Projeto de Navios segundo Sociedades Classificadoras (Rule-based design)

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Escopo

- Motivação
  - Falhas Estruturais (Modos de Falha)
- Revisão de Mecânica dos Sólidos
- Projeto Racional vs. Projeto segundo Norma
- Sociedades Classificadores de Navios
  - IACS
- Dimensionamento de Estruturas Navais
  - Oil Tanker (Caso de Estudo)

Escopo

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  - Falhas Estruturais (Modos de Falha)
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Motivação

- *Fatores de Segurança Possuem Base Empírica*

- *Cálculo de estruturas é feito com base na experiência previa*

Danos e Defeitos Comprometem a Integridade Estrutural!

Por Que as Estruturas e Componentes Mecânicos Falham?

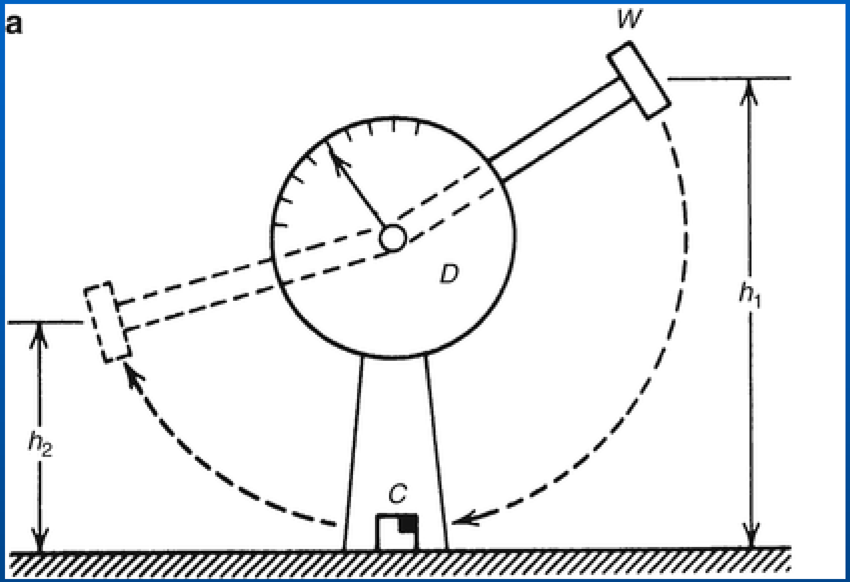
Ocorrência de Defeitos Durante a Vida em Serviço

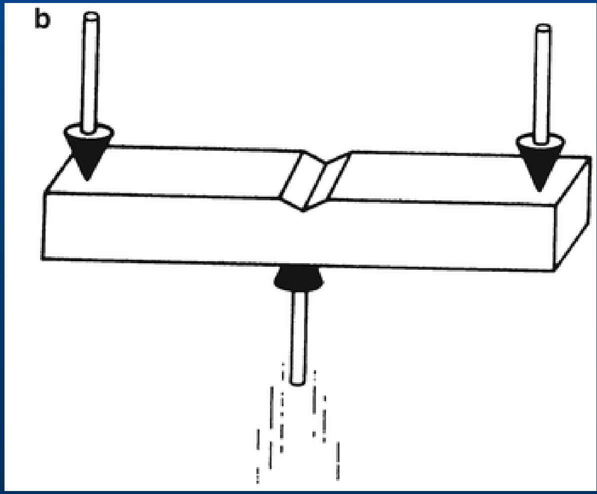
Erros Humanos, Construtivos e Operacionais

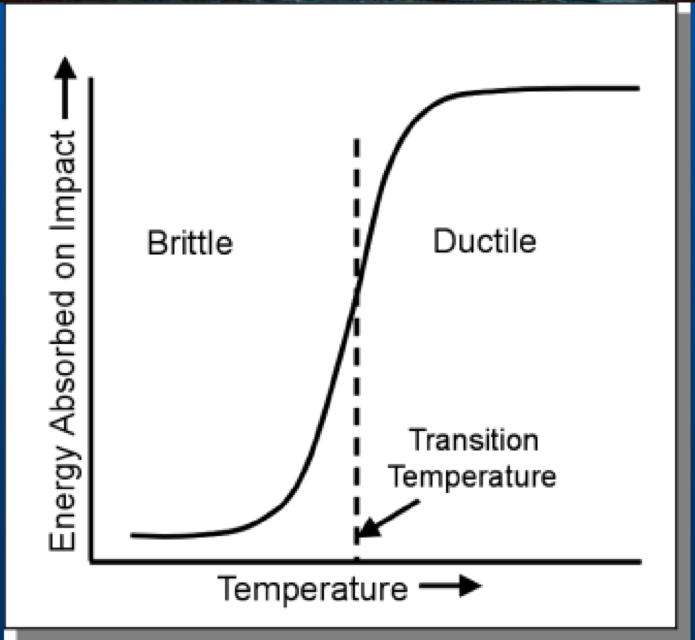
Uso de Novas Concepções de Projeto ou Novos Materiais

Navio *Titanic*

Temperatura de Transição Dúctil-Frágil





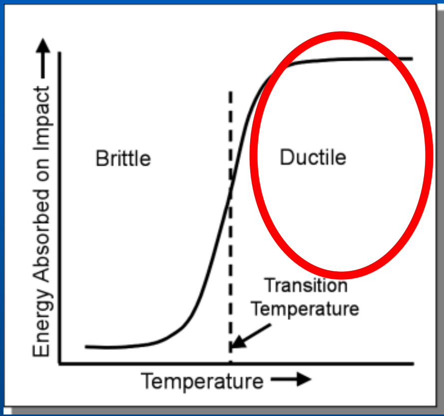


Navio *Titanic*

	C	*Mn*	*P*	*S*	*Si*	*Mn:S*
Aço Titanic	*0.21*	*0.47*	*0.045*	*0.069*	*0.017*	*6.8:1*
Aço ASTM A36	*0.20*	*0.55*	*0.012*	*0.037*	*0.007*	*14.9:1*

	σ_{ys} (MPa)	σ_t (MPa)	*Elong. (%)*
Aço Titanic	193	417	29
Aço ASTM A36	235	460	22

	T_{tr} (°C) @ 20 J
Aço Titanic (Longitudinal)	32
Aço Titanic (Transversal)	56
Aço ASTM A36	-27

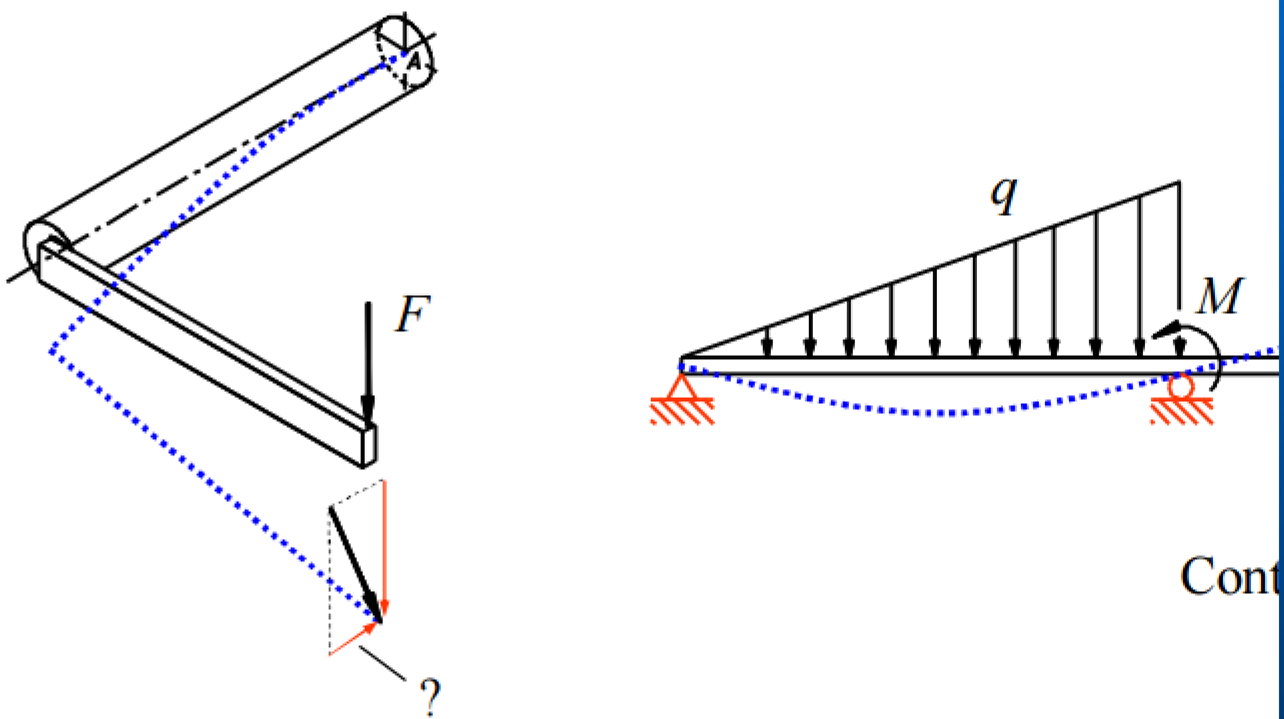


Temperatura de Transição Elevada

Modos de Falha

- Deformação excessiva
- Escoamento / Colapso Plástico
- Fadiga
- Fratura
- Flambagem
- Corrosão
- Creep

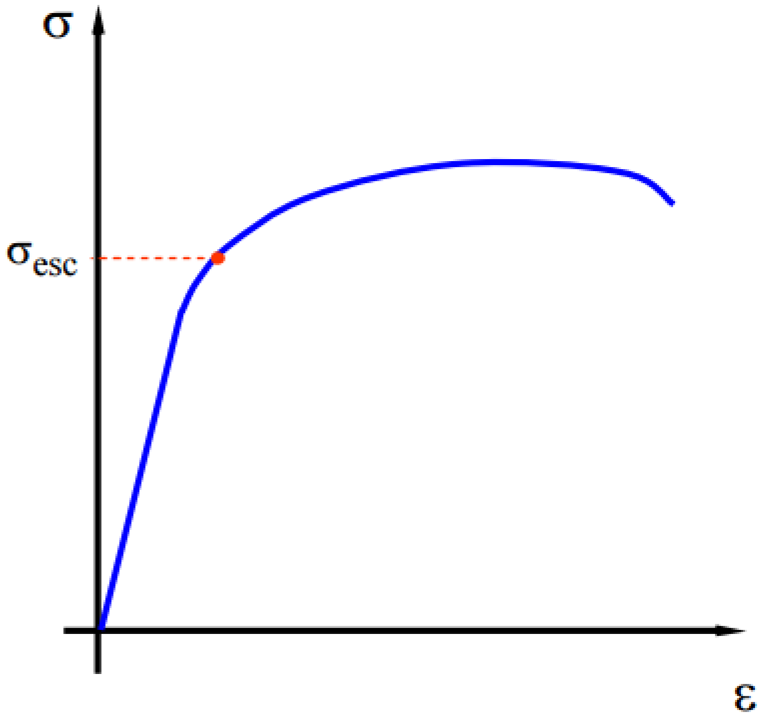
Deformação

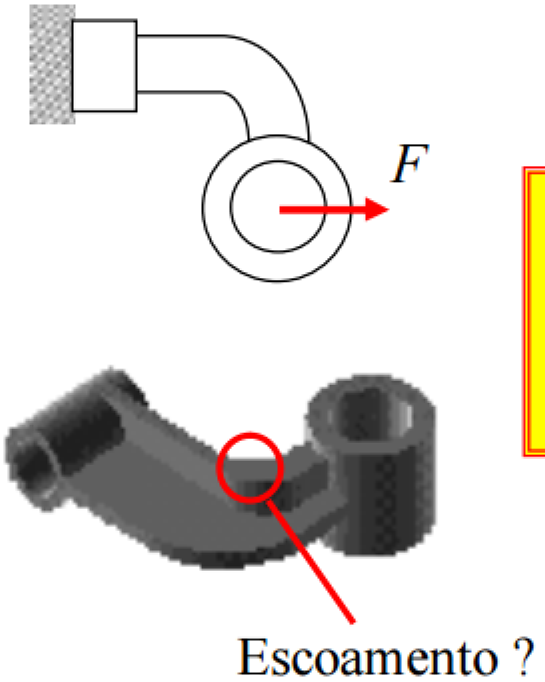


Normas: limitam deslocamentos máximos.

Escoamento

Escoamento à temperatura ambiente





- Material
- Geometria
- Carregamento

Projeta-se para que as tensões nos pontos críticos não ultrapassem σ_{esc}.

Fadiga

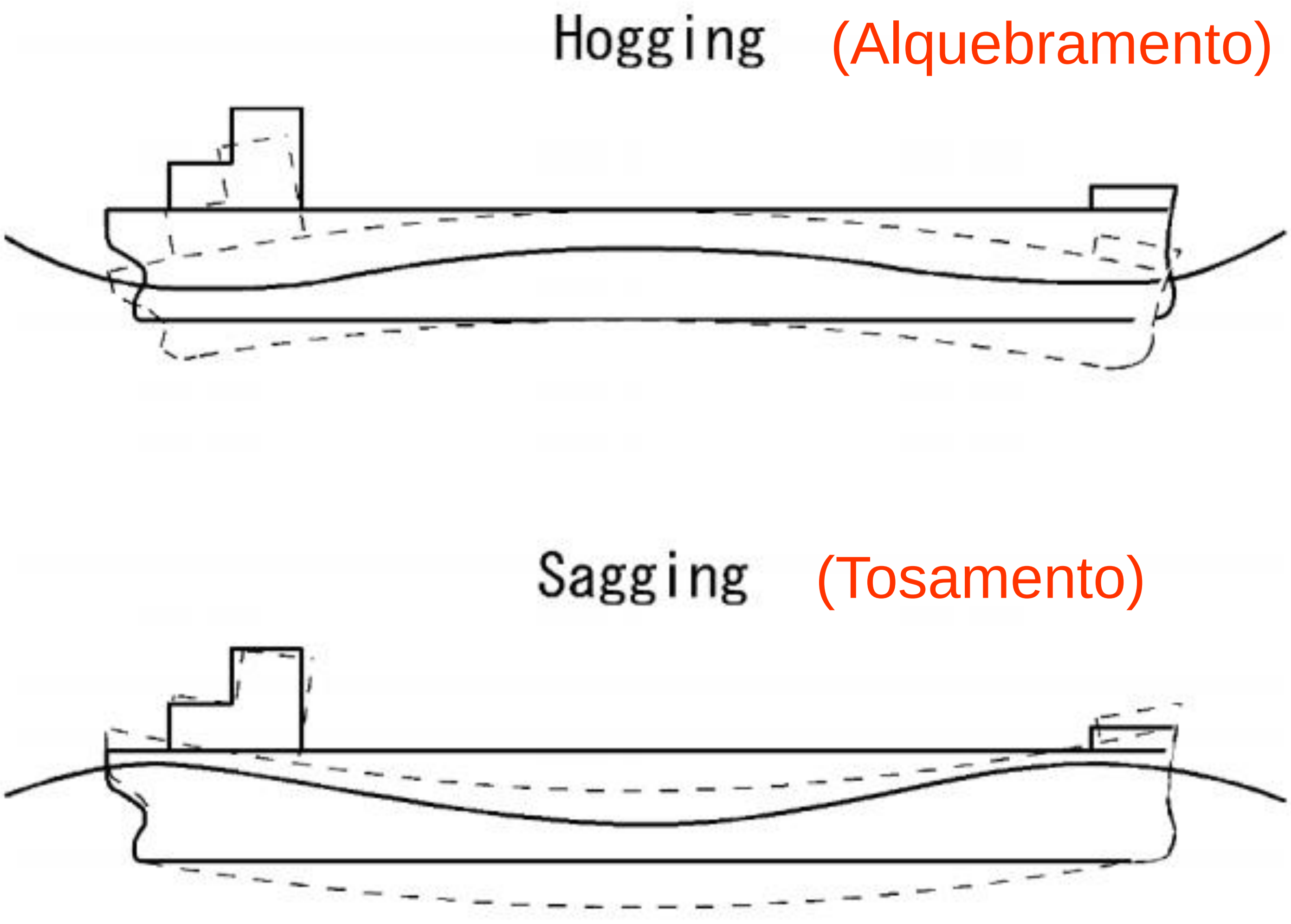


Fig. 2.2.1 Vertical bending due to waves

Fadiga

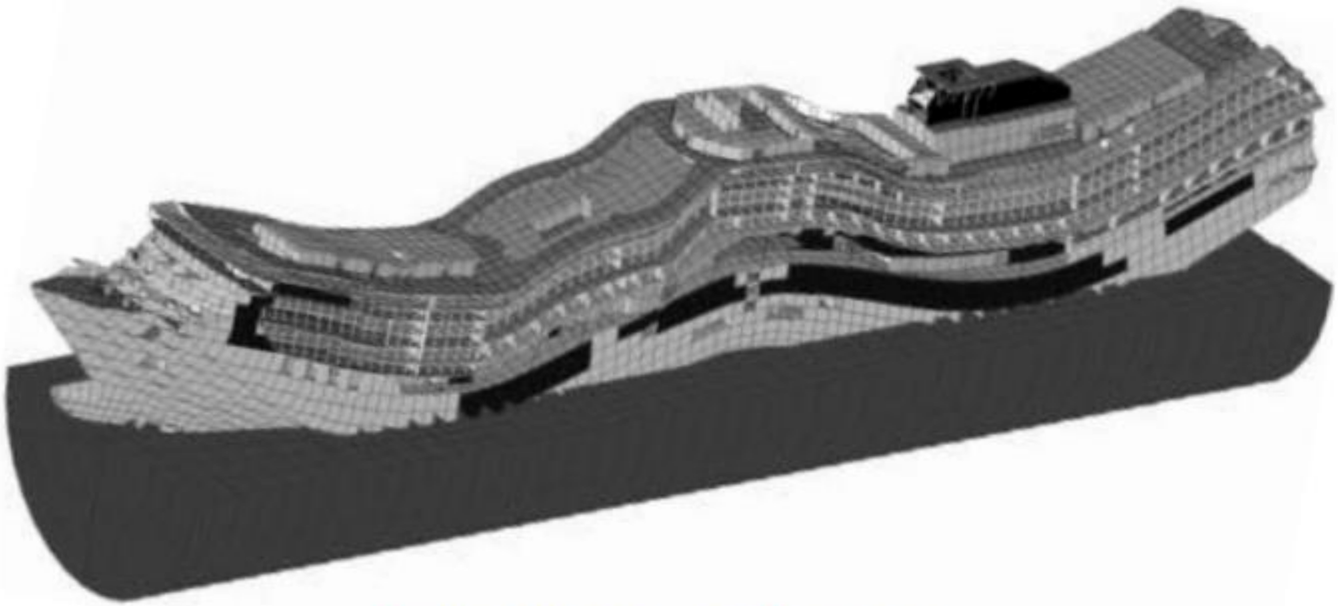


Figure 18.55 Hull Girder Vibration—Mode #3 (Principia Marine-France)

Fratura Frágil

Figure 1. Forward section of the FLARE [1].

ano 2000

Falha acontece mesmo sob tensões menores que o limite de escoamento

Fratura Frágil

ano
2000

Flambagem

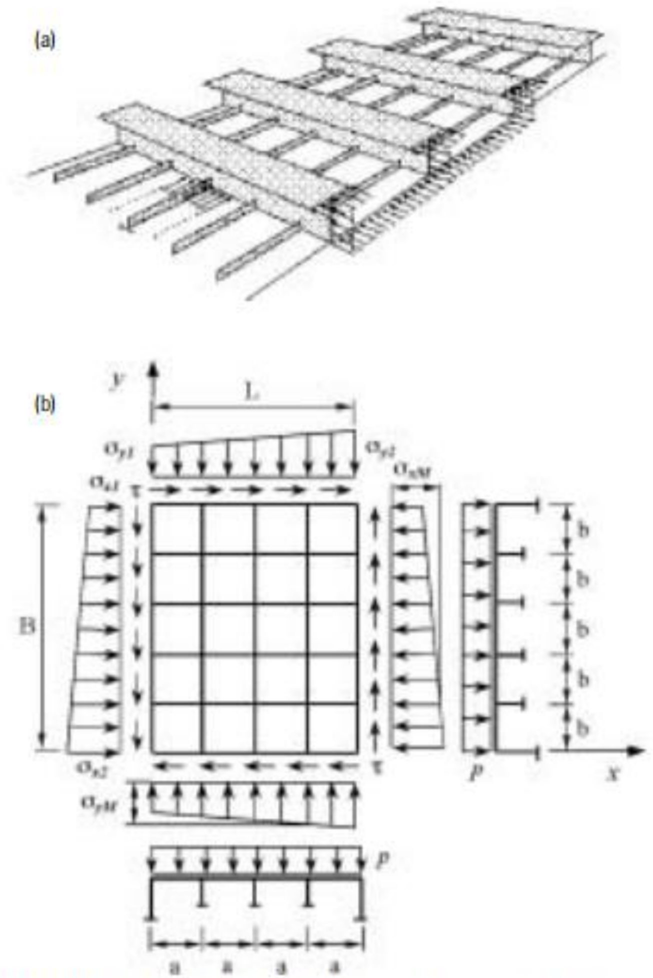


Figure 18.43 A Stiffened Steel Panel Under Biaxial Compression/Tension, Biaxial In-plane Bending, Edge Shear and Lateral Pressure Loads. (a) Stiffened Panel—Longitudinals and Frames (4), and (b) A Generic Stiffened Panel (38).

