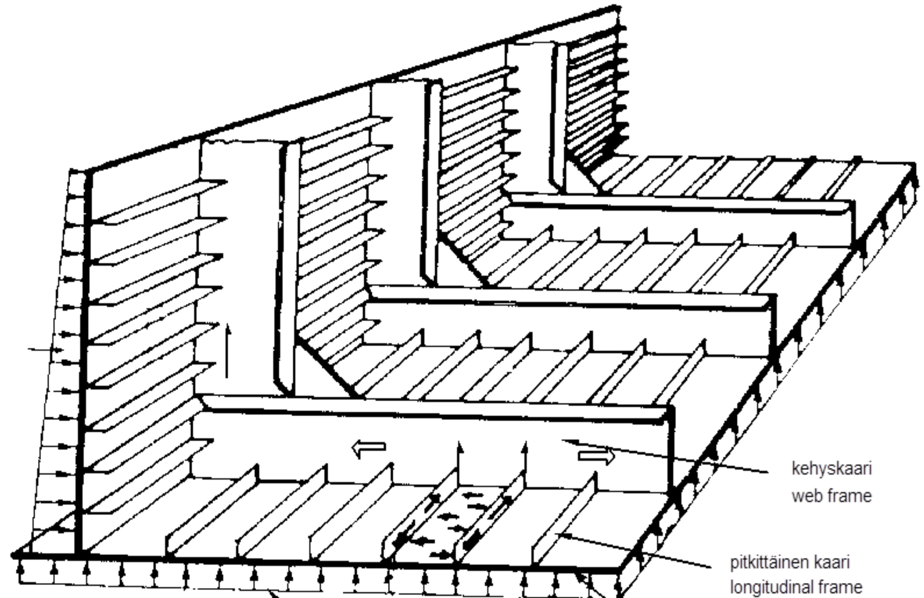
- Needed for ship systems, maintenance, etc.

- The size of a manhole is to be defined considering its required function (e.g. cabling) and general design criteria (e.g. vibration, strength)



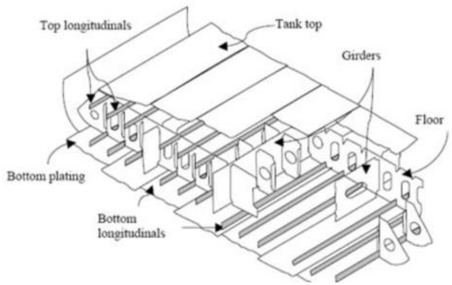
Load transfer mechanisms

- **Pressure** on plate supported by longitudinals and web frames
- **Line loads** on longitudinals supported by web frames
- **Point loads** on web frames supported by side structures



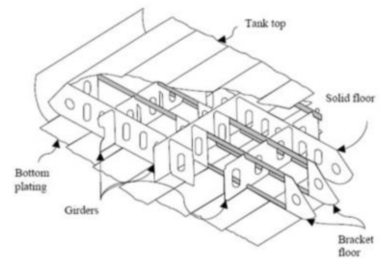
Framing systems - revision

Longitudinal framing



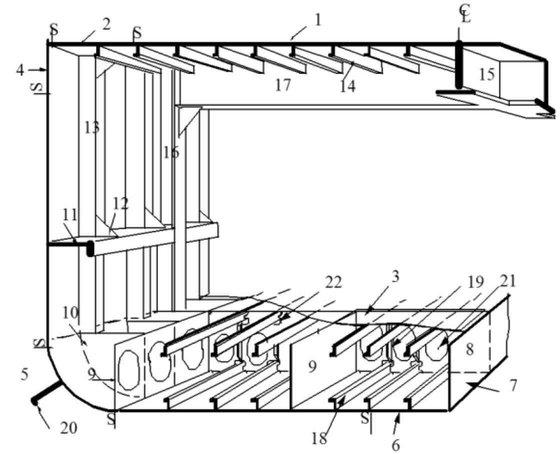
- Closely spaced longitudinals
- Few and widely spaced transverse frames

Transverse framing

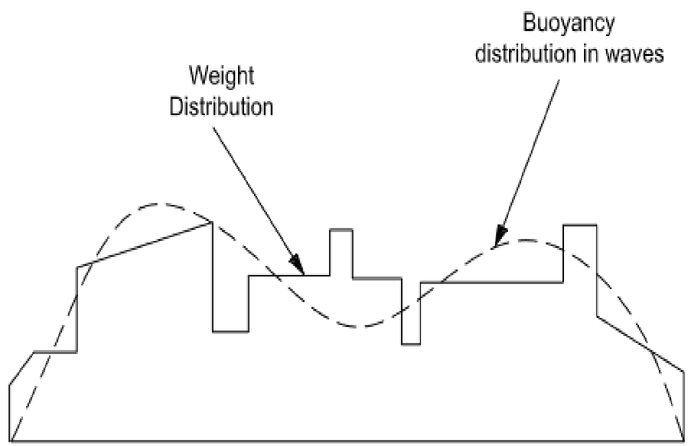


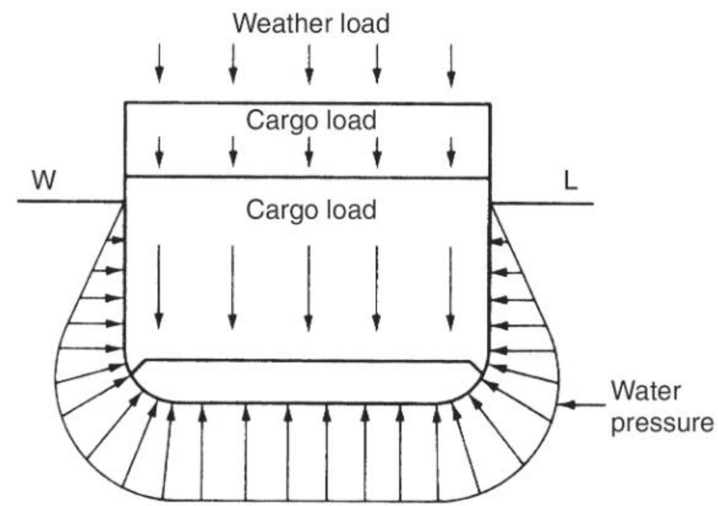
- Many closely spaced transverse frames
- Few and widely spaced longitudinals