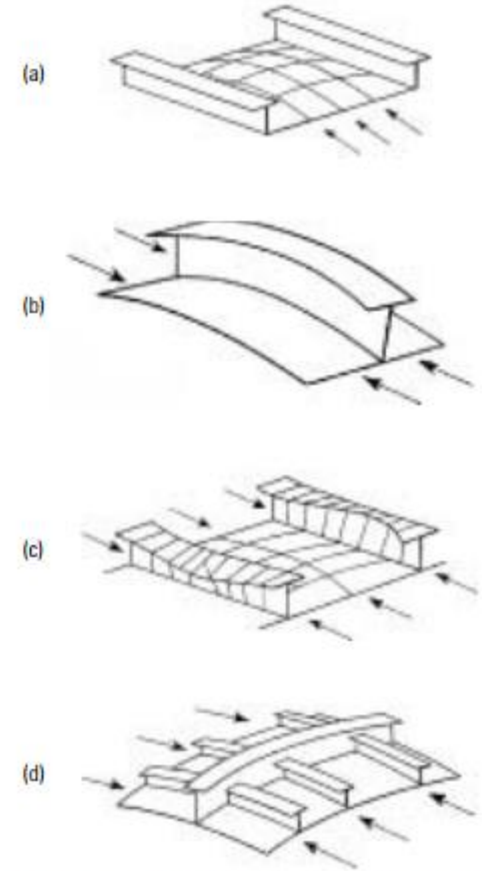


Figure 18.44 Modes of Failures by Buckling of a Stiffened Panel (2).

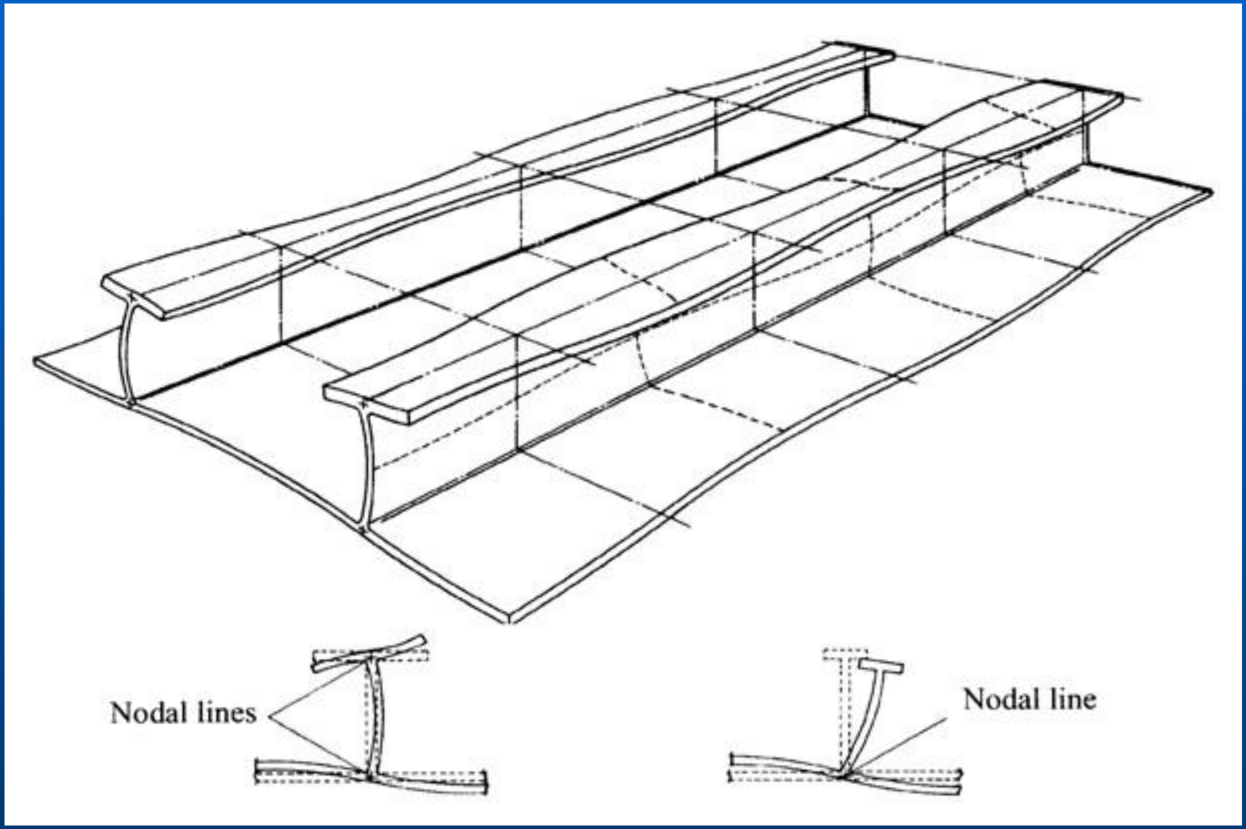
(a) Elastic buckling of plating between stiffeners (serviceability limit state).

(b) Flexural buckling of stiffeners including plating (plate-stiffener combination, mode III).

(c) Lateral-torsional buckling of stiffeners (tripping—mode V).

(d) Overall stiffened panel buckling (grillage or gross panel buckling—mode I).

Flambagem Painel



Flambagem Viga-Navio

Fratura Dúctil

ano

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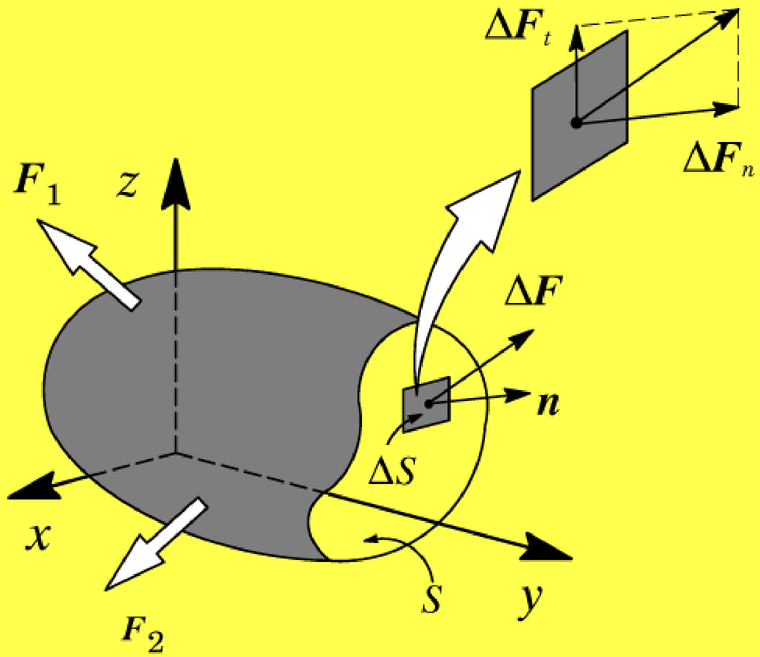
Breve Revisão de Mecânica dos Sólidos

- **Definição de Tensão e Estado de Tensões**
- **Definição de Deformação**
- **Relações Tensão *vs.* Deformações Elásticas**
- **Critério de Escoamento de *Von Mises***
- **Modelos Elasto-PLásticos**
- **Relações Tensão *vs.* Deformações Plásticas**

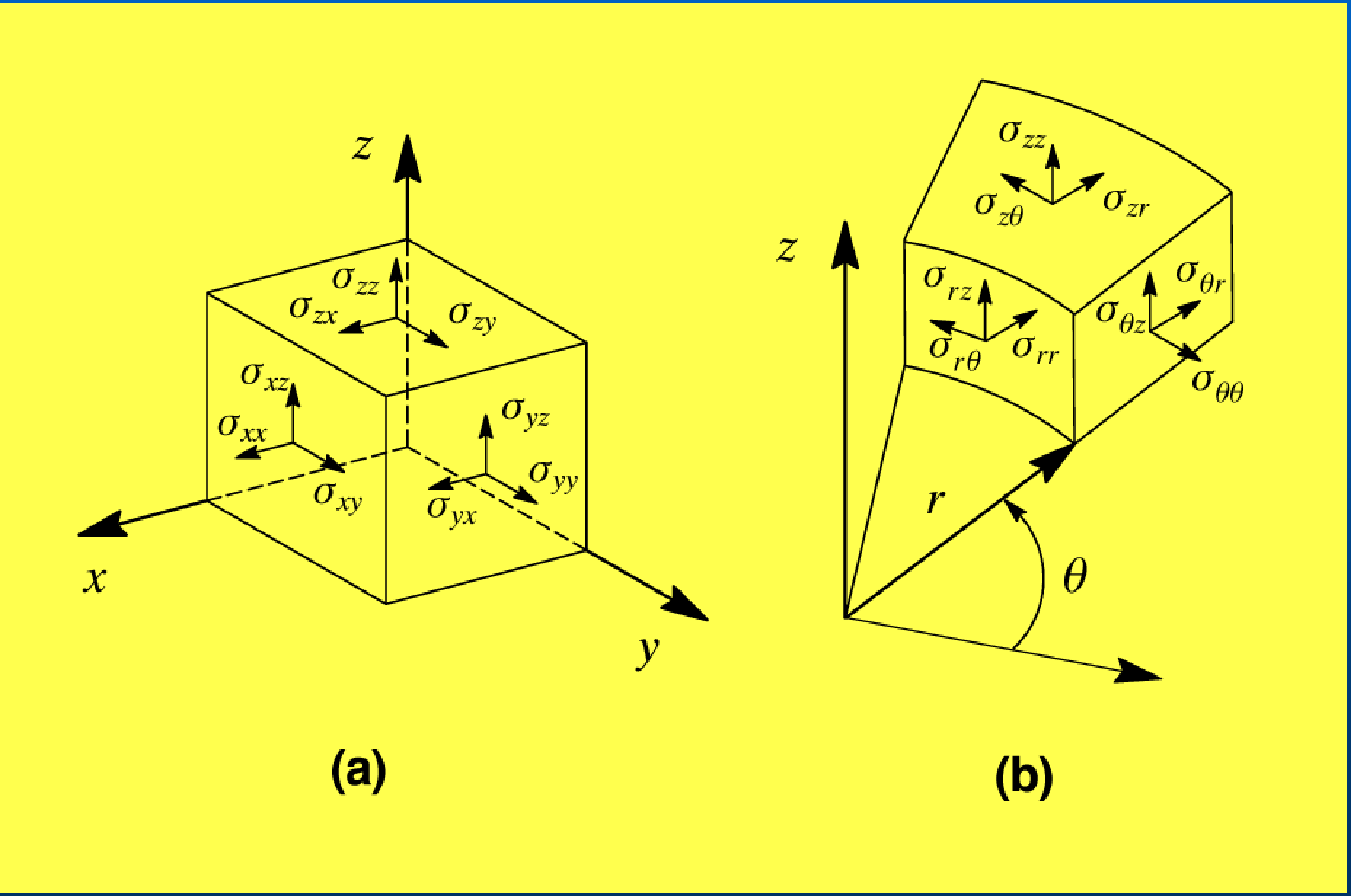
Conceito de Tensão



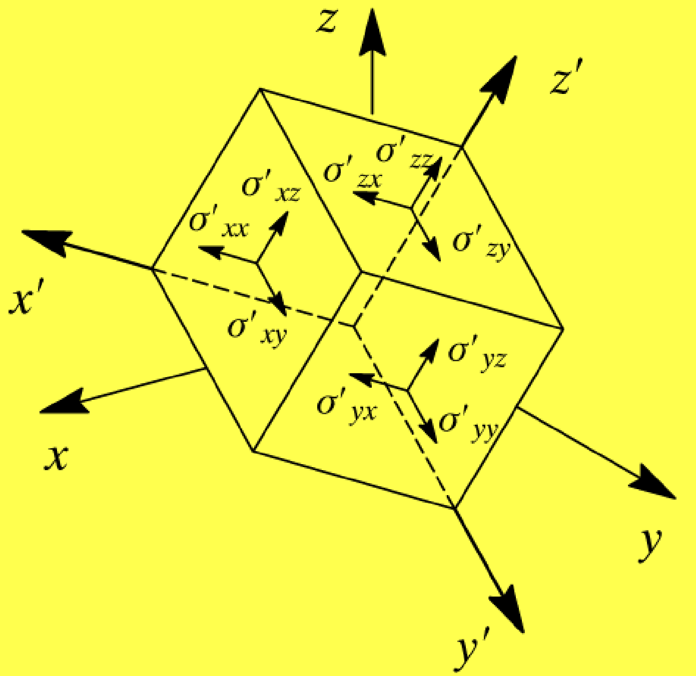
$$\sigma_n = \lim_{\Delta S \to 0} \frac{\Delta F_n}{\Delta S}$$

$$\sigma_t = \lim_{\Delta S \to 0} \frac{\Delta F_t}{\Delta S}$$

Estado de Tensões



Tensões Principais



Planos Principais :

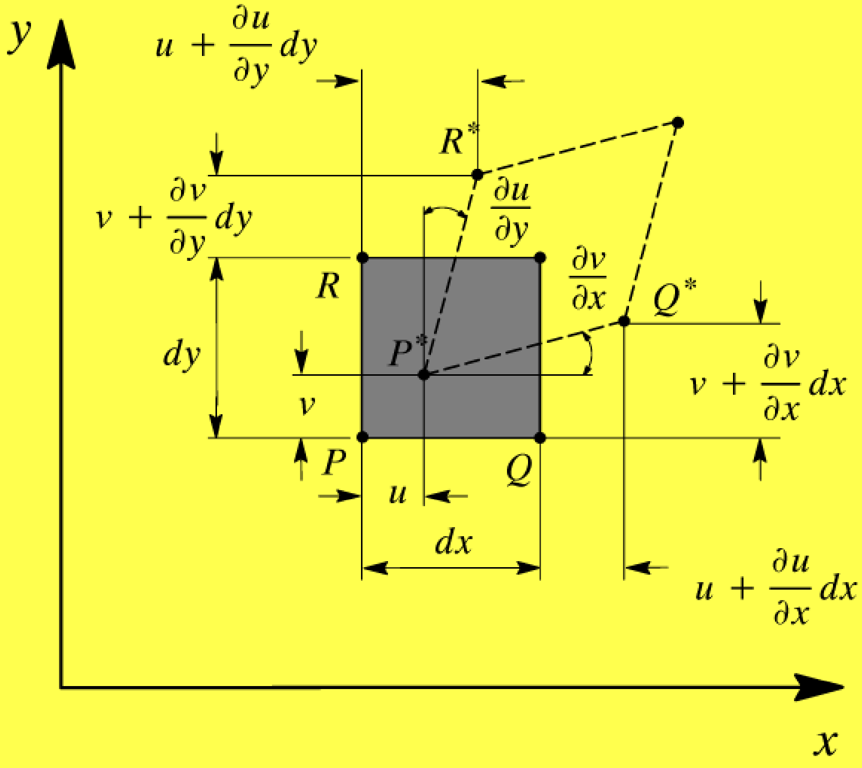
$$\sigma'_{xy} = \sigma'_{xz} = \sigma'_{yz} = 0$$

Tensões Principais :

$$(\sigma_1, \sigma_2, \sigma_3)$$

Máximas Tensões Atuantes nos Planos Principais

Deformações



$$\left.\begin{aligned} \epsilon_{xx} &= \frac{\partial u}{\partial x} \\ \epsilon_{yy} &= \frac{\partial v}{\partial y} \\ \gamma_{xy} &= \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \\ \epsilon_{xy} &= \frac{1}{2}\gamma_{xy} \end{aligned}\right\}$$

Relações σ *vs.* ε Elásticas

$$\epsilon_{xx} = \frac{1}{E}\left[\sigma_{xx} - \nu(\sigma_{yy} + \sigma_{zz})\right]$$

$$\epsilon_{yy} = \frac{1}{E}\left[\sigma_{yy} - \nu(\sigma_{xx} + \sigma_{zz})\right]$$

$$\epsilon_{zz} = \frac{1}{E}\left[\sigma_{zz} - \nu(\sigma_{xx} + \sigma_{yy})\right]$$

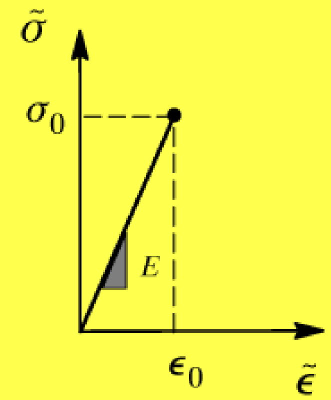
$$\gamma_{xy} = 2\epsilon_{xy} = \sigma_{xy}/G$$

$$\gamma_{yz} = 2\epsilon_{yz} = \sigma_{yz}/G$$

$$\gamma_{zx} = 2\epsilon_{zx} = \sigma_{zx}/G$$

$$G = \frac{E}{2(1+\nu)}$$

Carregamento Uniaxial :



$$\epsilon_{xx} = \sigma_{xx}/E$$

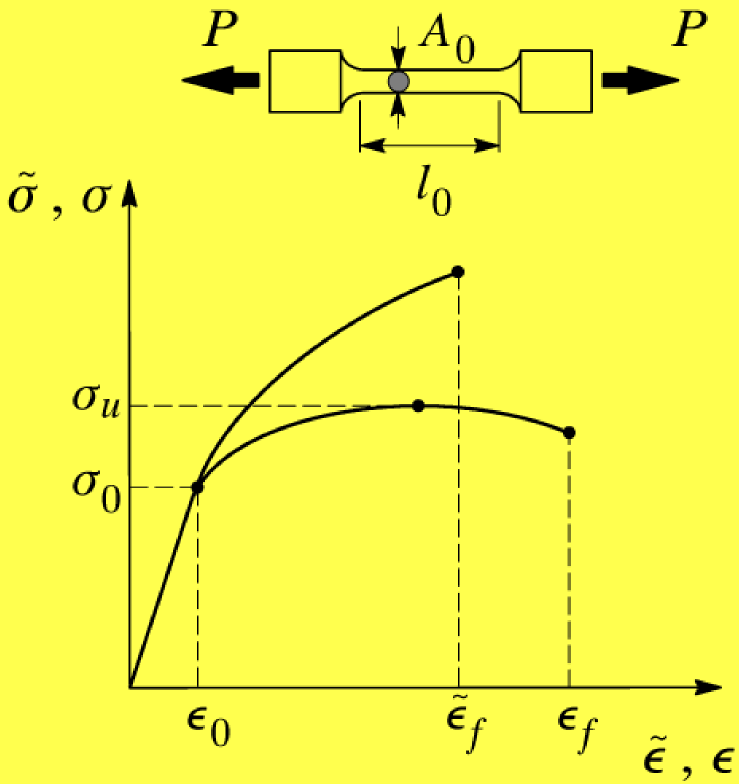
$$\epsilon_{yy} = \epsilon_{zz} = -\nu\epsilon_{xx}$$

Estado Plano de Deformações :

$$\epsilon_{zz} = 0$$

$$\sigma_{zz} = \nu(\sigma_{xx} + \sigma_{yy})$$

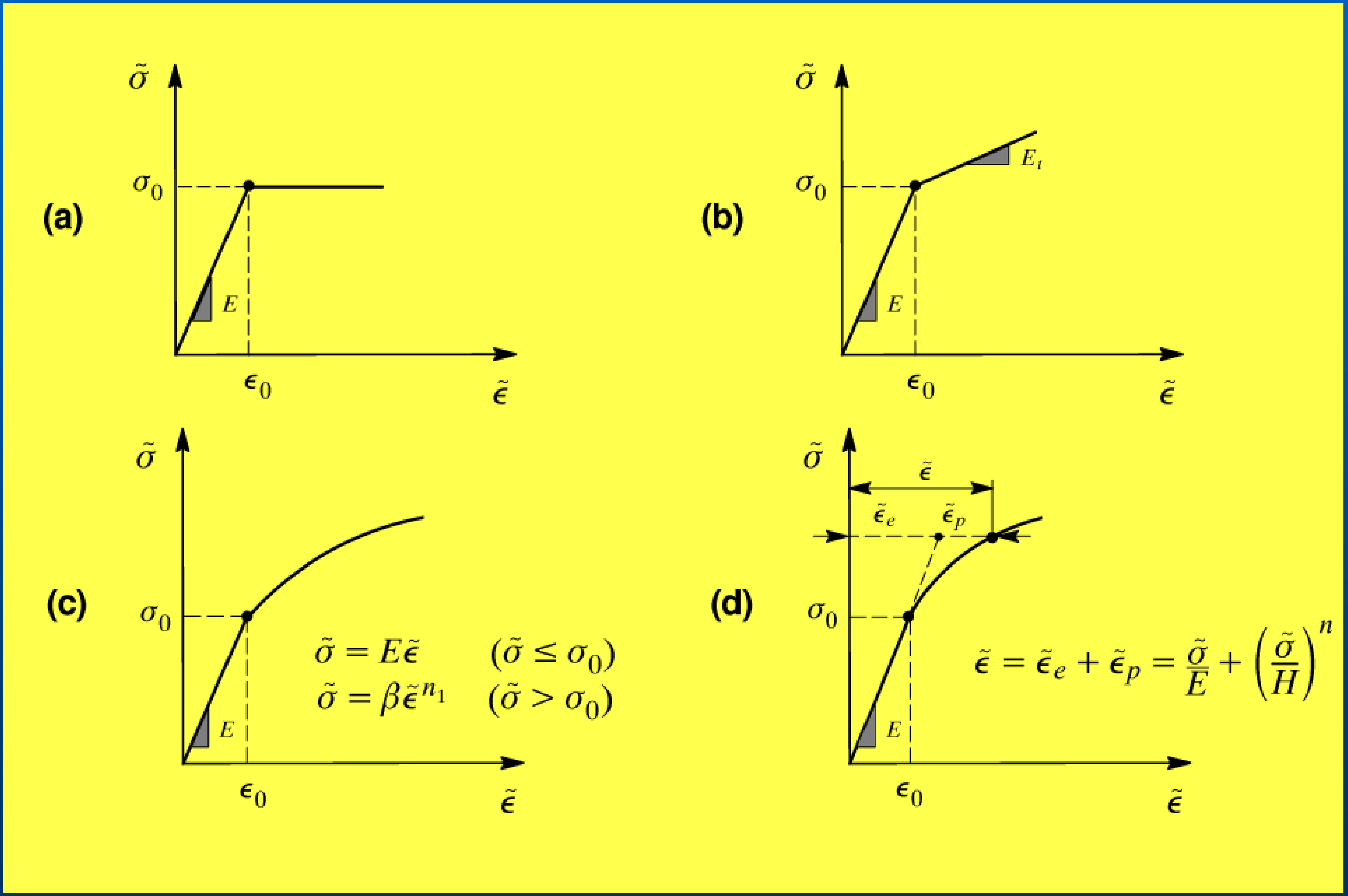
Comportamento Elasto-PLástico



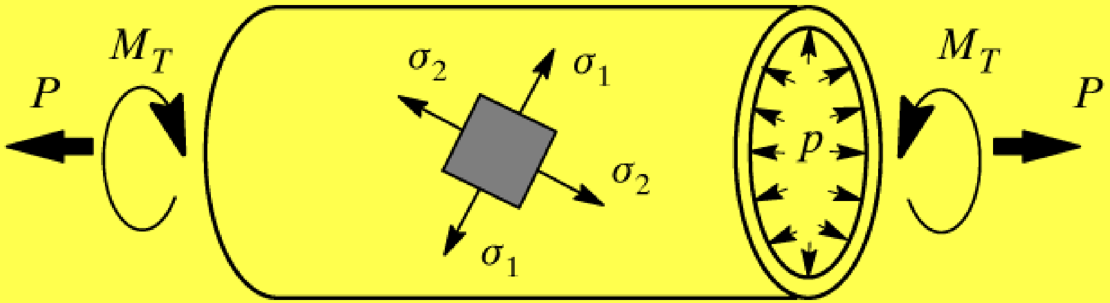
$$\left.\begin{aligned}\sigma &= \frac{P}{A_0}\\ \epsilon &= \frac{l_i - l_0}{l_0}\end{aligned}\right\}$$ **Convencional**

$$\left.\begin{aligned}\tilde{\sigma} &= \frac{P}{A_i}\\ \tilde{\epsilon} &= \ln\frac{A_0}{A_i}\end{aligned}\right\}$$ **Verdadeira**

Modelos Elasto-Plásticos



Critério de *Von Mises*



$$\sigma_0 = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$$

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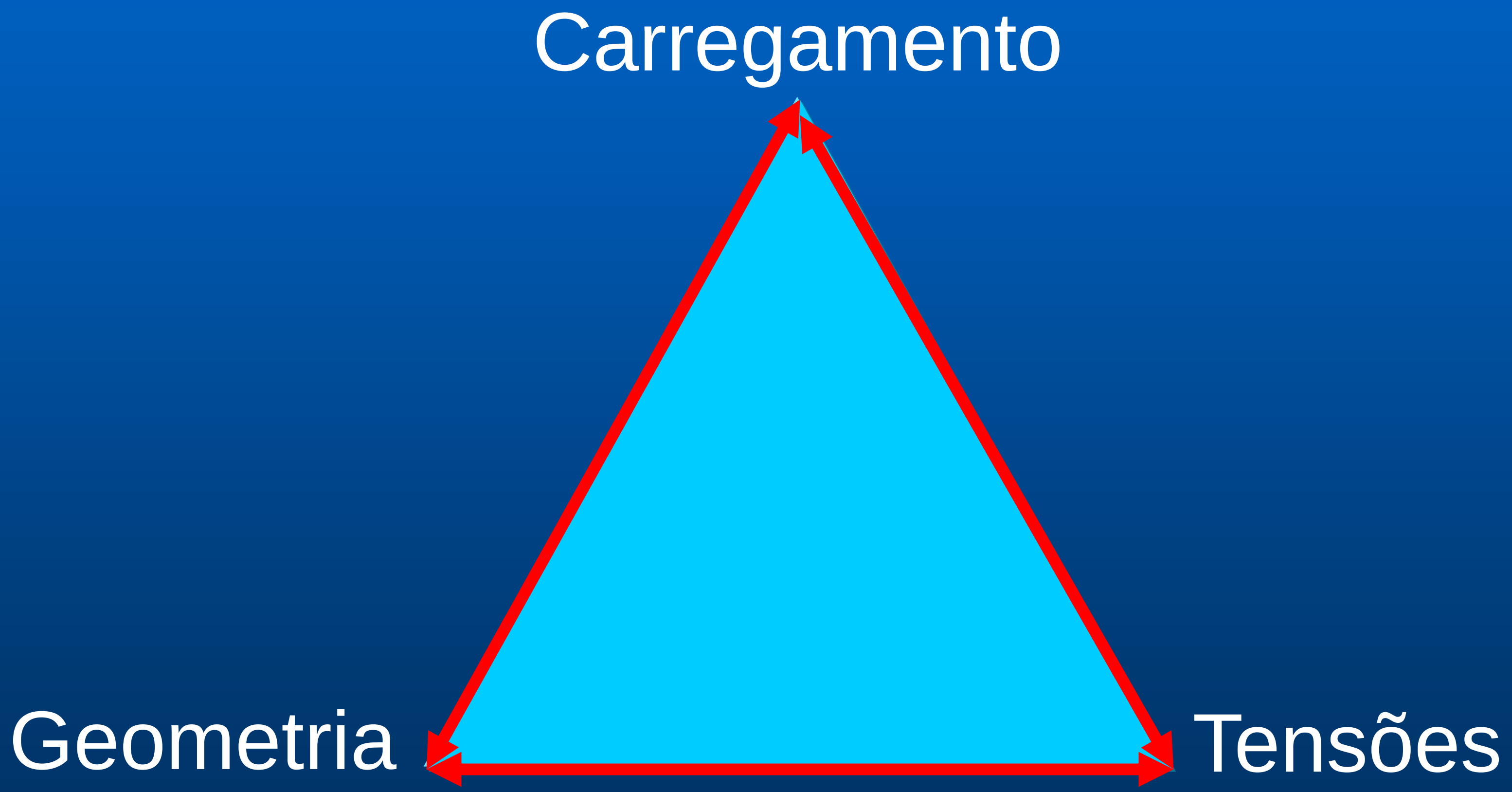
Projeto Estrutural



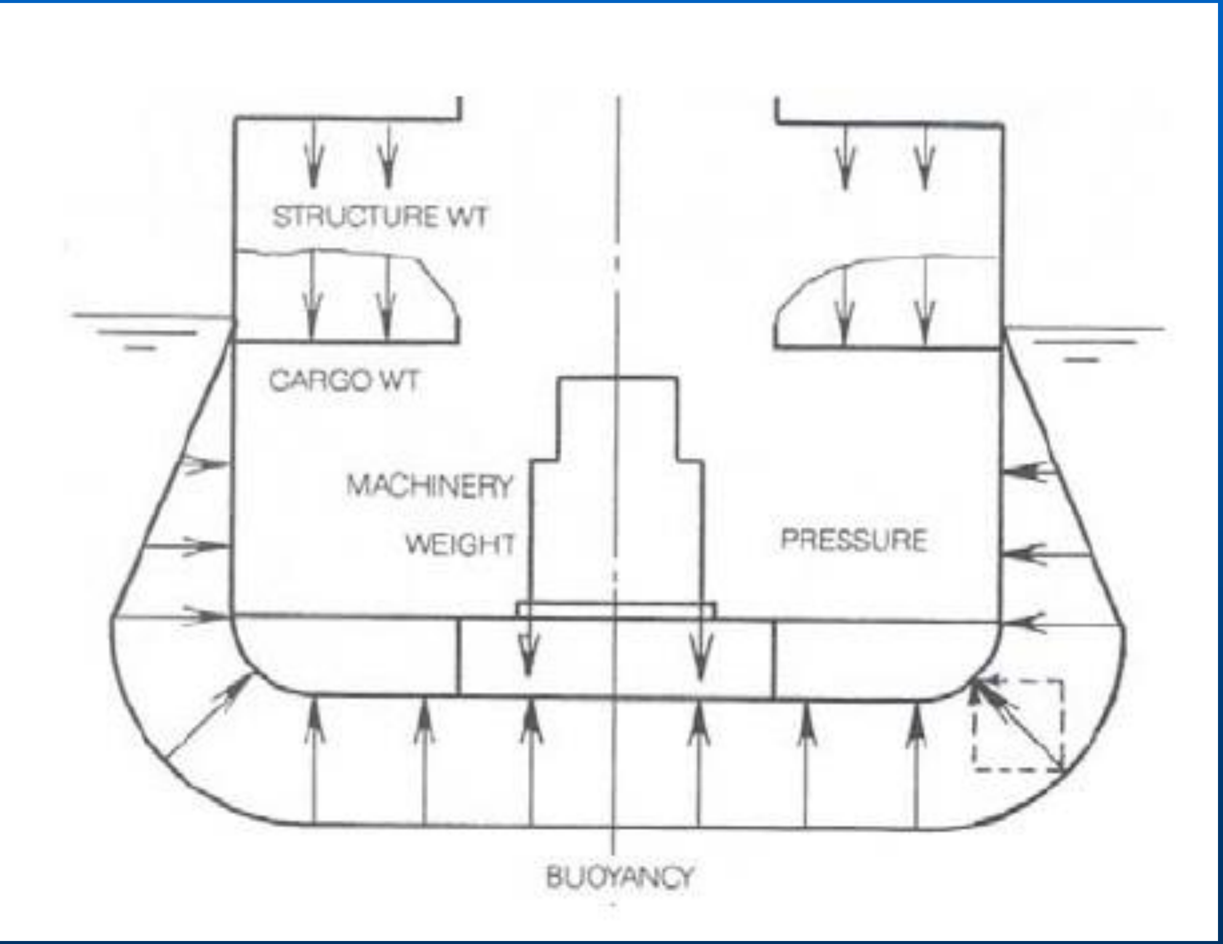
Cargas

- Internas
  - Carga
  - Lastro
  - Consumíveis
- Externas
  - Ondas
  - Vento
  - Correnteza
- Combinações

Carregamento

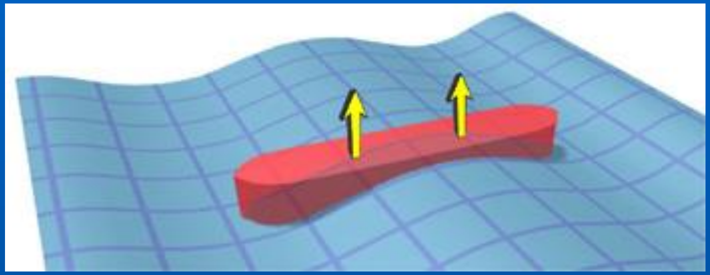
- Estático
- Dinâmico
- Combinações
- Incertezas no valor do Carregamento
  - Determinístico
  - Probabilístico

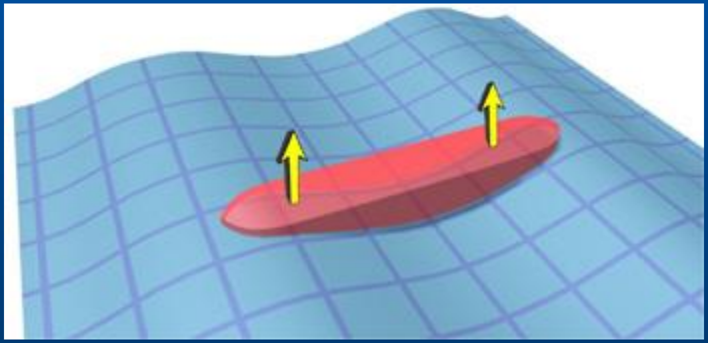
Estáticas

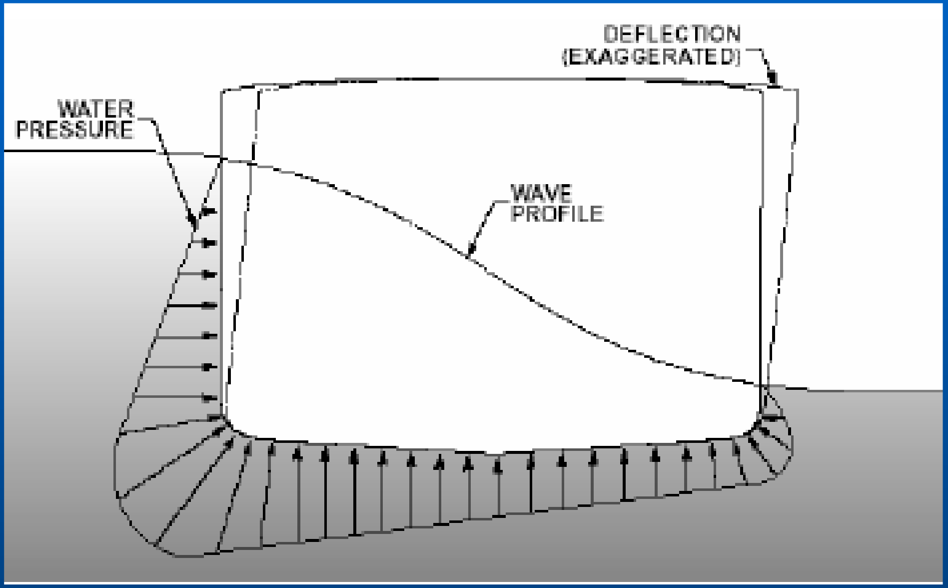


Dinâmicas

Dinâmicas

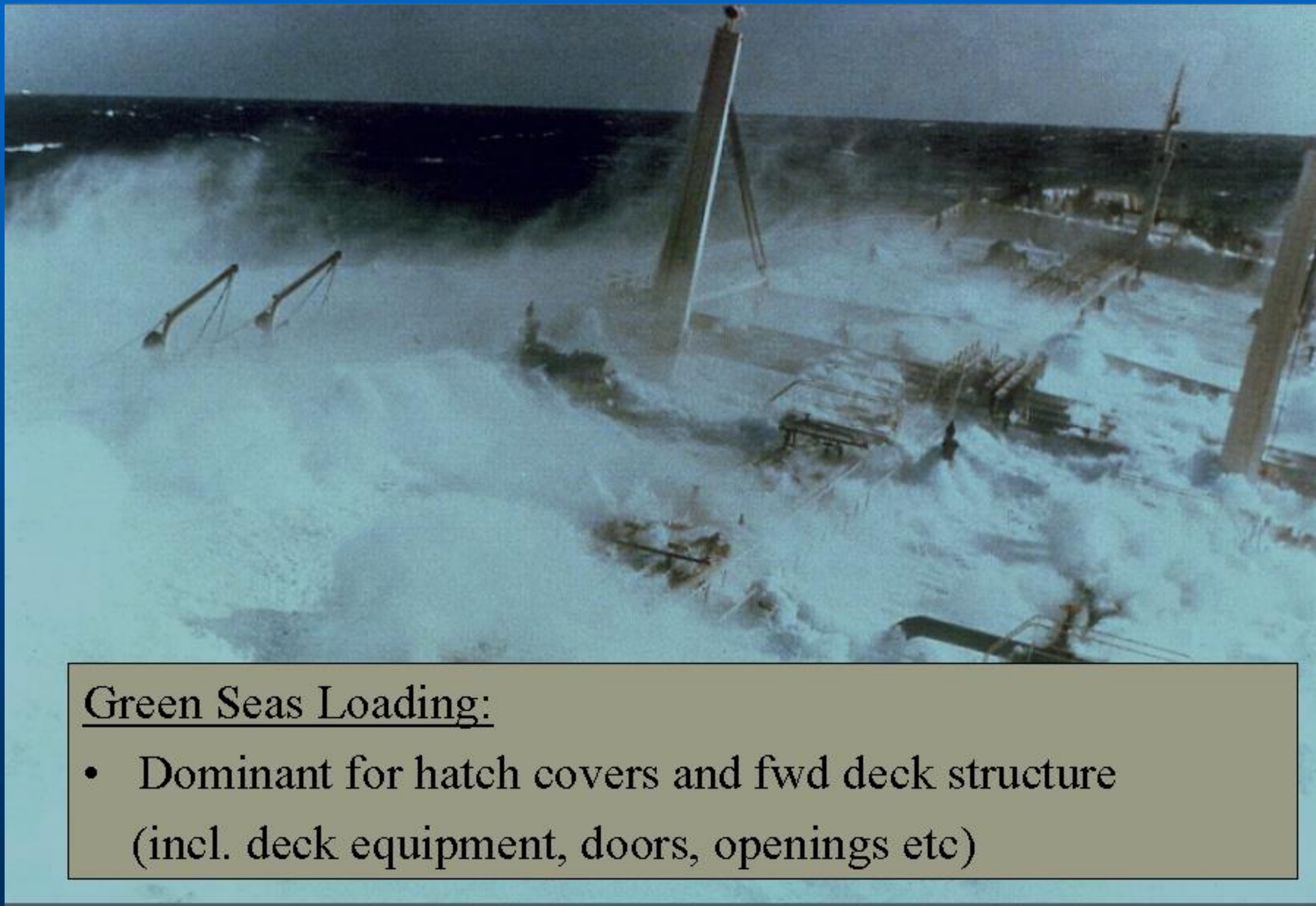






Cargas Ocasionais (Impacto)

Água no convés



Incertezas nas Cargas

Somewhere out there

Probabilidade de Falha

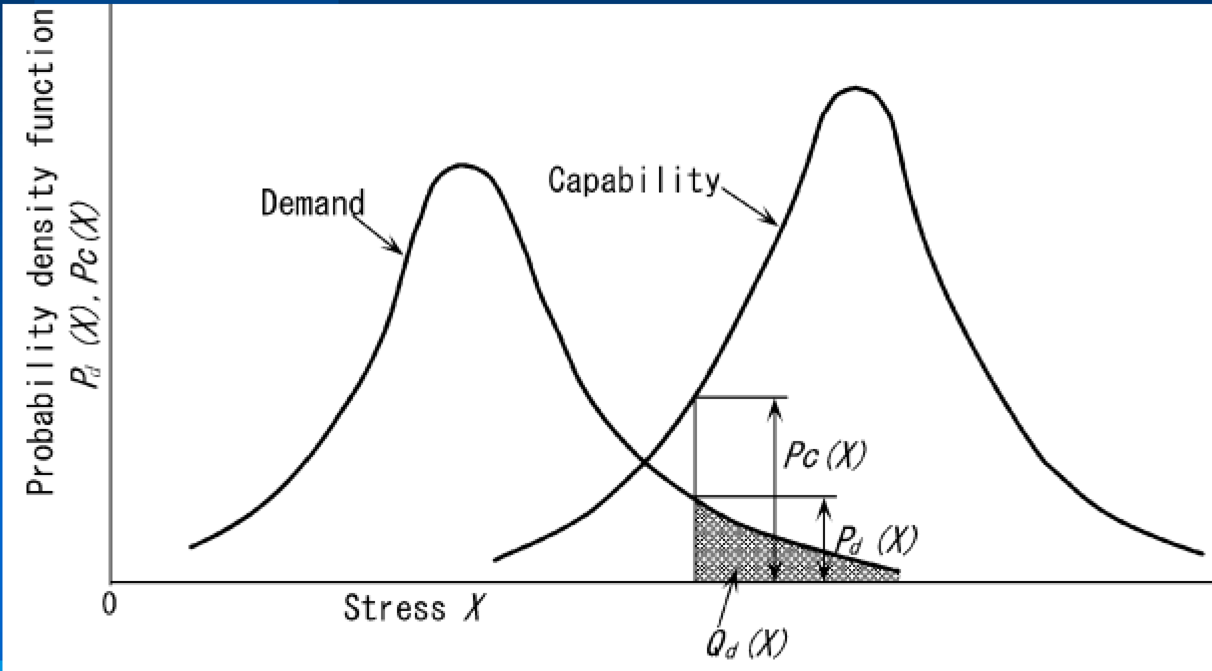


Fig. 1.6.2 Probability of fracture

- **Falhas por:**
- **Colapso plástico**
- **Flambagem**
- **Fratura frágil**

$$\boxed{P_f = \int_0^{\infty} Q_d\{X\}P_c\{X\}dX = \int_0^{\infty}(1 - Q_c\{X\})Pd\{X\}dX}$$

where

$P_d\{X\}$: probability density function of demand
$P_c\{X\}$: probability density function of capacity
$Q_d\{X\}$: probability of demand exceeding certain value
$Q_c\{X\}$: probability of capacity exceeding certain value

Wave Loads

Colapso Plástico　　　　　　Flambagem

Onda que causa a Max. Demanda (Carga)

Pior Demanda → Maior Onda excedida uma vez em $\mathbf{10^8}$ **Ciclos** é usada na análises.