Mixed framing

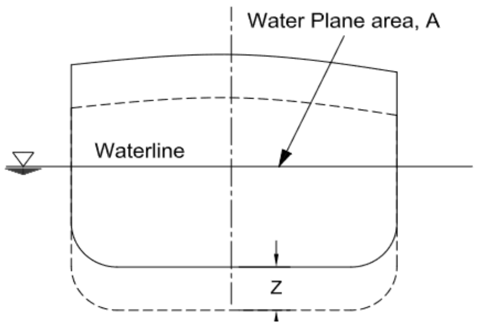


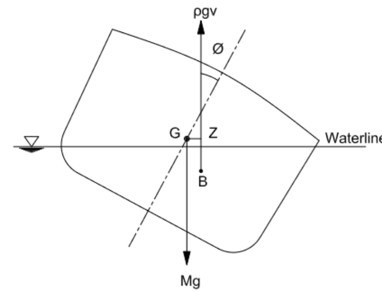
Still water loads

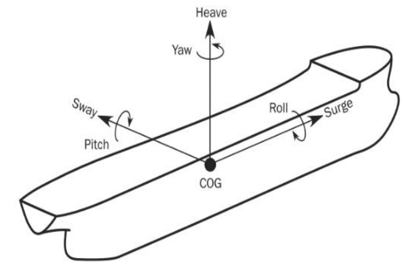


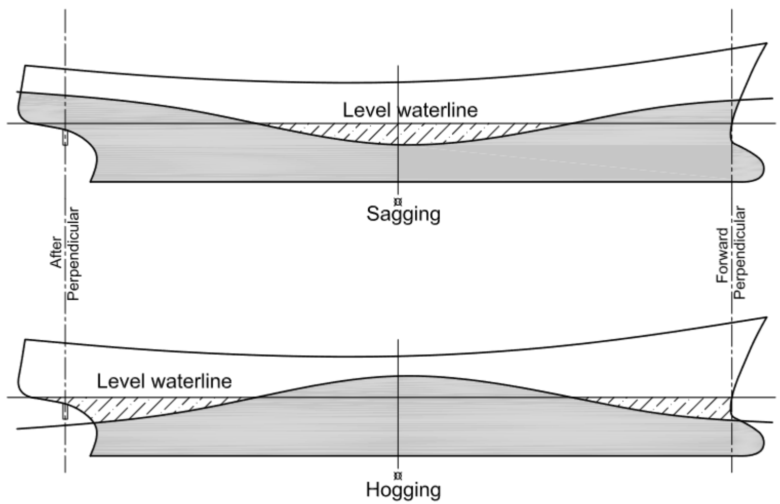


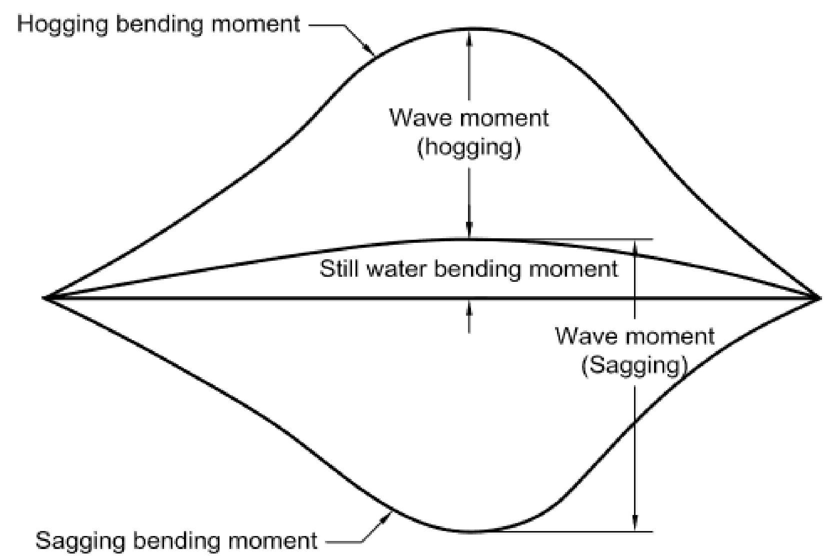
How about ship motions ?