Wave Loads

$$10^8 \, ciclos$$

$$\bar{T} = 7\,s$$

$$320 \, {dias}/{ano}$$

$$\frac{1}{7}\frac{Ciclos}{s} \times \frac{3600\,s}{1\,h} \times \frac{24\,h}{1\,dia} \times \frac{320\,dias}{1\,ano} \approx 4 \times 10^6 \; \frac{Ciclos}{ano}$$

10^8 ciclos $\longrightarrow$ $\approx$ 25 anos

Wave Loads

Wave Loads

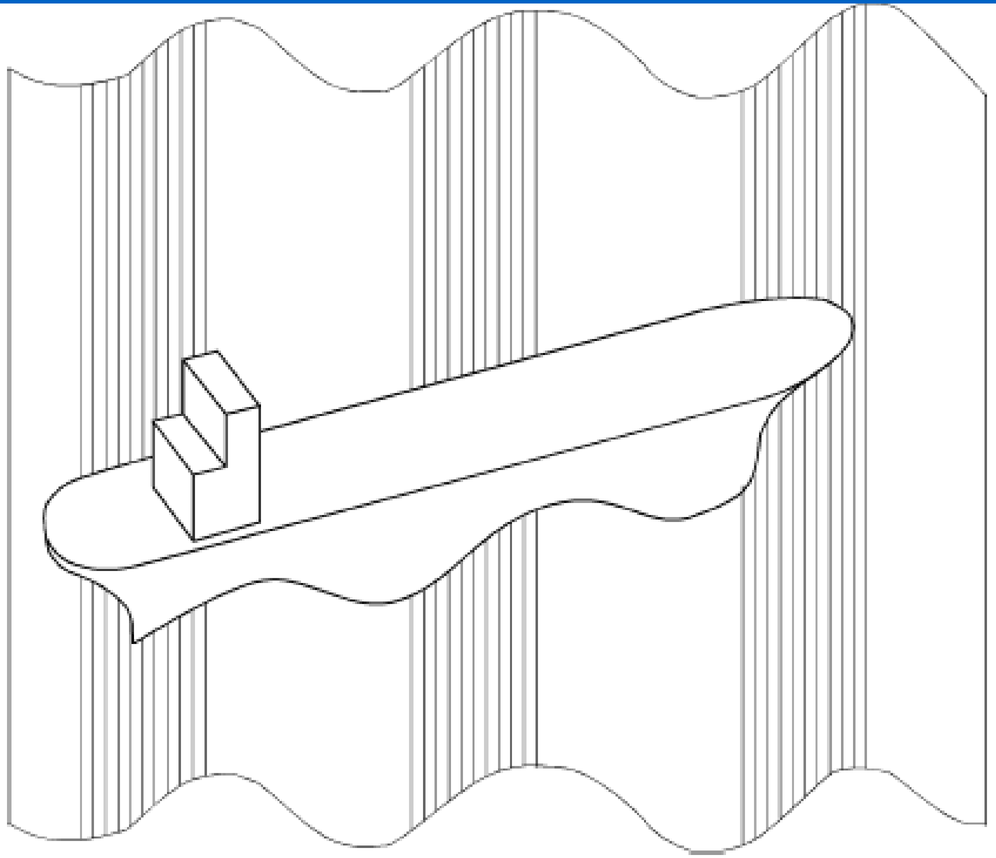
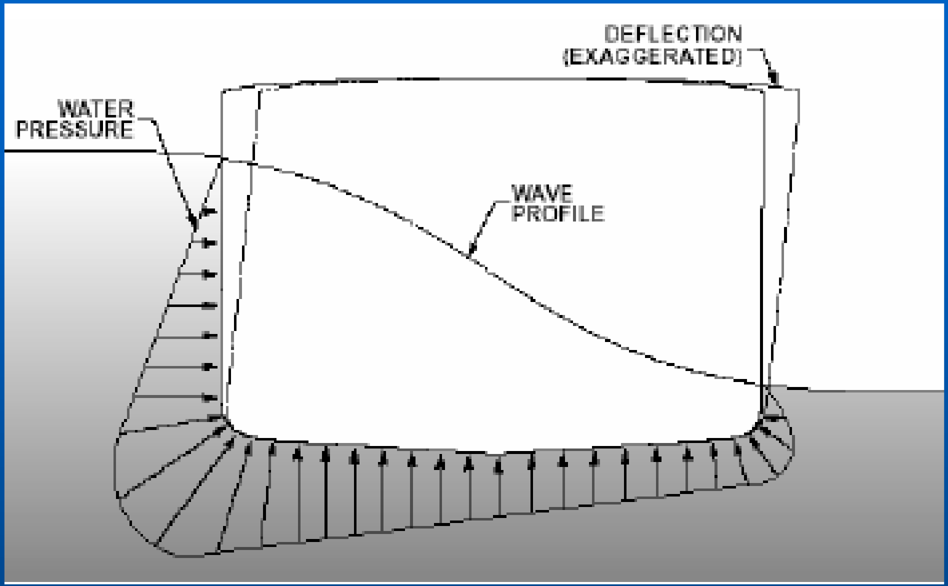
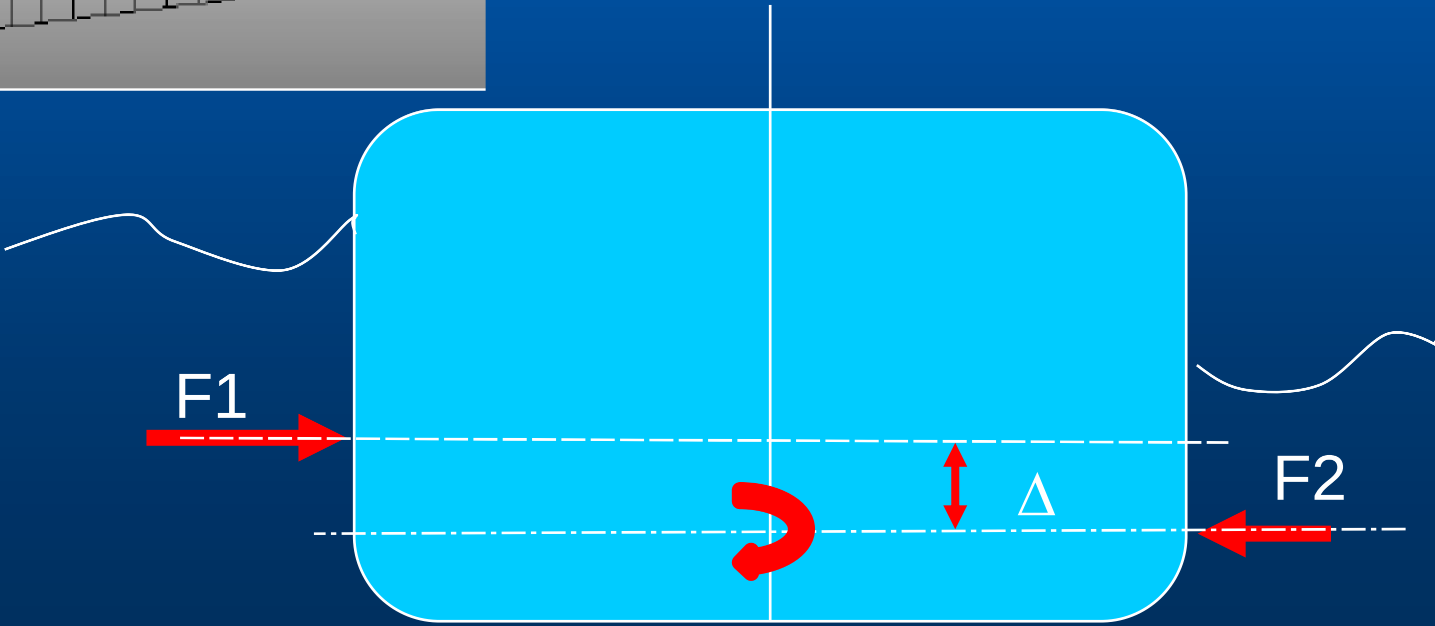


Fig. 2.1.1 Ship in oblique waves

- **Momento Fletor Vertical**
  - Alquebramento
  - Tosamento (Sagging)
- **Momento Fletor Horizontal**
  - Forças horizontais agindo no costado do navio.
- **Momento Torção**
  - Variação das superfície da onda em diferentes seções do navio

Wave Loads

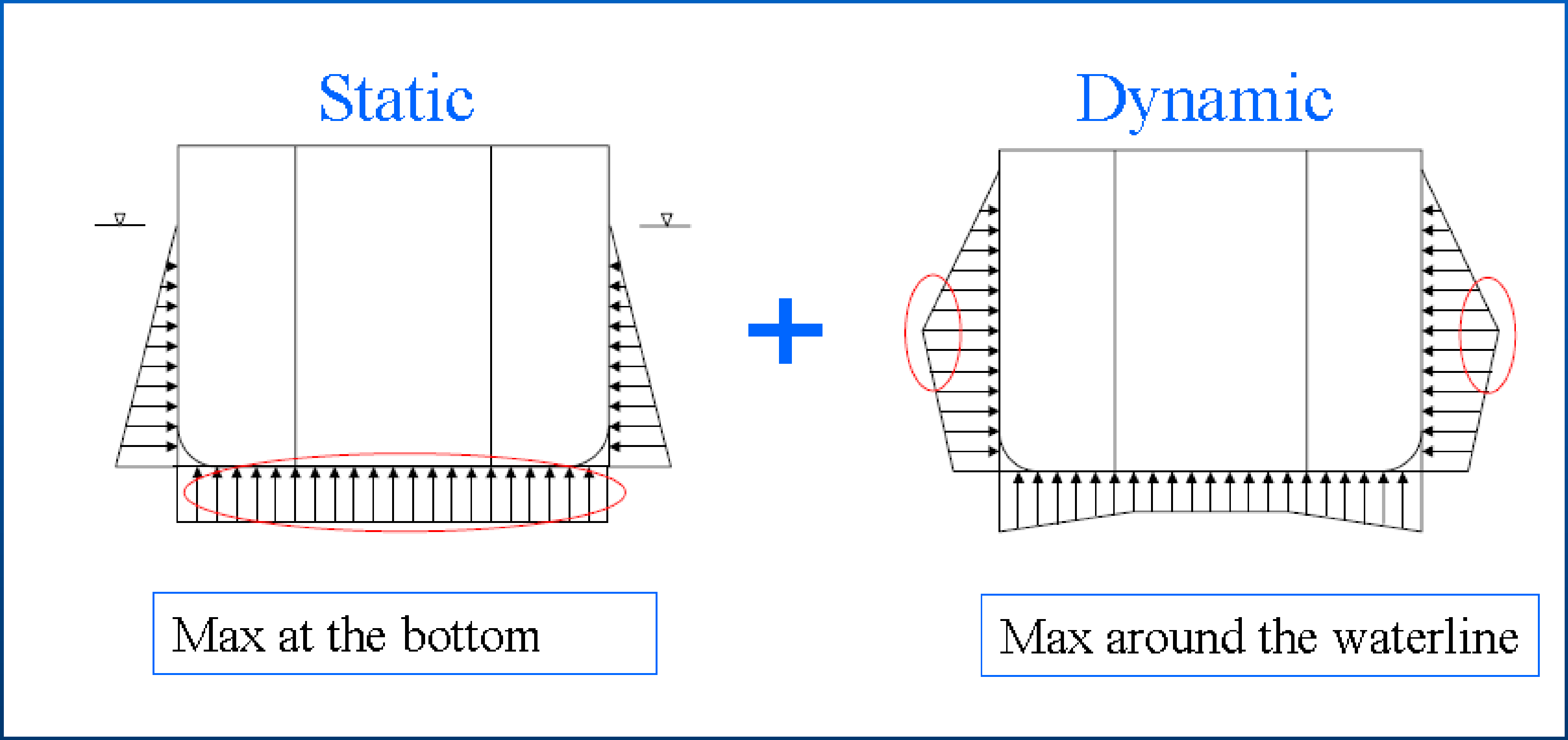




$T = F \times \Delta$

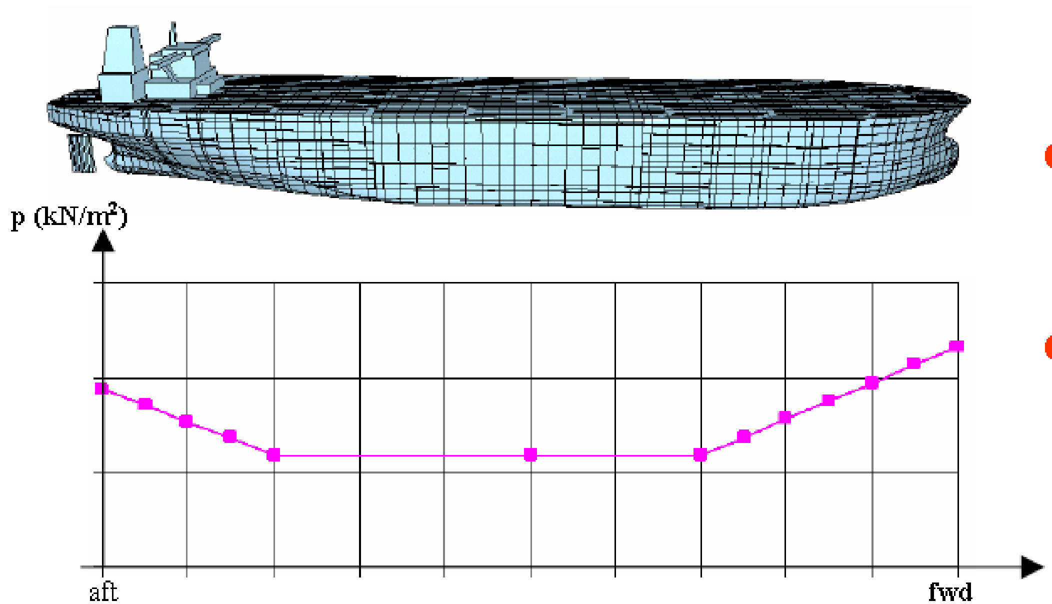
Wave Loads

TOTAL



Wave Loads

- **Estática+Dinâmica**

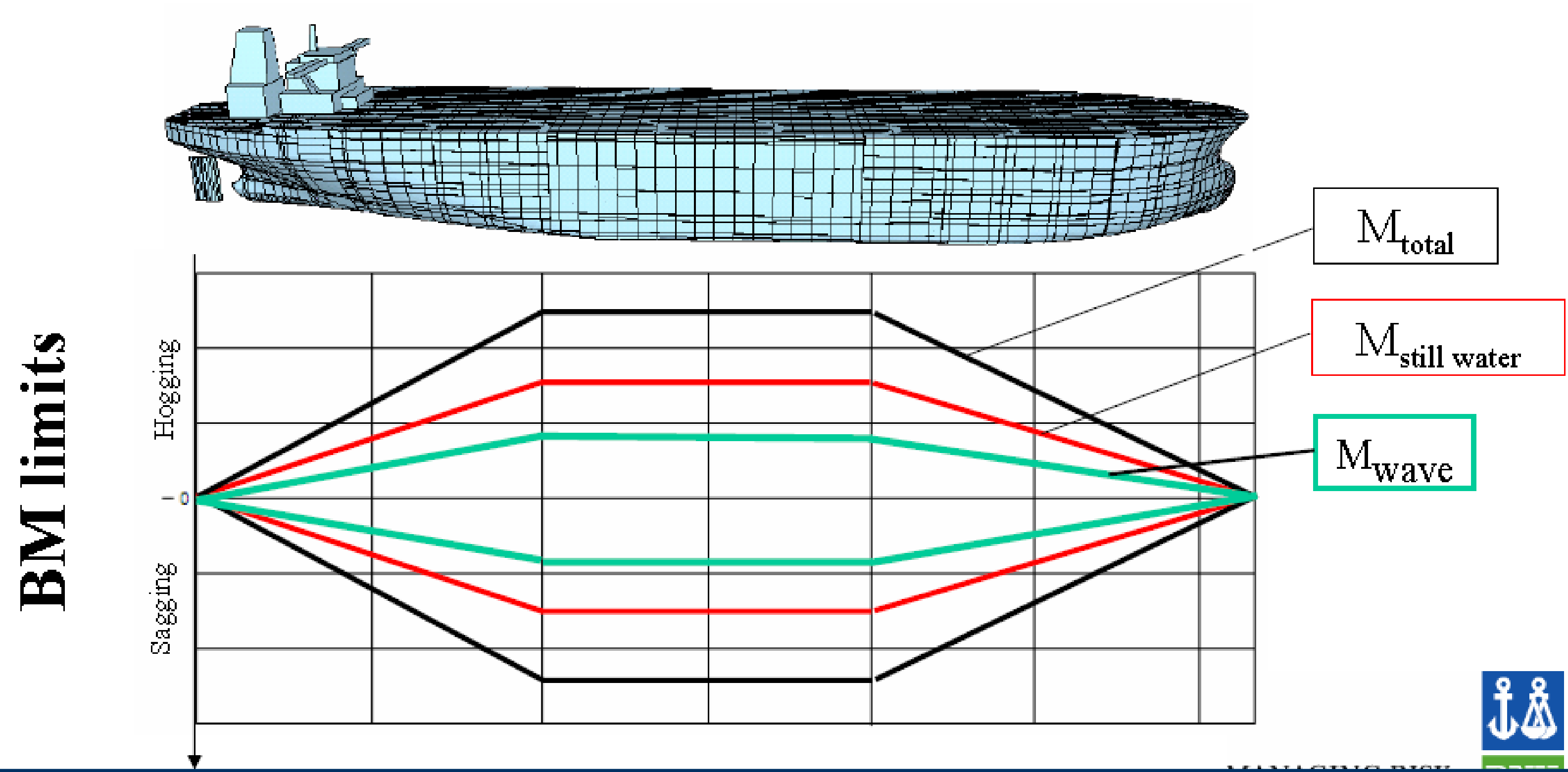


Local sea pressure
(example for a bottom longitudinal)

- Plotted sea pressure curve is a sum of the static and dynamic contribution
- Constant in the midship area, increasing towards ends