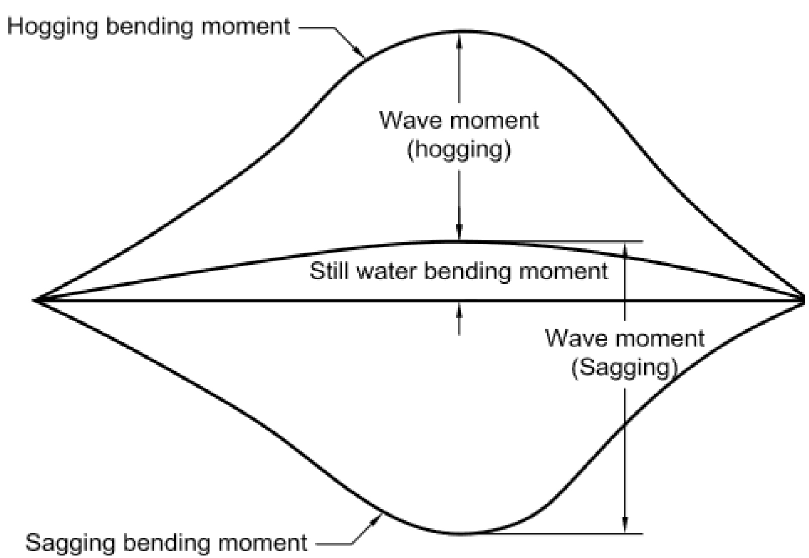




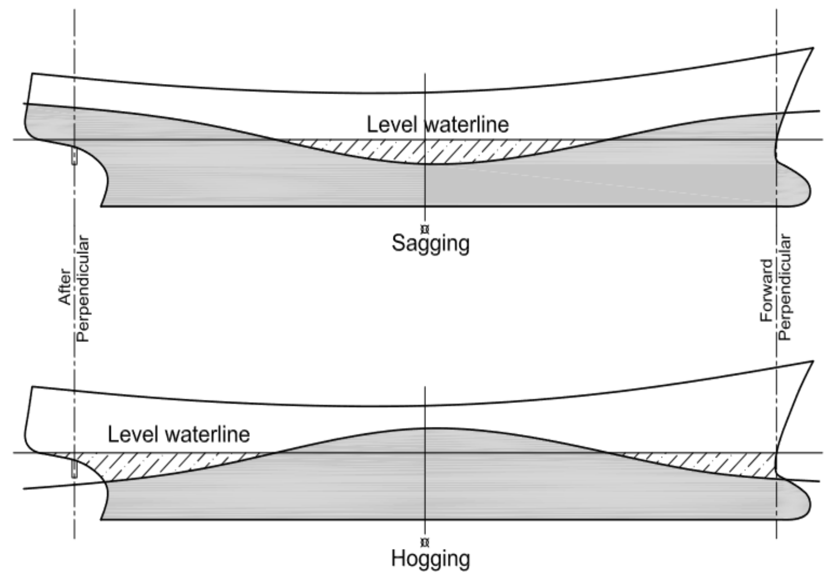




Wave loads



Hogging bending moment
Wave moment
(hogging)
Still water bending moment
Wave moment
(Sagging)
Sagging bending moment



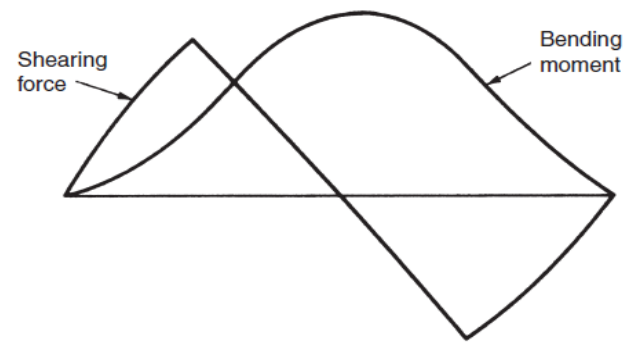
Level waterline
Sagging
After
Perpendicular
Forward
Perpendicular
Level waterline
Hogging

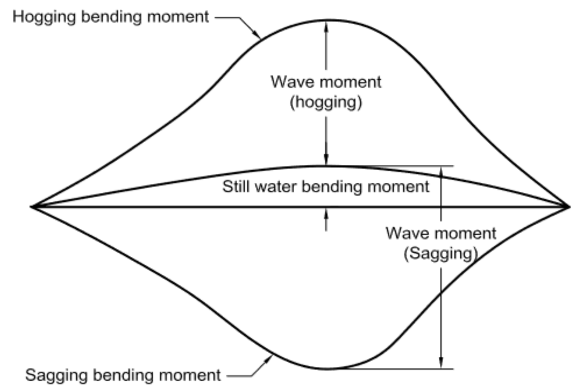
Mid-ship section

- Maximum longitudinal bending moment is experienced by a hull girder within this midship zone.

- The midship section plays an important role from longitudinal strength point of view

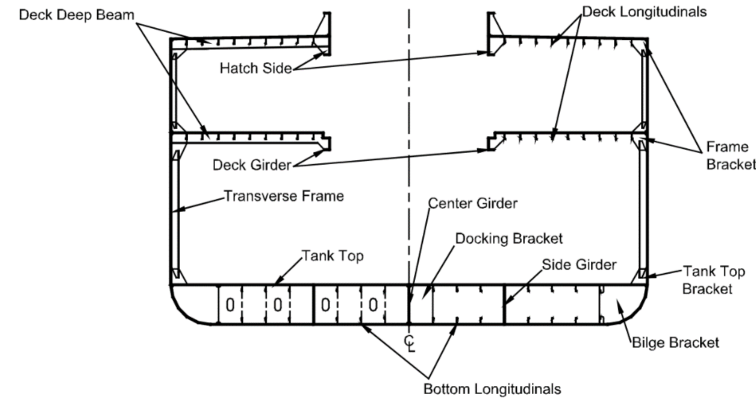
- It also depicts the structural layout depending on the type of cargo the ship is going to carry.

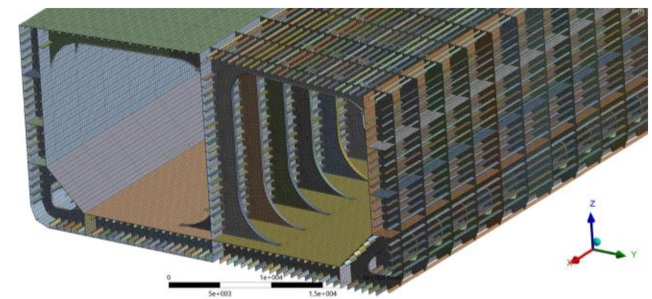




The mid ship section

- The longitudinal strength of hull girder depends on the section modulus of the midship section.
- This in turn depends on the scantlings and layout of the structural members in the midship region.
- The midship region extends **¼ length** of the ship forward and aft of midship. Over this midship region the scantlings of the structural members are kept the same.