Momento Fletor

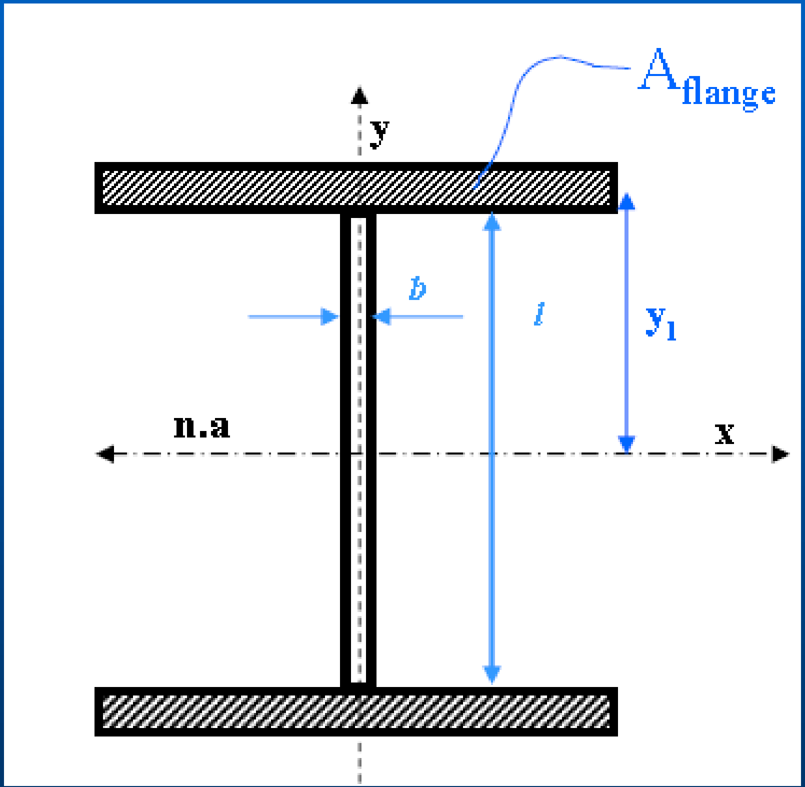
Total hull girder bending moment $M_{Total} = M_{still\ water} + M_{wave}$

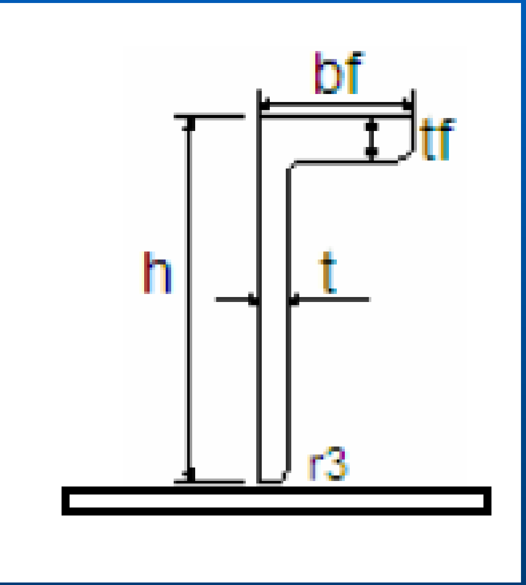


Geometria

- Comprimento
- Dimensões da seção transversal
  - Área
  - Momento de Inércia
  - Momento polar
- Apoio

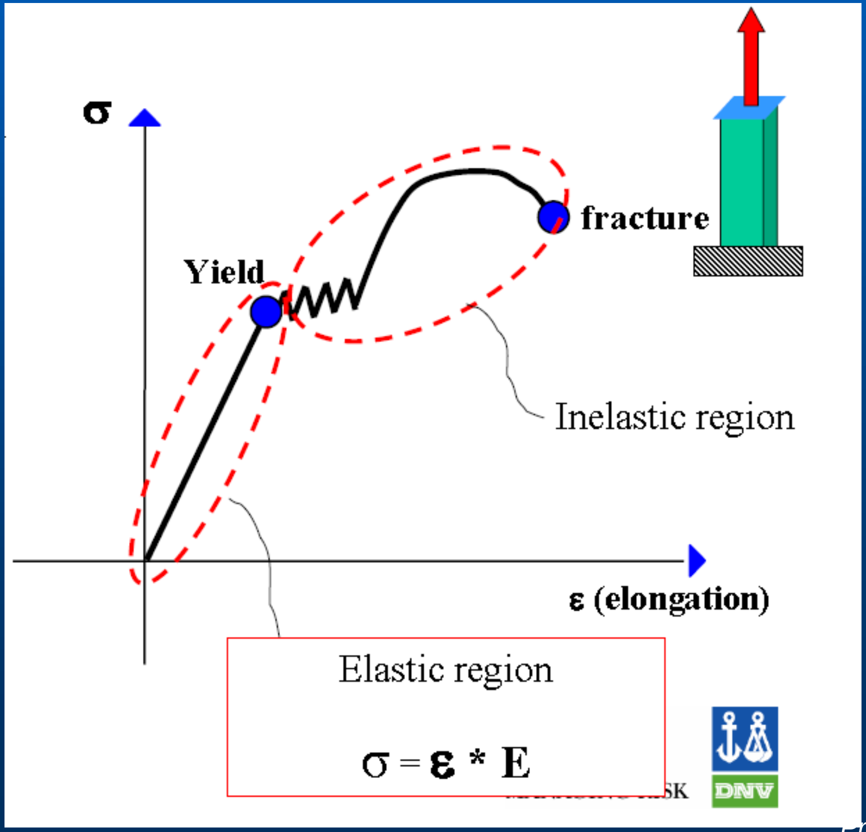
Geometria





Tensões admissíveis

- Tensão de Escoamento
- Tensão Última

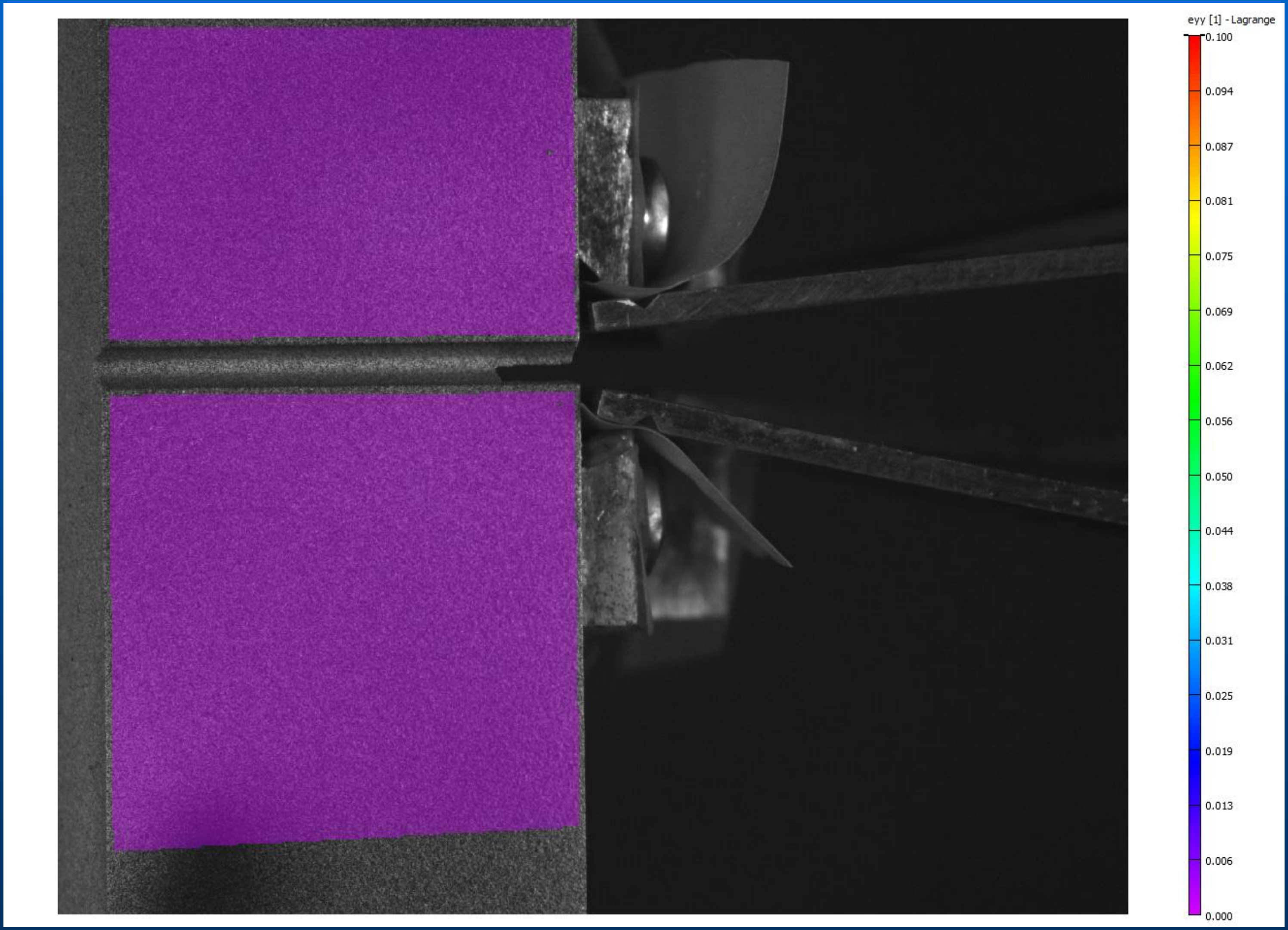


Tensões admissíveis

- Impacto
- Fadiga
- Colapso

Tensões admissíveis

Tensões admissíveis



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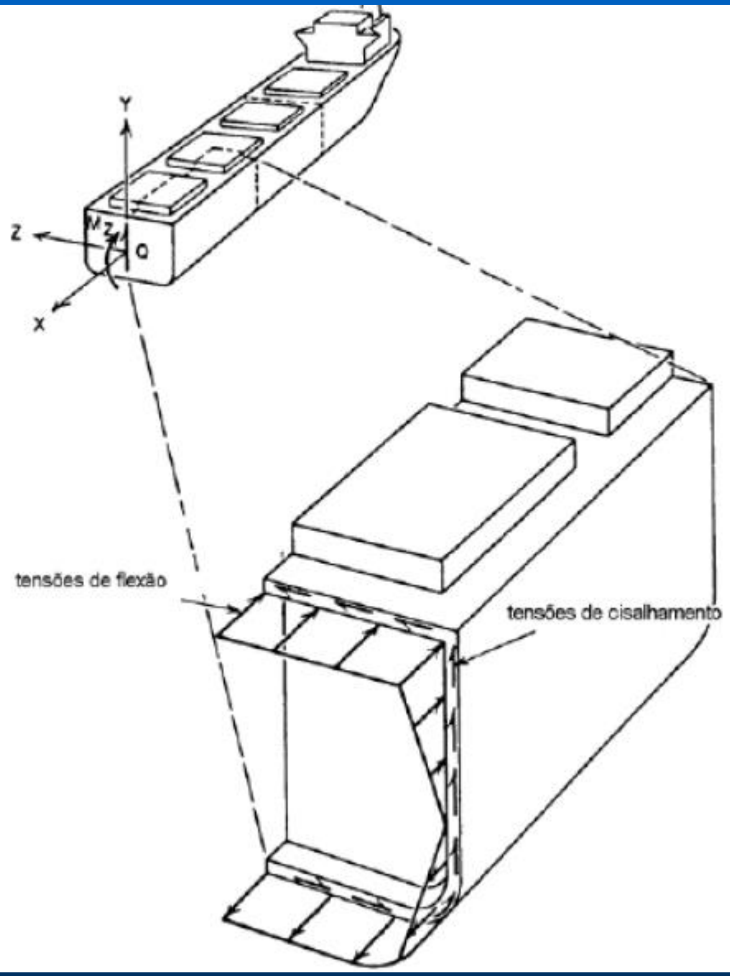
Projeto Racional

- Resistência Longitudinal
  - – Estrutura Primária (Viga-Navio)
  - – Estrutura Secundária
    - Leves
    - Pesados
  - – Estrutura Terciária
- Resistência Transversal

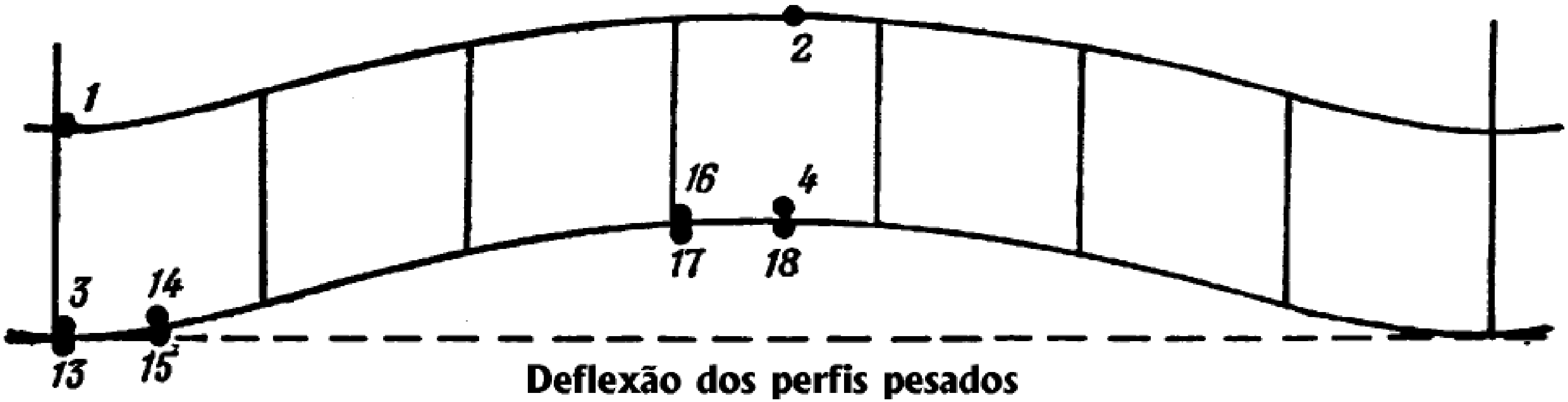
Tensões Primárias



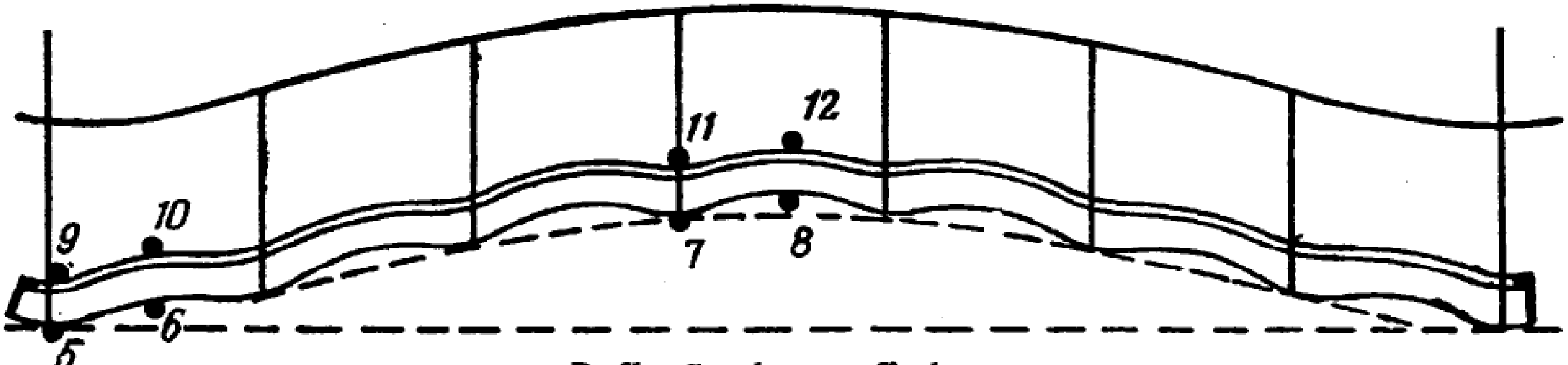
$$\tau_{xy}^{A} = \frac{Q_{\text{secção}}}{I_{\text{secção}}^{LN}} * \frac{Ms^{A}}{t^{A}}$$

$$\sigma_{xx}^{A} = \frac{M_{\text{secção}} * y^{A}}{I_{\text{secção}}^{LN}}$$

Tensões Secundárias

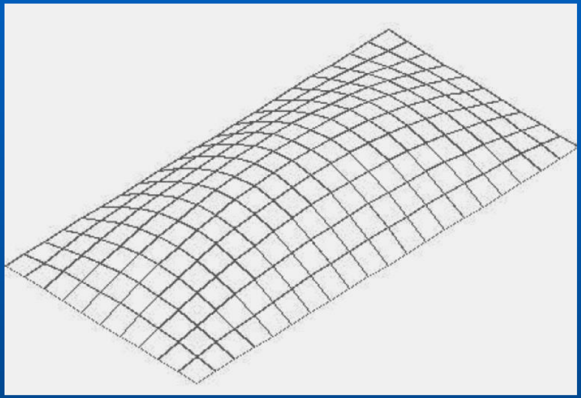


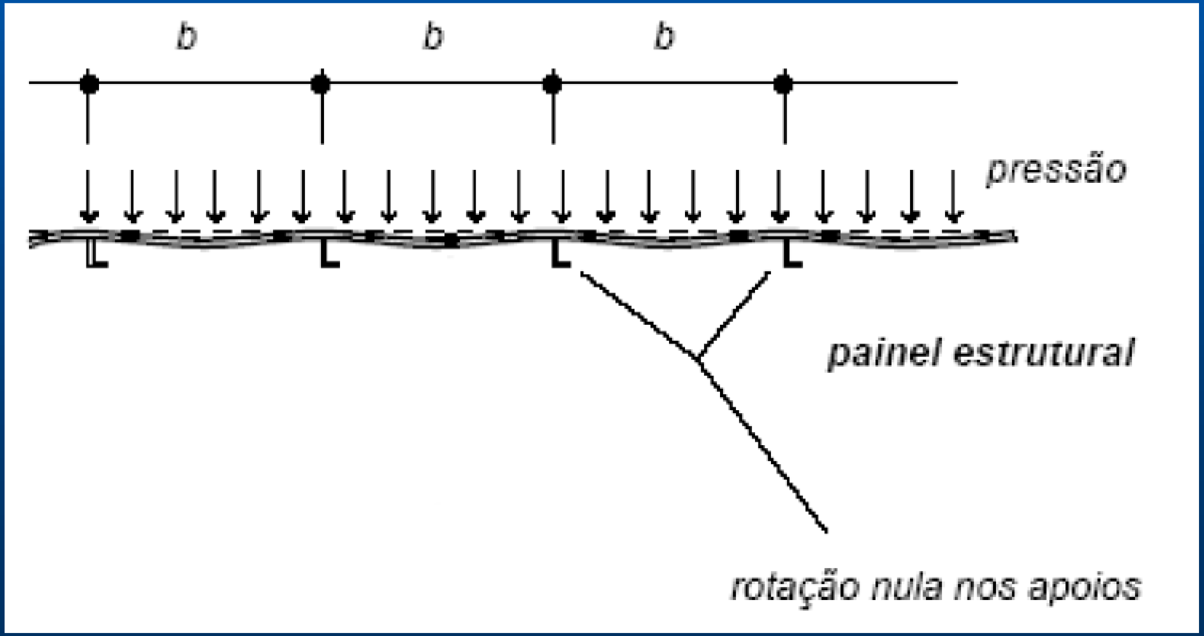
Deflexão dos perfis pesados



Deflexão dos perfis leves

Tensões Terciárias





Hierarquia dos Componentes Estruturais do Navio

- Cargas em cada estrutura (componente) podem ser tratadas como independentes.
- Transferência das cargas nos suportes entre componentes locais para estruturas maiores.

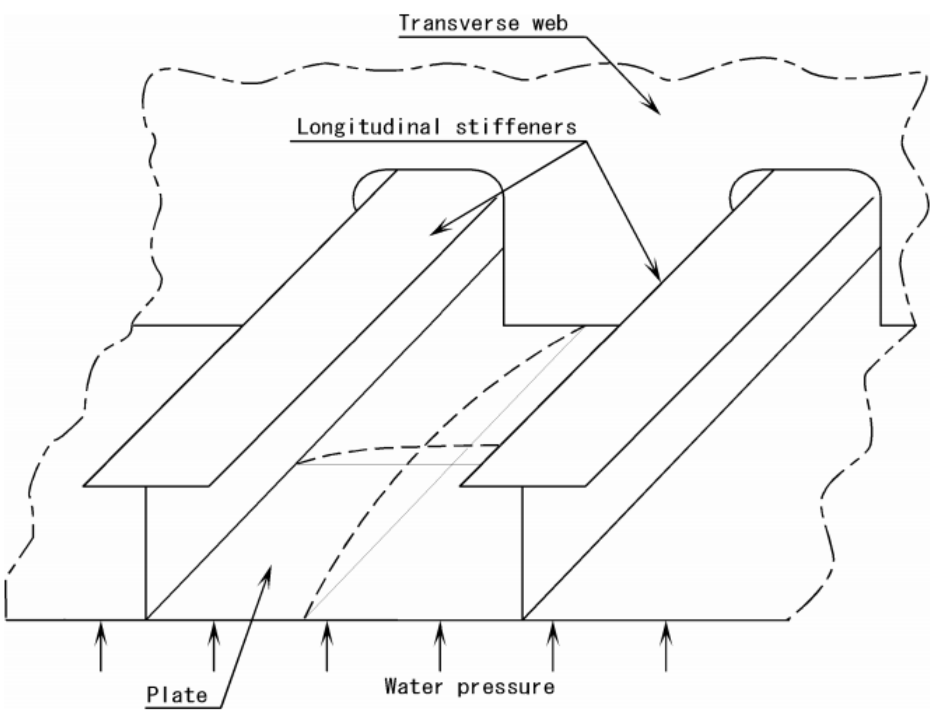


Fig. 2.1.3 Bottom structure under water pressure

Unidade de chapeamento

Hierarquia dos Componentes Estruturais do Navio

- **Cargas em cada estrutura (componente) podem ser tratadas como independentes.**
- **Transferência das cargas nos suportes entre componentes locais para estruturas maiores.**

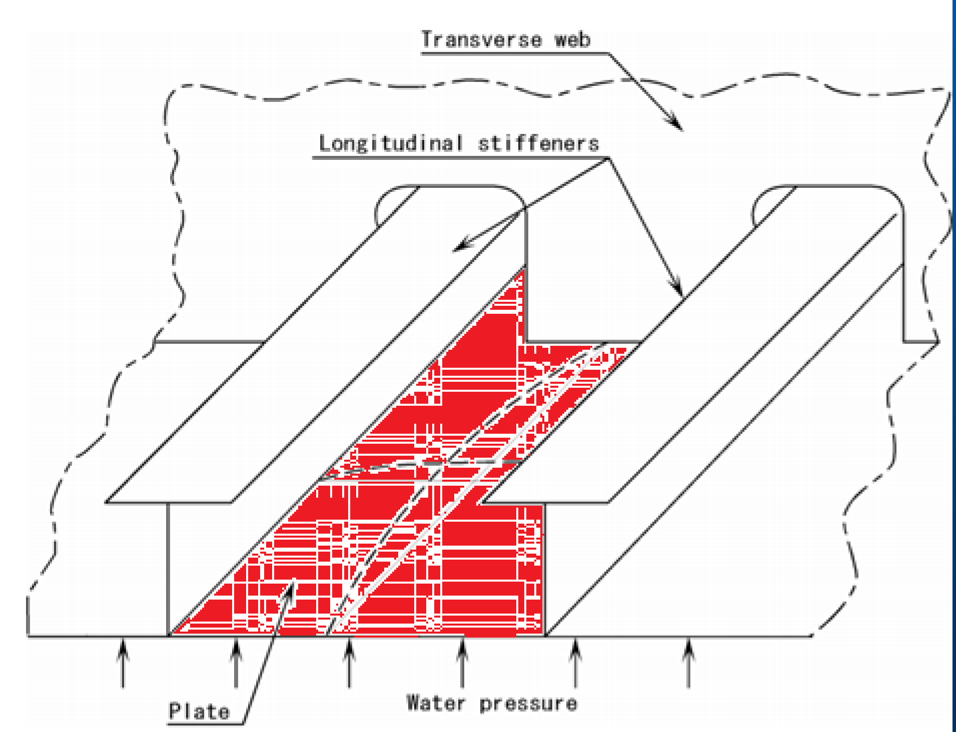


Fig. 2.1.3 Bottom structure under water pressure

Unidade de chapeamento

↓

Ref. Longitudinal (suporte da chapa)

↓

Ref. Transversal (suporte do longitudinal)

↓

Resistência Global do Panel

Hierarquia dos Componentes Estruturais do Navio

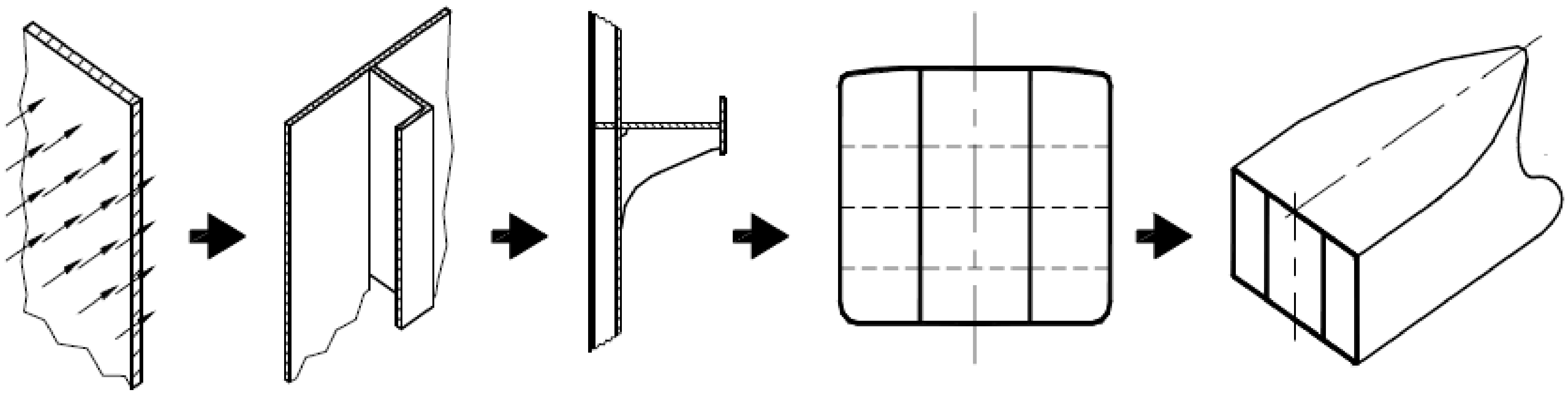
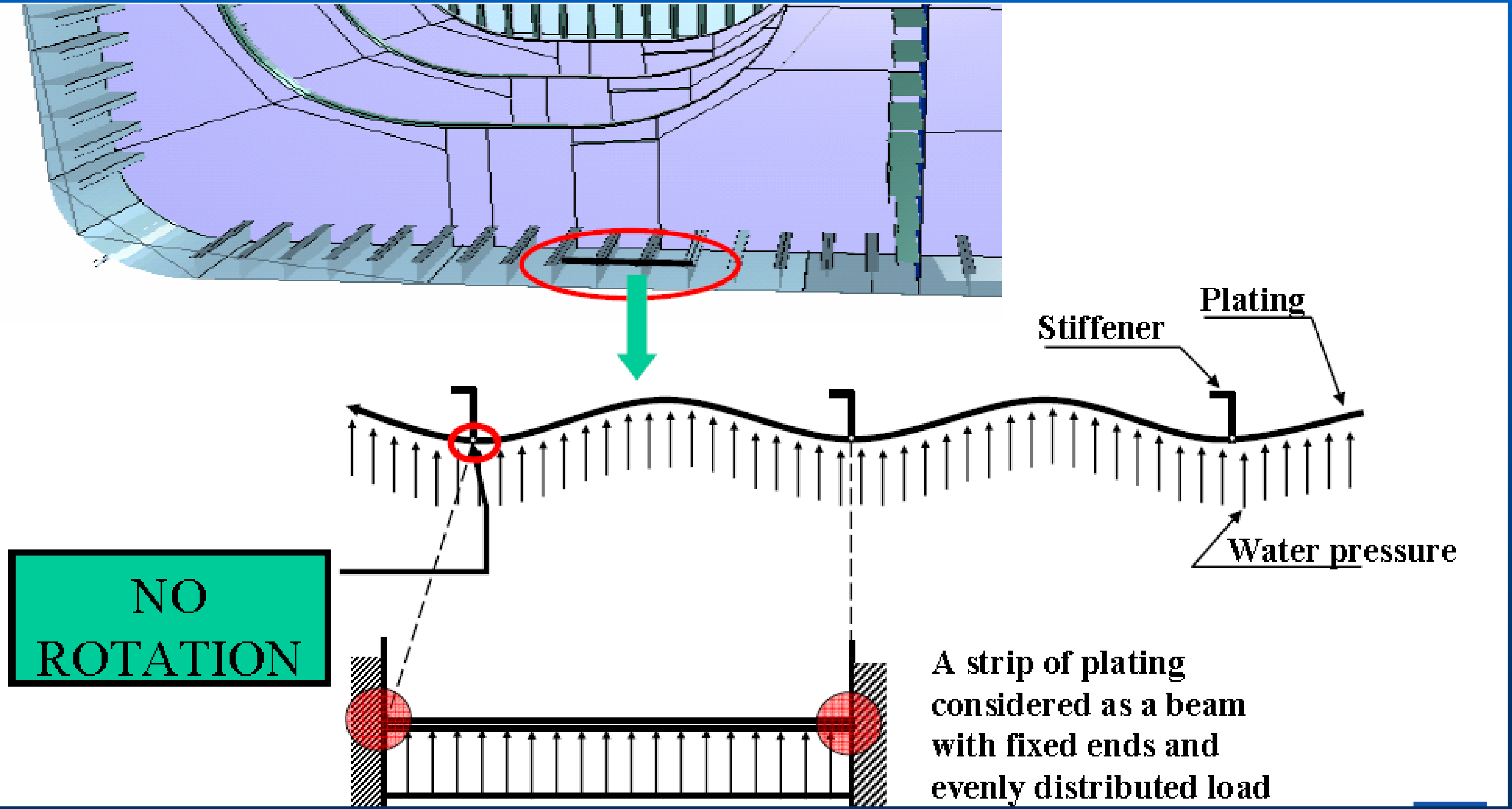


Plate – Stiffener – Stringer / girder – Panel – Hull

Stresses in a hull plate due to external sea pressure, are transferred further into the hull structure through the hierarchy of structures.

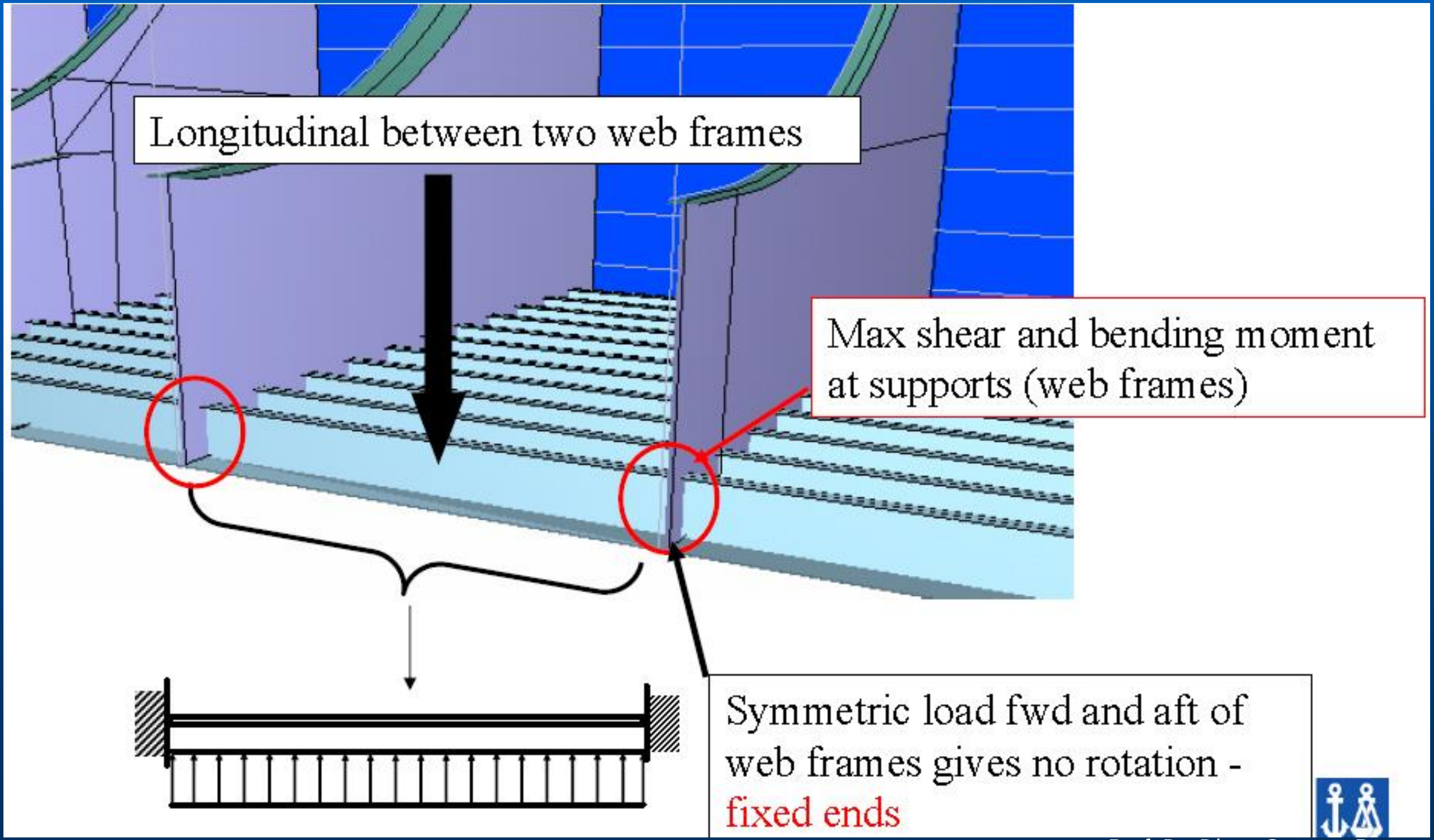
Hierarquia dos Componentes Estruturais do Navio

- Chapa



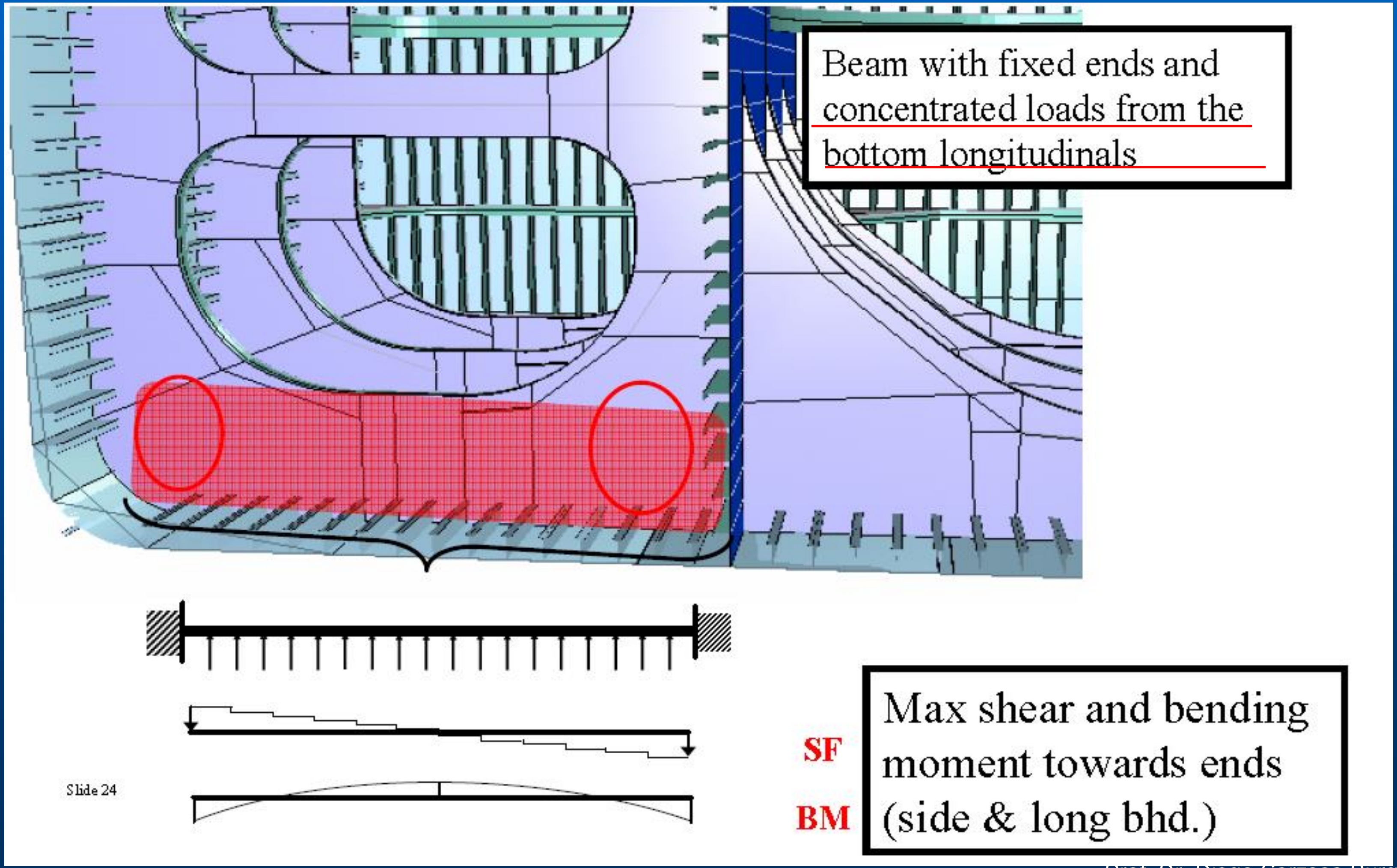
Hierarquia dos Componentes Estruturais do Navio

- **Longitudinal Leve**



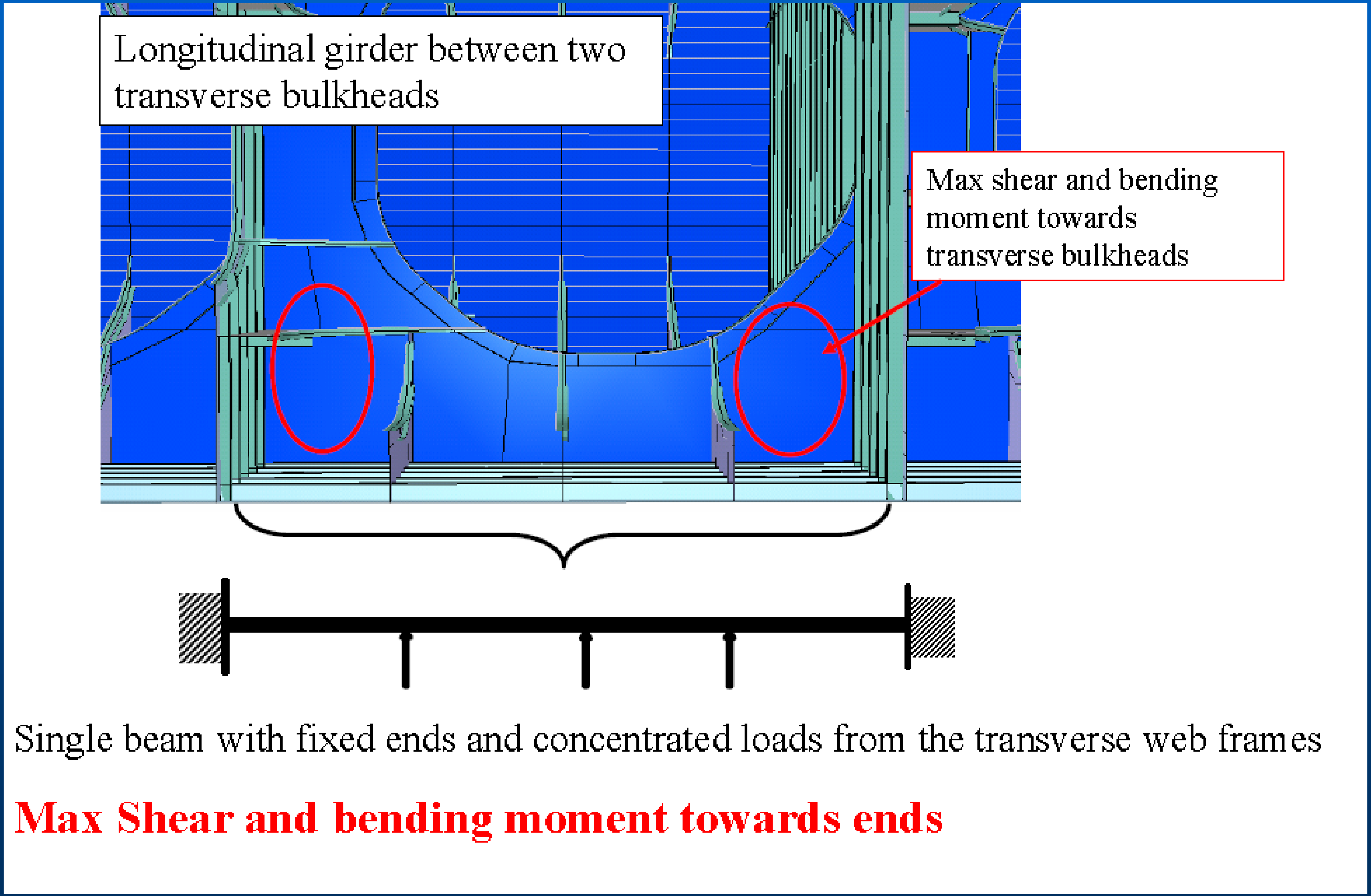
Hierarquia dos Componentes Estruturais do Navio