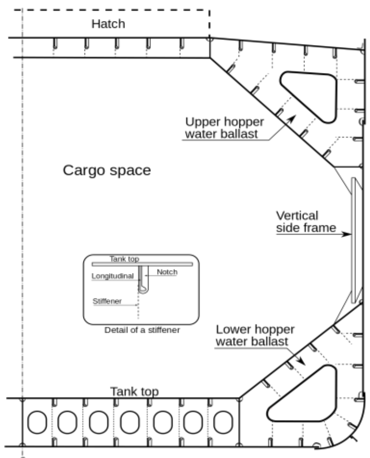


https://www.youtube.com/watch?v=a_hRHgG5-8s

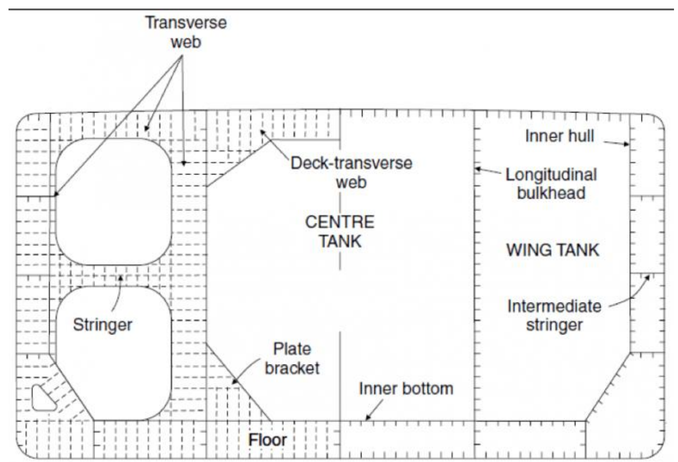
Different mid ship sections (1)

- Different types of ships have different midship sections.
- The structural arrangement and their scantlings are shown in these plans
- These are statutory structural plans which are to be approved by the concerned classification society prior to actual construction of ship

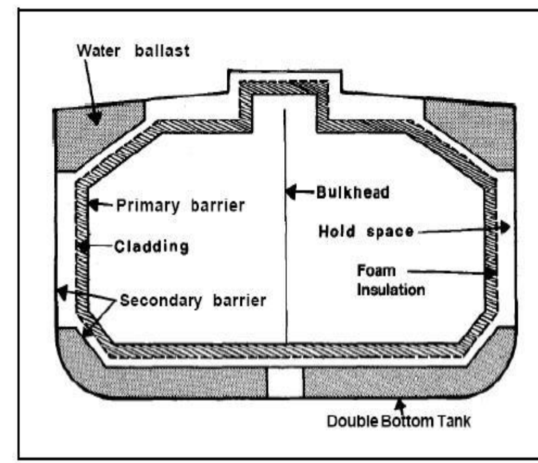
Bulk Carrier



Tanker



LNG



Different mid ship sections (2)

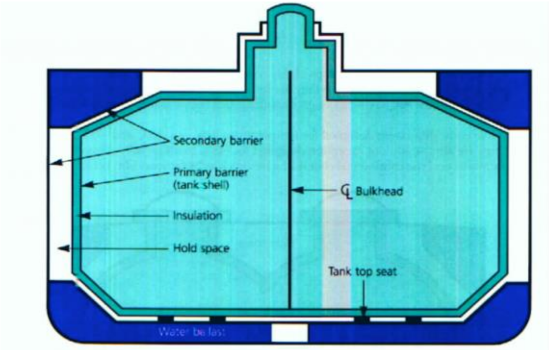


Figure A2.3a Self-supporting independent prismatic tank for LPG/Ammonia

LPG

LNG - spherical

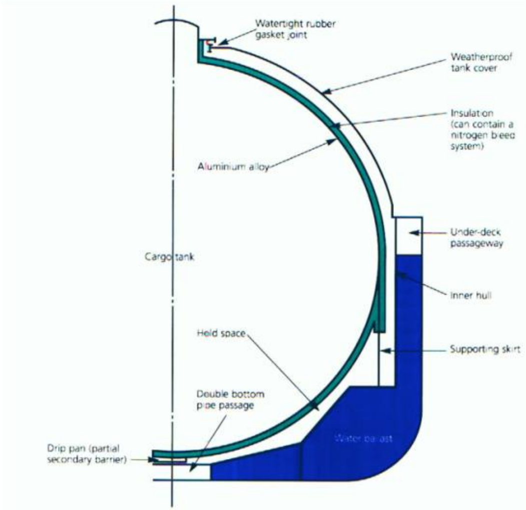


Figure A2.4b Spherical free-standing tank

General Cargo

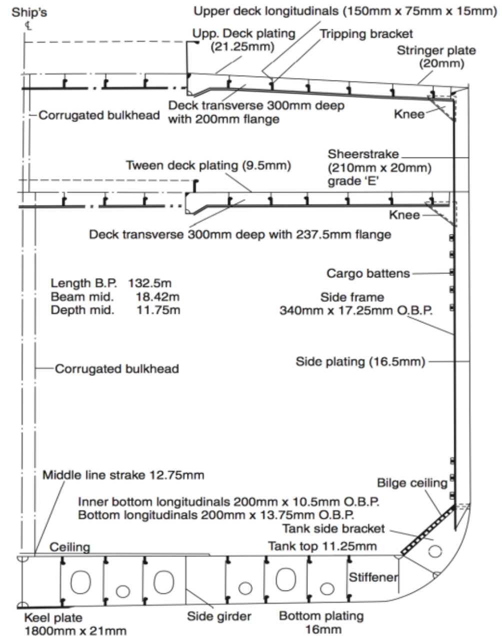
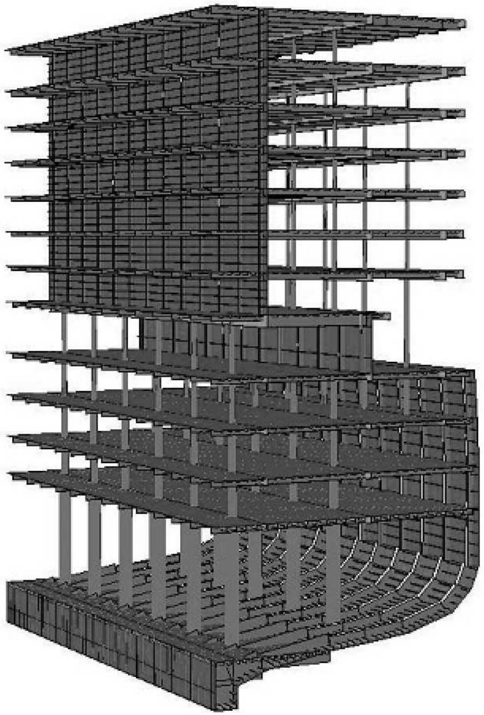