- Transversal Pesado

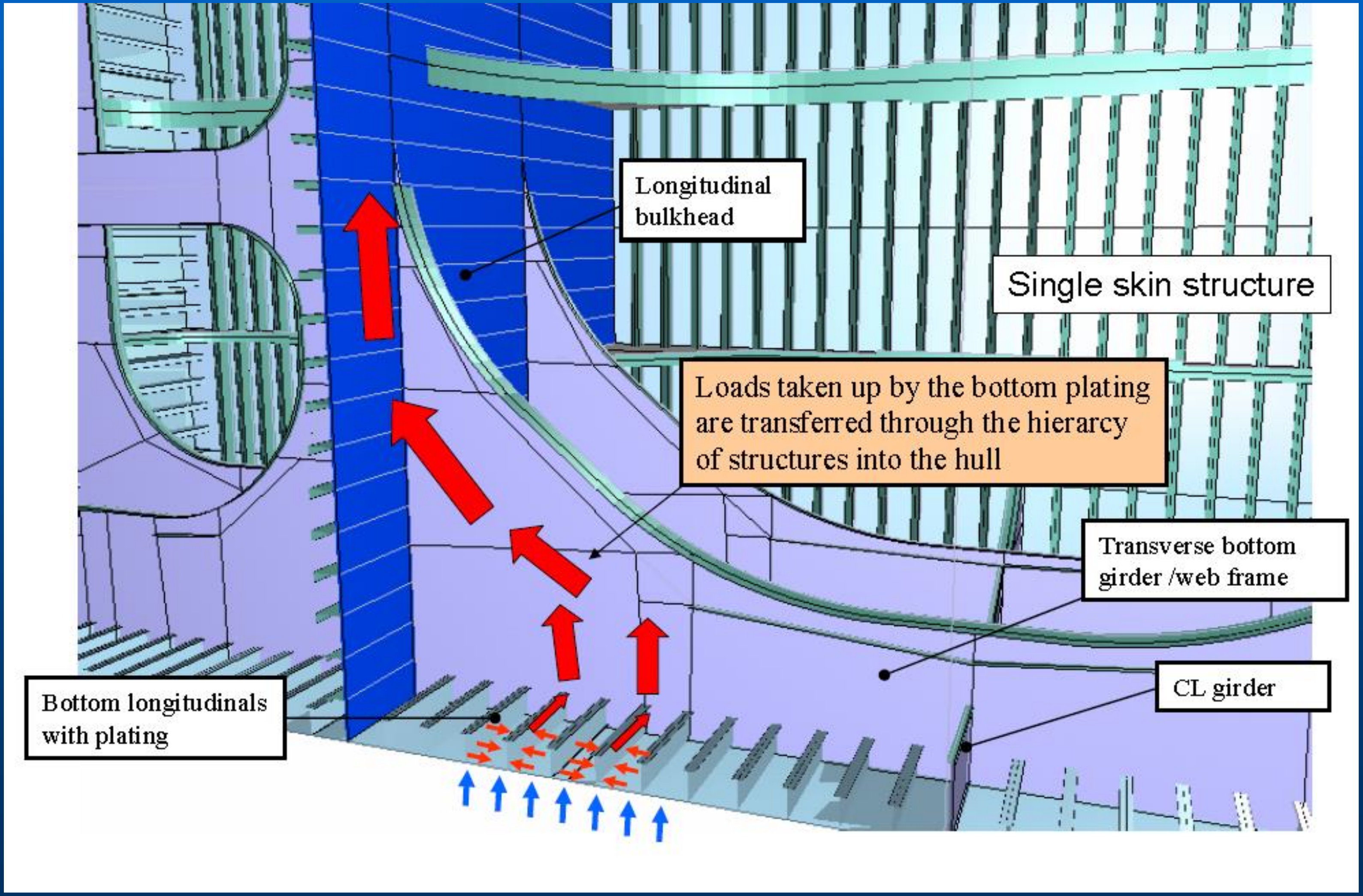


Hierarquia dos Componentes Estruturais do Navio

- **Longitudinal Pesado**

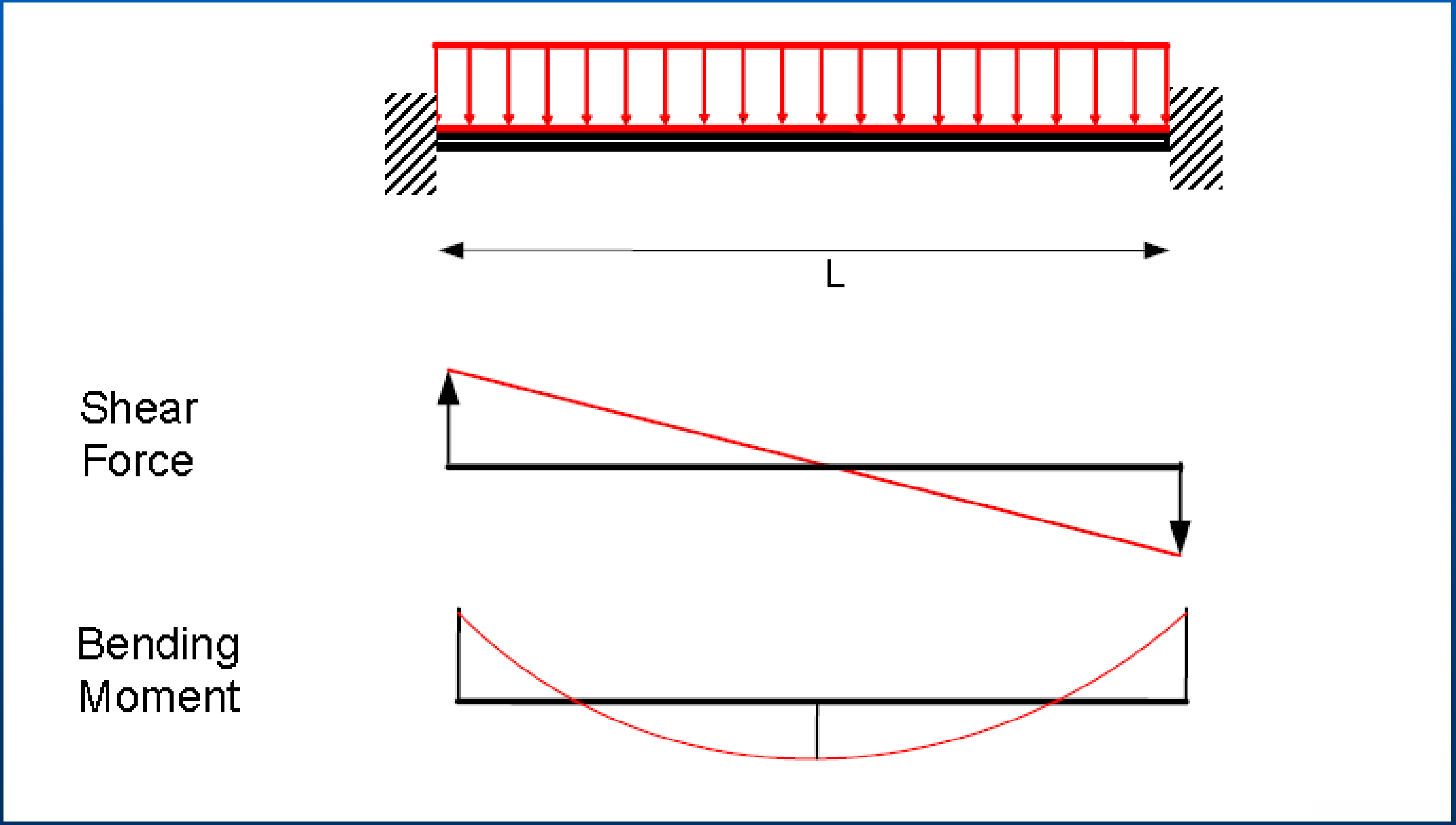


Hierarquia dos Componentes Estruturais do Navio

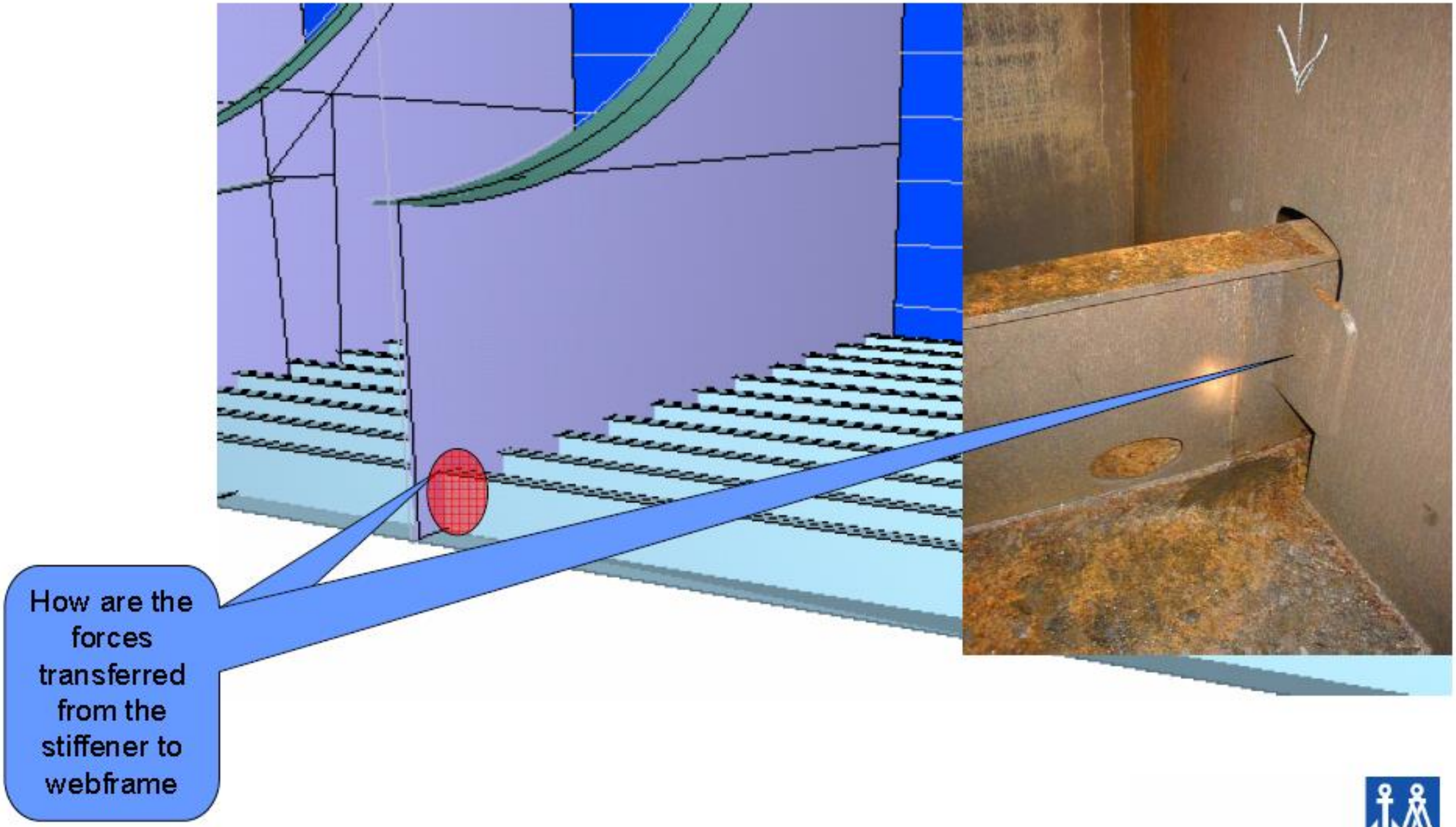


Conexões

- **Quais forças devem ser transmitidas?**



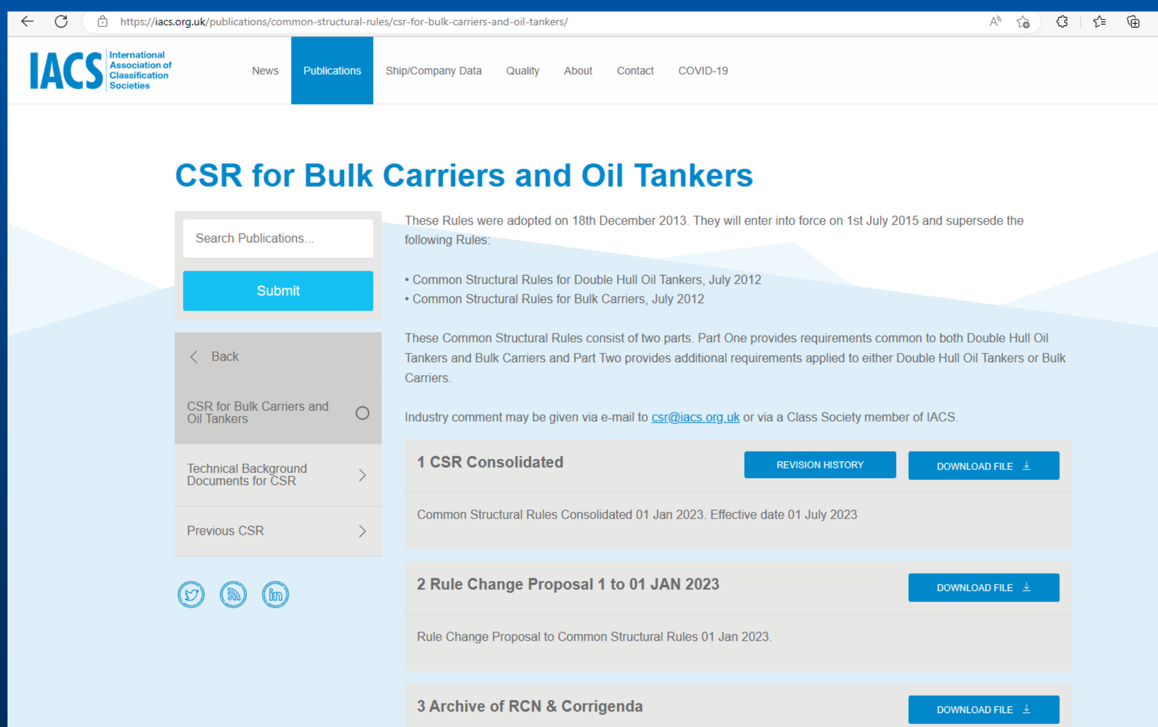
Conexões dos Reforços



Rule-based Design

- ABS (USA)
- DNV (Noruega)
- RINA (Itália)
- GL (Alemanha)
- BV (França)
- NKK (Japão)
- Bureau Colombo – RBNA (Brasil)

- [Safer and Cleaner Shipping - IACS]
- [China Classification Society (ccs.org.cn)]



- **RBNA**

  PBNA

International Association of Classification Societies

Rule-based

RULES FOR
CLASSIFICATION OF

SHIPS

DNV

IACS COMMON STRUCTURAL RULES

PART 8 CHAPTER 1

COMMON STRUCTURAL RULES FOR DOUBLE HULL OIL TANKERS WITH LENGTH 150 METRES AND ABOVE

JANUARY 2007

CONTENTS

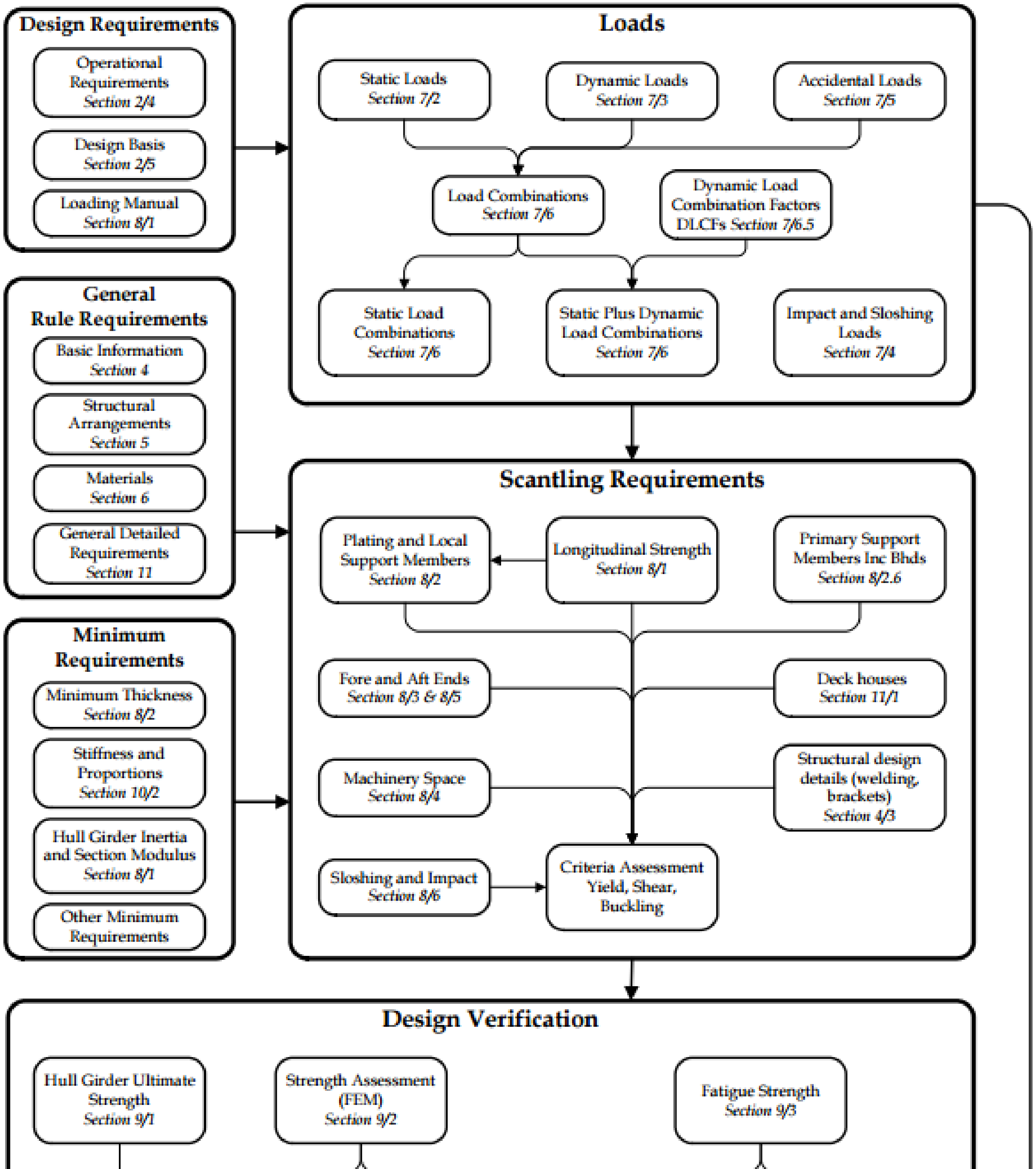
- Tratamento “simplificado”
- Extenso conhecimento adquirido experiência com embarcações em serviço.
- Fornecem tabelas e formulas “simples”
- 714 pages

Projeto segundo Norma

- Hull Structure Arrangement
- Longitudinal Strength of Hull Girder
- Transverse Strength of Ship
- Torsional Strength
- Shell Structure
- Bulkheads
- Deck Structure
- Double Hull Structure
- Fore Construction
- Engine Room
- Stern Construction
- Superstructure