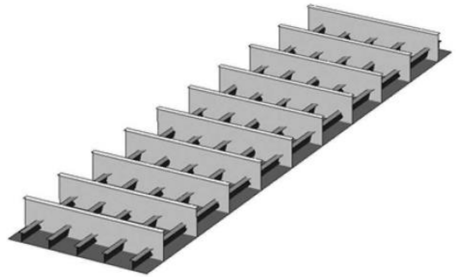
FIGURE 17.6 General cargo ship—midship section

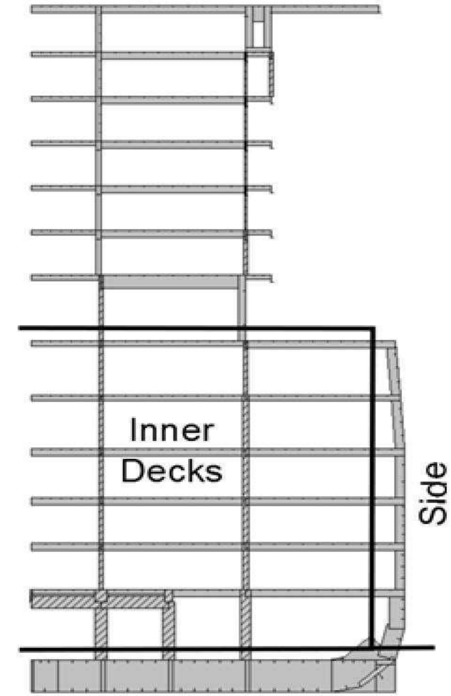
Different mid ship sections (3)

Cruise ship



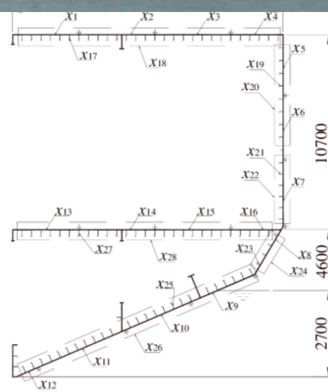
Stiffened plate element



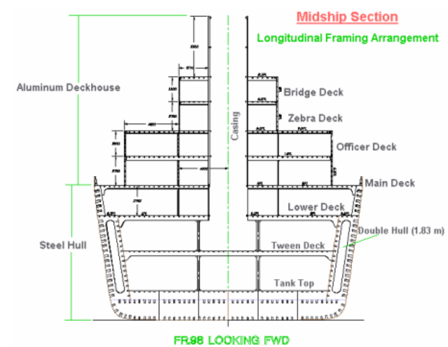


Different mid ship sections (4)

Ro-Pax ship



Ice breaker



Section Modulus (Home work)

- Calculate the section modulus of your ship's mid ship section (this is part of your assignment)

- Refer to :
  - *Page 88,89 of course booklet*
  - *Tutorial background notes files : T7_Background notes 1.pdf, T7_Background notes 2.pdf*
  - *Section modulus calculation.xls*

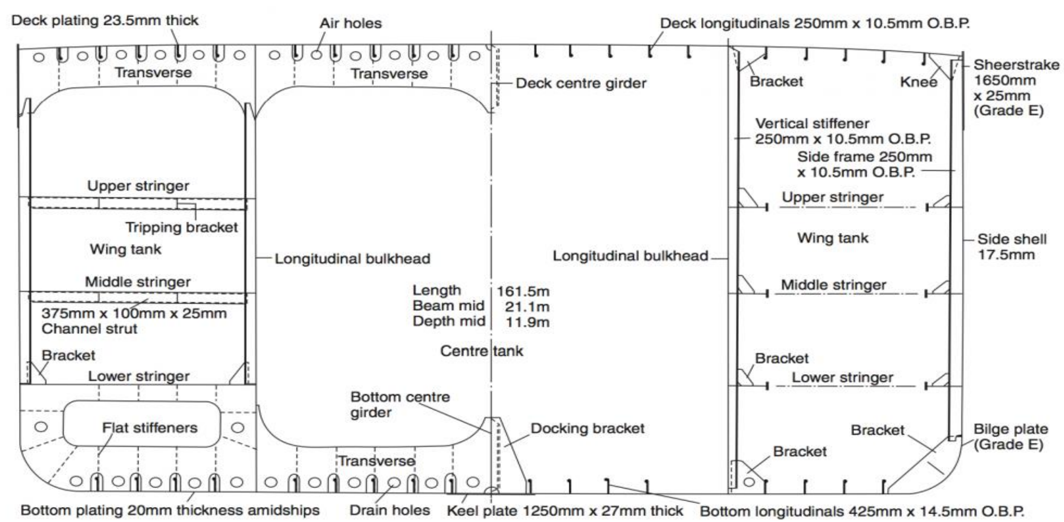


FIGURE 22.2 Midship section of oil tanker

Structural loads

Question: What different types of structural loads can you mention?

Structural loading

- Internal vs. external loads
- Static vs. dynamic loads
  - *Inertia forces in case of dynamics*
- Controlled vs. uncontrolled loads
  - *Can the crew impact on the load e.g. by adjusting the speed and bearing of the ship?*
- Deterministic vs. probabilistic loads
- Design loads vs. accidental loads
  - *Forces of nature are unknown and do not have any specific upper limit*

	Type of load	Frequency	Examples
1	Constant	Non-periodic	Ship production and own weight
2	Once	Non-periodic	Launching, water pressure on bulkheads in accidents
3	Docking period	Docking period	Docking loads, e.g. bottom pillars
4	Journey	Typical journey time	Still water shear and moment Static pressure Temperature loads
5	Daily	24h	Loads due to temperature variations
6	Wave	Wave experiencing period wave length, ship speed	Hydrodynamics loads Acceleration loads Sloshing loads
7	Vibrations	Eigenfrequency of the structure	Hull girder vibration due to impact (whipping) and waves (springing)
8	Impact	Seconds	Slamming Ice load Collision and Grounding

Wave loading

- The sea surface is random and causes high loading on ships

- The amount of loading depends on the operational area
  - *Selection of design operational area affects the ship design*
  - *The North Atlantic is often considered "as the worst case" for wave loads*
  - *Operations in ice cause high local loads*
  - *Structural loads acting on a ship are stochastic and complex – there is no maximum for the loads!*
  - *Uncertainty must be treated probabilistically.*

Image credit AP

Image credit Arctia

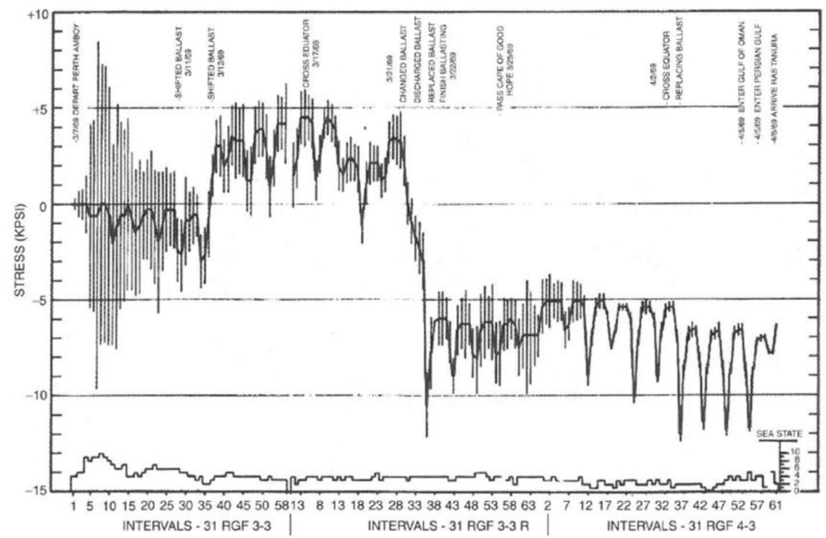


Fig. 4 Typical voyage variation in stresses, *R.G. Follis*, in ballast.

Strength vs Structural Failure

- **Ship Strength is a measure of the capacity of the ship structure to withstand/carry a load**

- If a load induced stress exceeds ship strength a structural failure may occure

- Different types of structural failures
  - *Ductile fracture*
    - ✓ Extensive plastic deformation
  - *Brittle facture*
    - ✓ Sudden, very rapid cracking of equipment under stress where the material exhibited little or no evidence of ductility or plastic degradation before the fracture occurs
  - *Fatigue fracture*
    - ✓ Material failure that occurs as a result of excessive cyclic loading
  - *Elastic or plastic deformation*
  - *Instability: buckling or tripping*
  - *Creep*
    - ✓ Deformation that happens gradually

- Strength and corrosion margins necessary

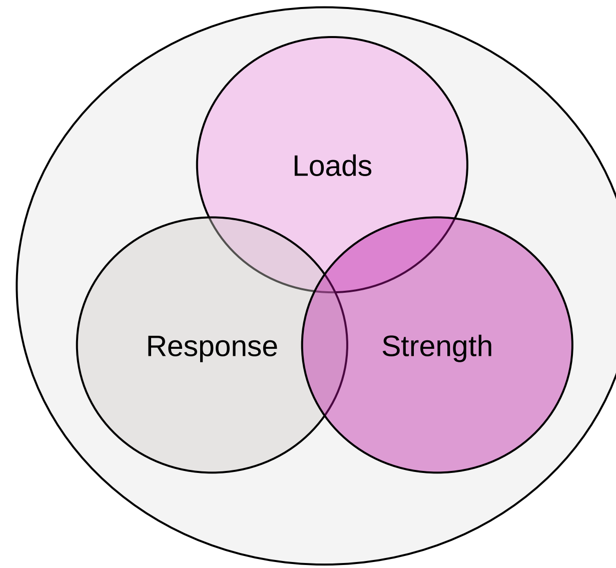
Image credit RINA

Image credit Canadian Coast Guard

Structural design – work steps

- ❑ Estimation of loads
  - *Hydrostatic and hydrodynamic loads*
  - *Considerations of accelerations due to ship motions*
- ❑ Evaluation of the structural response
  - *Normal and shear stresses*
  - *Deflections*
  - *Eigen frequencies and modes*
- ❑ Strength assessment
  - *Ultimate (yield)*
  - *Buckling*
  - *Fatigue*
  - *Brittle fracture*
- ❑ Allowable stress vs. limit state design
  - *Designers typically account for a strength marginal whose magnitude depends on level of optimization and uncertainty*

Structural Design Framework

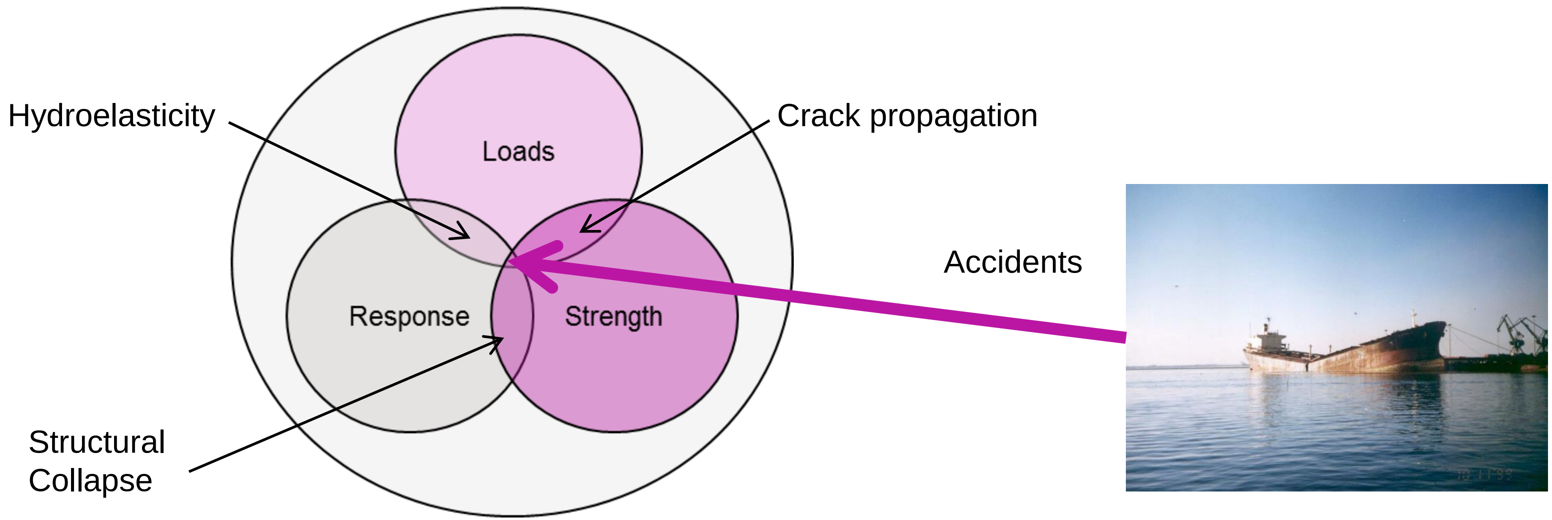


What happened here ?

Structural analysis

Successful vs. unsuccessful structural analysis

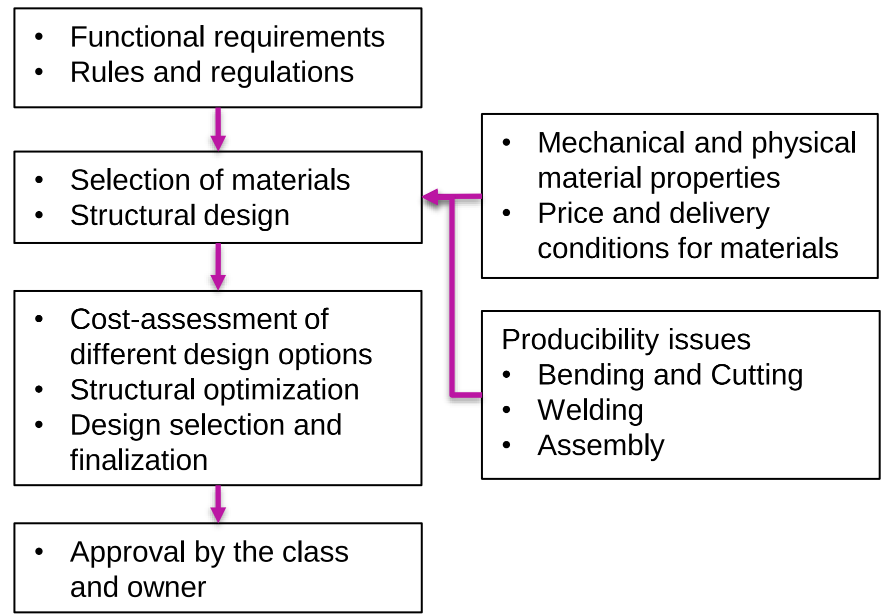
Load	X	Response	X	Strength	=	Result
50%		100%		100%		50%
90%		90%		90%		73%



The structural design process

- Many stakeholders

- Process steps
  - *Preliminary weight estimates using empirical data*
  - *Class regulations → basic dimensioning*
  - *Determination of a steel GA*
    - Stiffener spacing
    - Web frame spacing
  - *Detailed weight estimates*
  - *Identification of problem areas*
    - Direct analysis of problem areas
  - *Class approval*
  - *Determination of production drawings*
  - *Consideration of feedback from*
    - The builder
    - The operator/owner



Shipbuilding materials

- ❑ Steels are the most common materials being used for shipbuilding (AH36 typical)
  - *Provide a favorable combination of a relatively high strength/weight ratio, producibility, and costs*

- ❑ Alternative materials include
  - *Composites*
    - ✓ Lightweight, strong, and stiff (+)
    - ✓ Do not corrode (+)
    - ✓ Excellent fatigue properties (+)
    - ✓ Fire safety issues (-)
    - ✓ High building costs (-)
  - *Aluminum*
    - ✓ High strength/weight ratio (+)
    - ✓ Corrosion resistant (+)
    - ✓ Challenging to work with (-)
    - ✓ Fire safety issues (-)

Composite vessels. Image credit DAMEN

Aluminium catamaran. Image credit Meyer Turku

Shipbuilding materials

- Classification of steel
  - *Classification based on yield point*
    - normal steel (NS),
    - high strenght steel (HS)
    - extra high strenght steel (EHS)
  - *Classification based on impact toughness (grade):*
    - A-, B-, D, F- and E-grade
  - *Production methods need approval from classification society*

- Steel quality measures
  - *Chemical composition*
  - *Carbon equivalent*
  - *Yield and tensile stress*
  - *Fracture strain*
  - *Impact toughness*
  - *Z-strength properties*

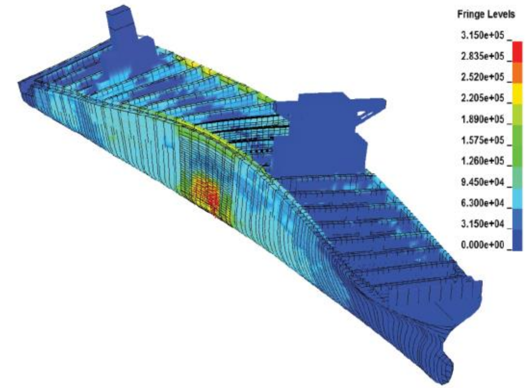
STEEL TYPES AND GRADES							
SHIPBUILDING STEELS ACCORDING TO THE RULES OF THE LISTED CLASSIFICATION SOCIETIES (SEE BELLOW)					STRUCTURAL STEELS ACCORDING TO EURONORMS		
Strength	Grade	Delivery Condition	Max CE[1]	Others	Euronorm	Grade [2]	Delivery Condition
Normal	A, B	AR	–		EN 10025:1990 + A1:1993	S235JR / S235JRGn[2]	AR
	D	CR				S235J0	
	E	TM				S235J2Gn[2]	CR
High	A32		0,36			S275JR / S275JRGn[2]	AR
	D32					S275J0	
	E32					S275J2Gn[2]	CR / TM
	F32					S355JR	TM
	A36		0,38			S355J0	
	D36					S355J2Gn[2]	
	E36					S355K2Gn[2]	
	F36				EN 10025-2:2005	S235JR	AR
	A40		0,40			S235J0	
	D40					S235J2	CR
	E40					S275JR	AR
	F40					S275J0	
Extra high	A420					S275J2	CR / TM
	D420					S355Jn[2] +M	TM
	E420				EN 10113-3:1993 or EN 10025-4:2000	S275M	
	A460					S275ML	
	D460					S355M	
	E460					S355ML	
	A500					S420M	
	D500					S420ML	
	E500					S460ML	
Normal	NV 2-2		0,34	Steel for Low Temperature Service		S460ML	
	NV 2-3				EN 10225:2001 (OFFSHORE STEELS)	S355G4+M	
	NV 2-4					S355G11+M	
High	NV 4-2		0,38			S355G12+M	
	NV 4-3					S420G3+M	
	NV 4-4					S420G4+M	

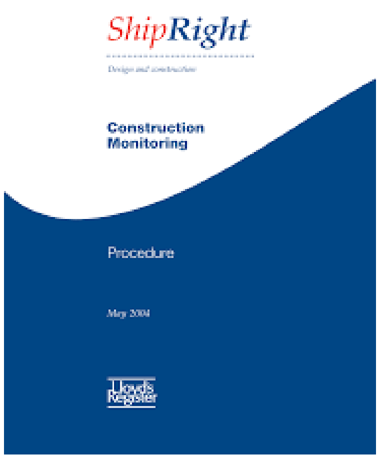
1) lower values and a max Pcm can be agreed upon.
2) The letter (suffix) n to be replaced by the current number or letter in the current Euronorm.

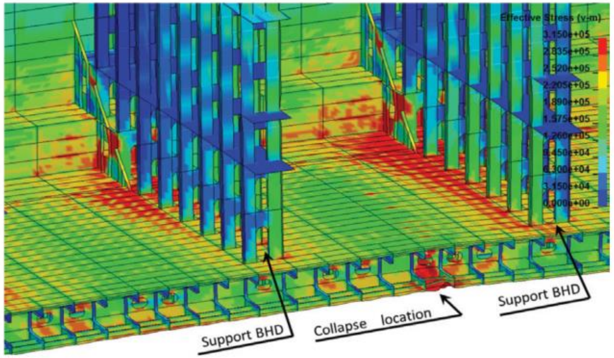
Ruukki Profiler AS is approved by the following Classification Societies

DnV - Det norske Veritas
LR - Lloyds Register of Sipping
GL - Germanischer Lloyd
BV - Bureau Veritas
ABS - American Bureau of Shipping
RS - Russian Maritime Register of Shipping
RINA - Registro Italiano Navale
NK - Nippon Kaiji KYOKAI

Structural design tools – FEA method







Structural design tools – NAPA steel

❑An integrated tool for structural design tasks

- *Weight and center of gravity, bill of materials, welding lengths and painting areas*
- *Generating data for production planning and cost estimation*
- *Section modulus and radius of gyration*
- *Generation of drawings and visualizations for plan approval*
- *Data exchange with classification societies' systems for scantling analysis and FEM*
- *Export of the 3D structural model to outfitting and production design systems*
- *Automatic idealization and generation of FEM mesh, export to FEM solvers such as Nastran and Ansys*
- *..*

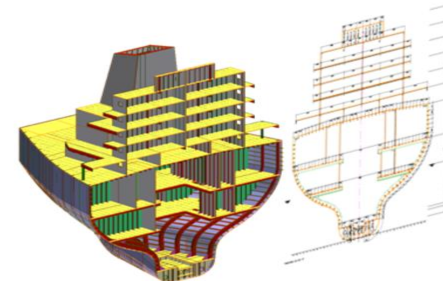
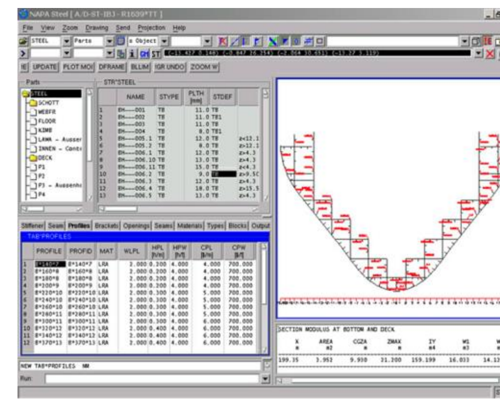
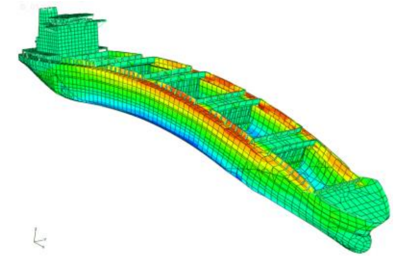


Image credit NAPA



Summary

- Different levels with regards to structural analysis
  - *Primary, secondary, tertiary*
- Components of the structural design framework
  - *Load, response and strength*
- Time scales
  - *Dynamic, quasi-static, static*
- Loads in the maritime environment are stochastic



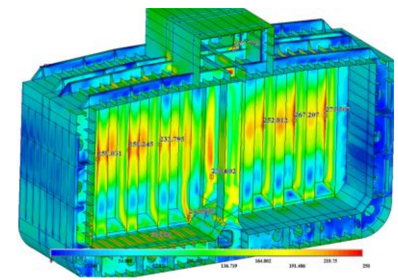


Image credit Mesh.com.tr

Aalto University
School of Engineering

Thank you !