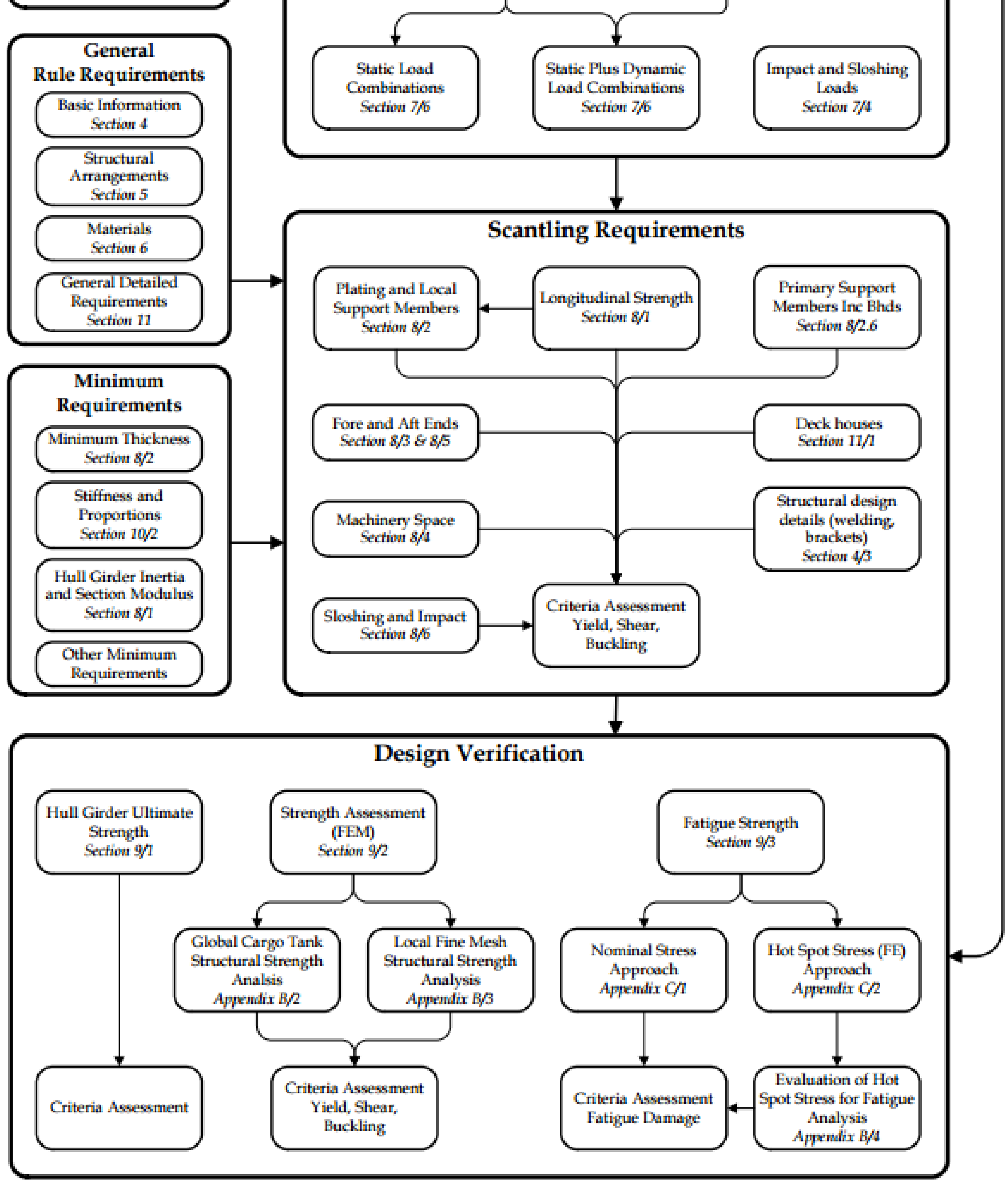
Rule-based

Rule Layout



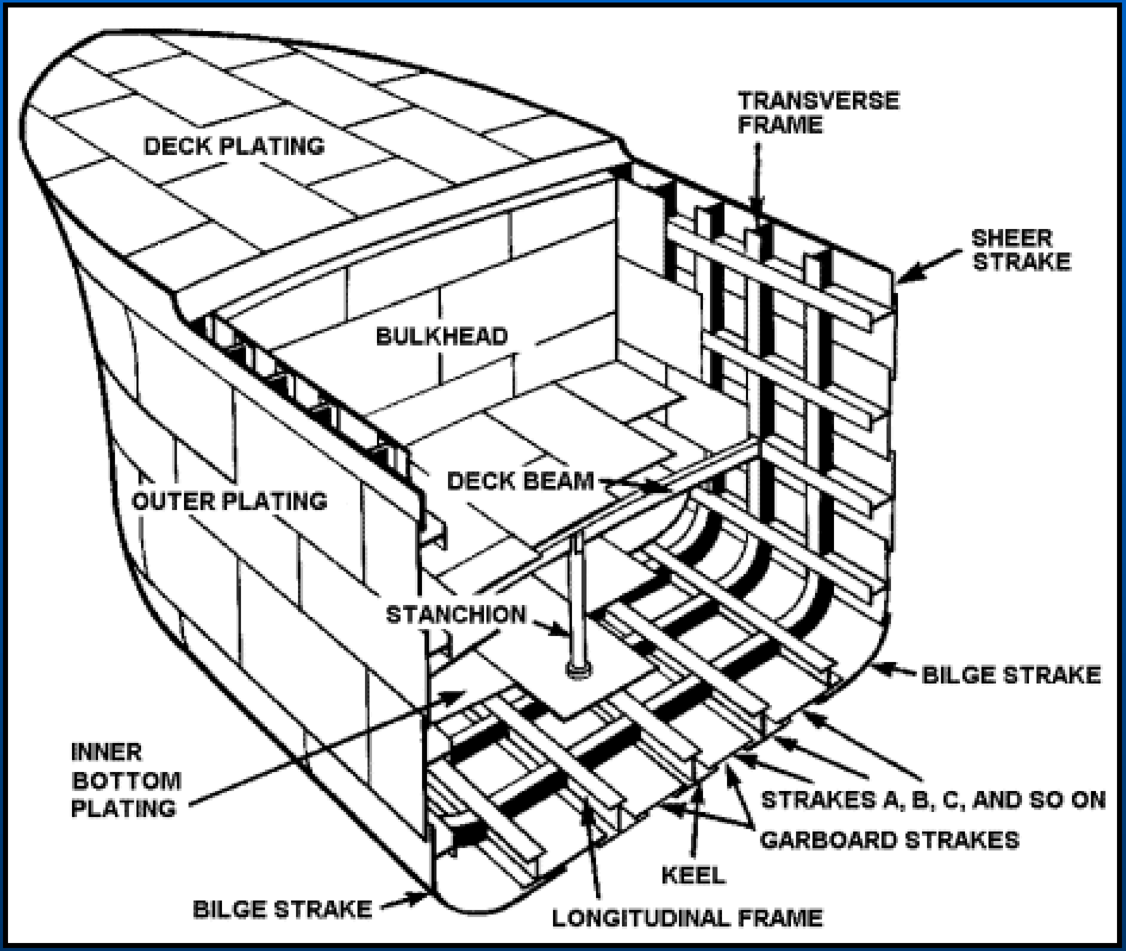
CONTENTS

Rule-based

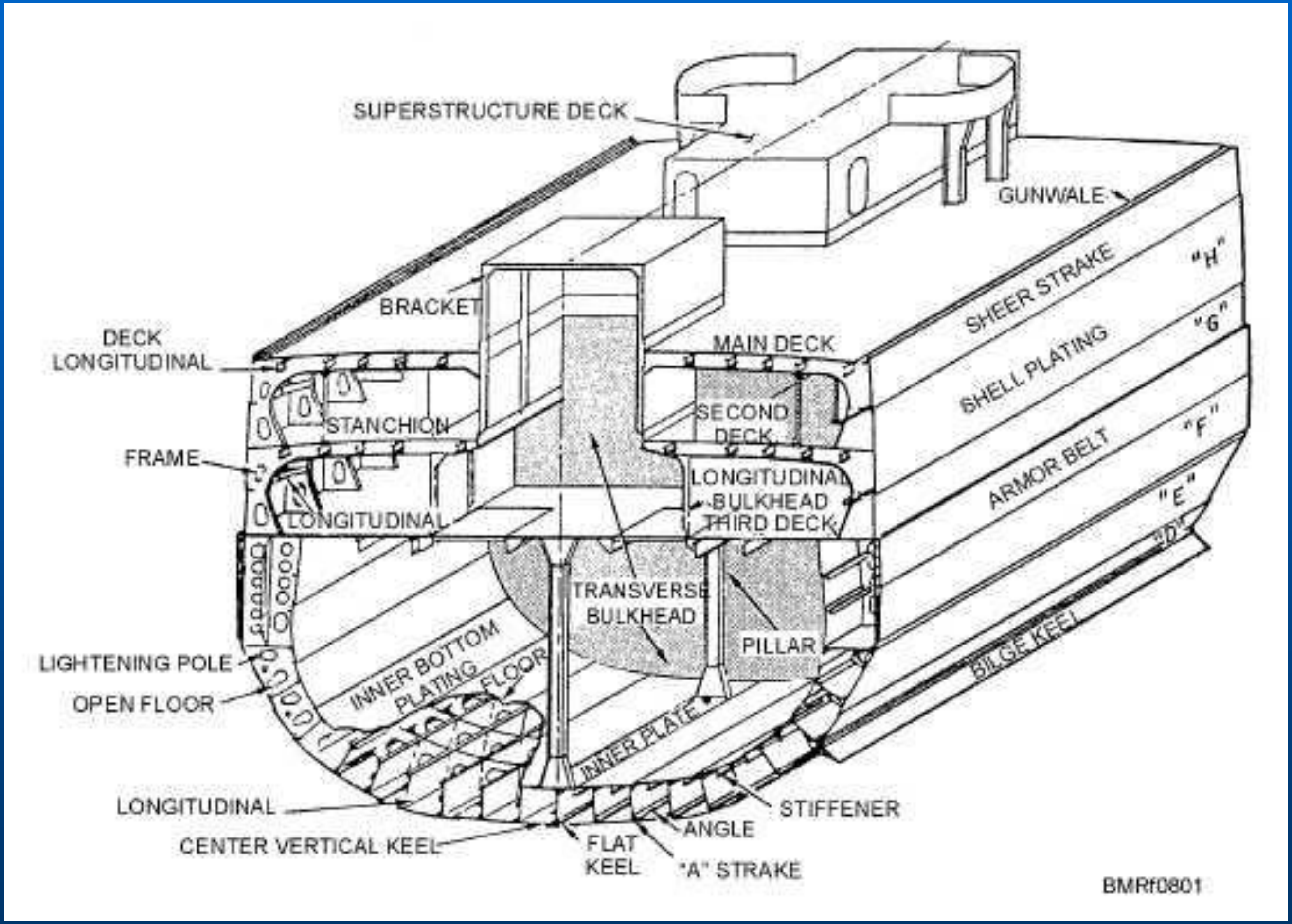


CONTENTS

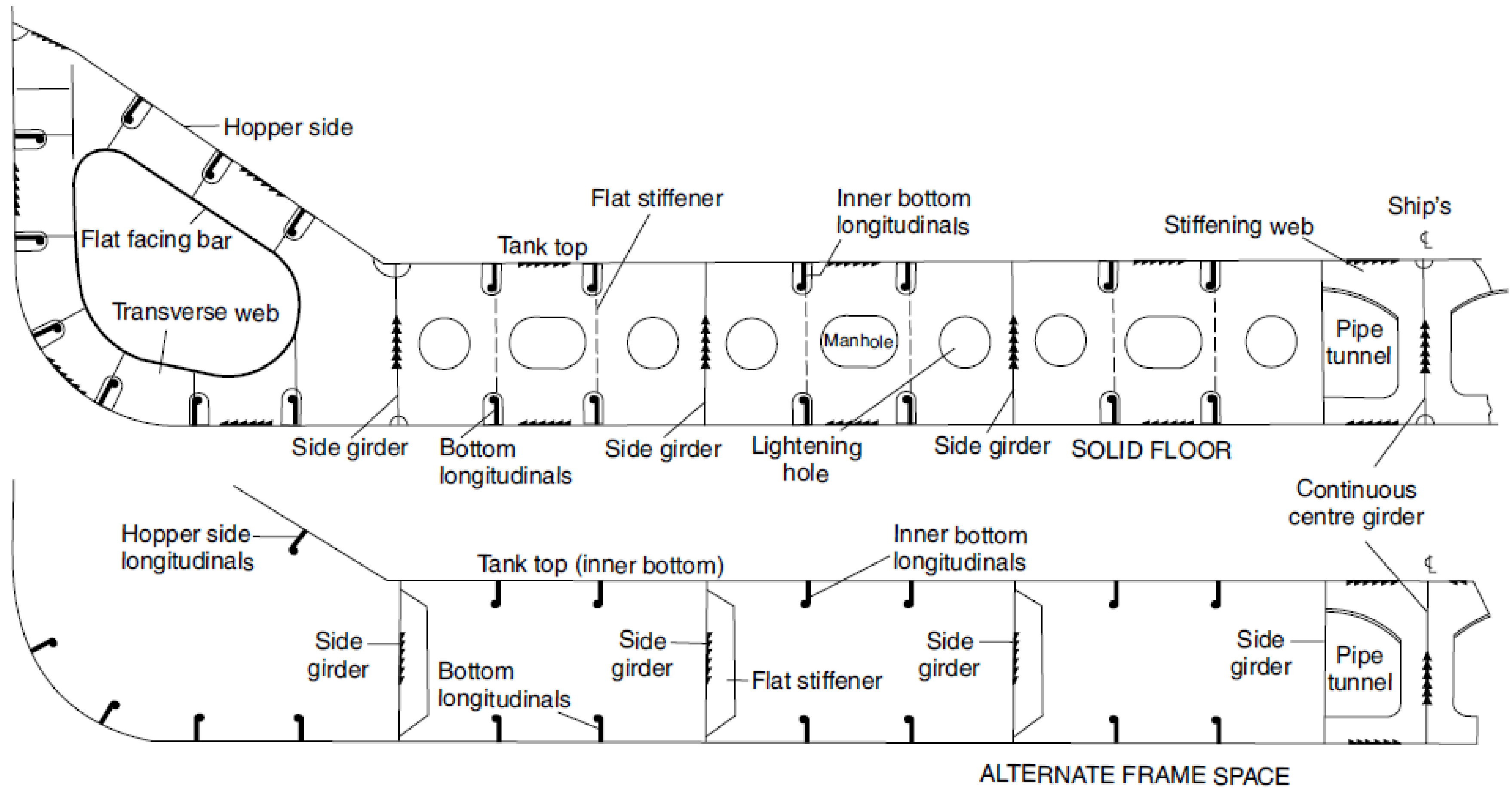
Nomenclatura Estrutural



Nomenclatura Estrutural



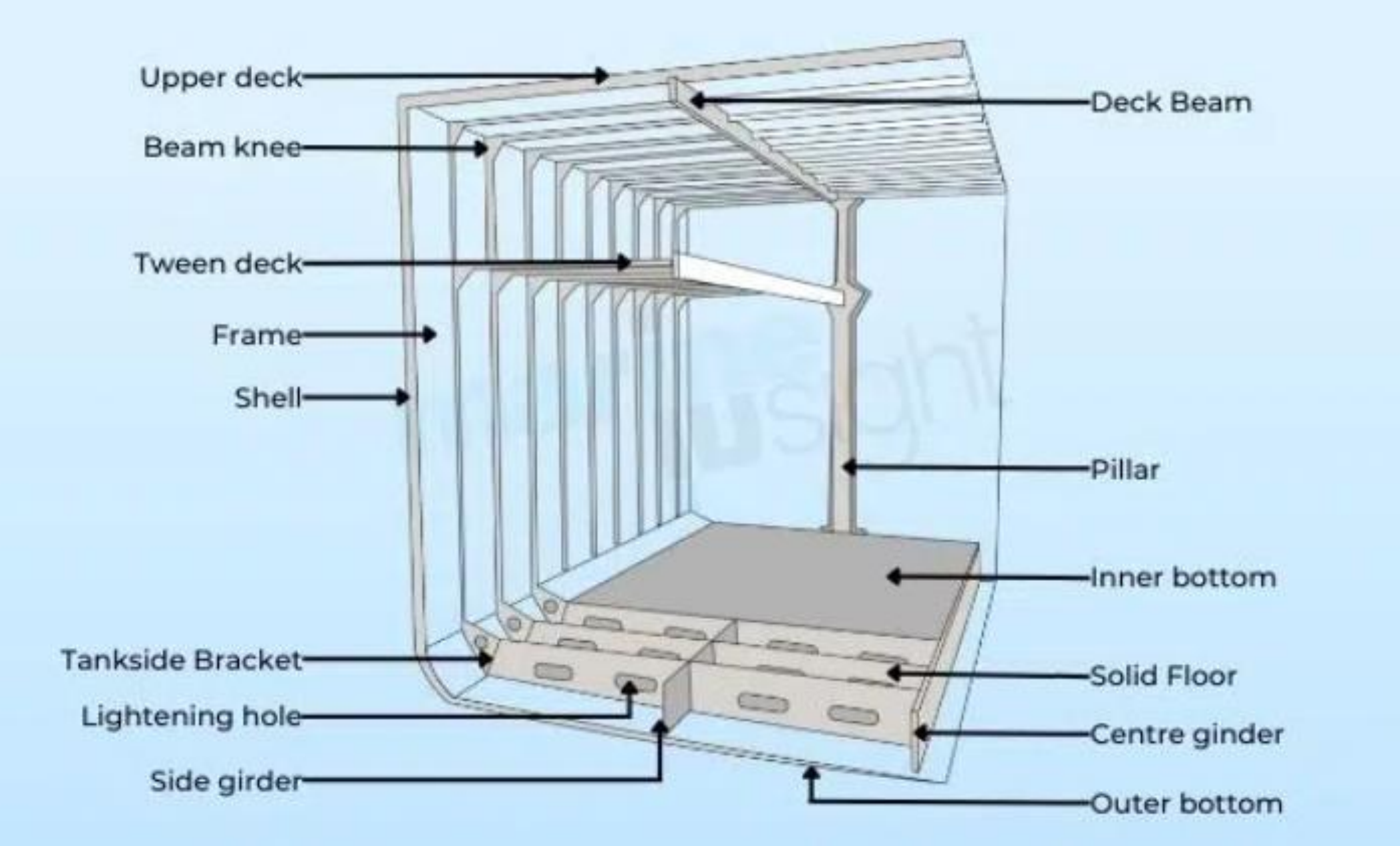
Nomenclatura Estrutural



Nomenclatura Estrutural

Floors can be of three types: Solid Floors, Plate Floors and Bracket Floors.

Solid floor requirements of water tightness or oil tightness like in tanks.



Nomenclatura Estrutural

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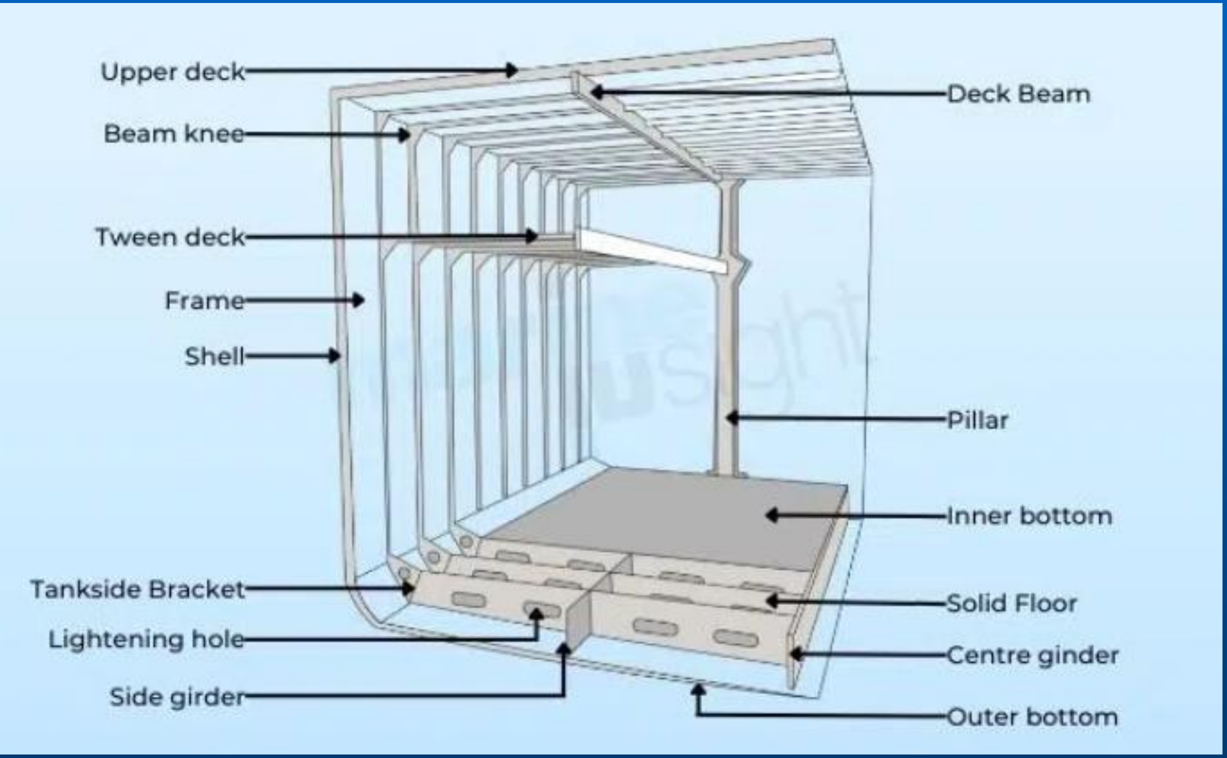
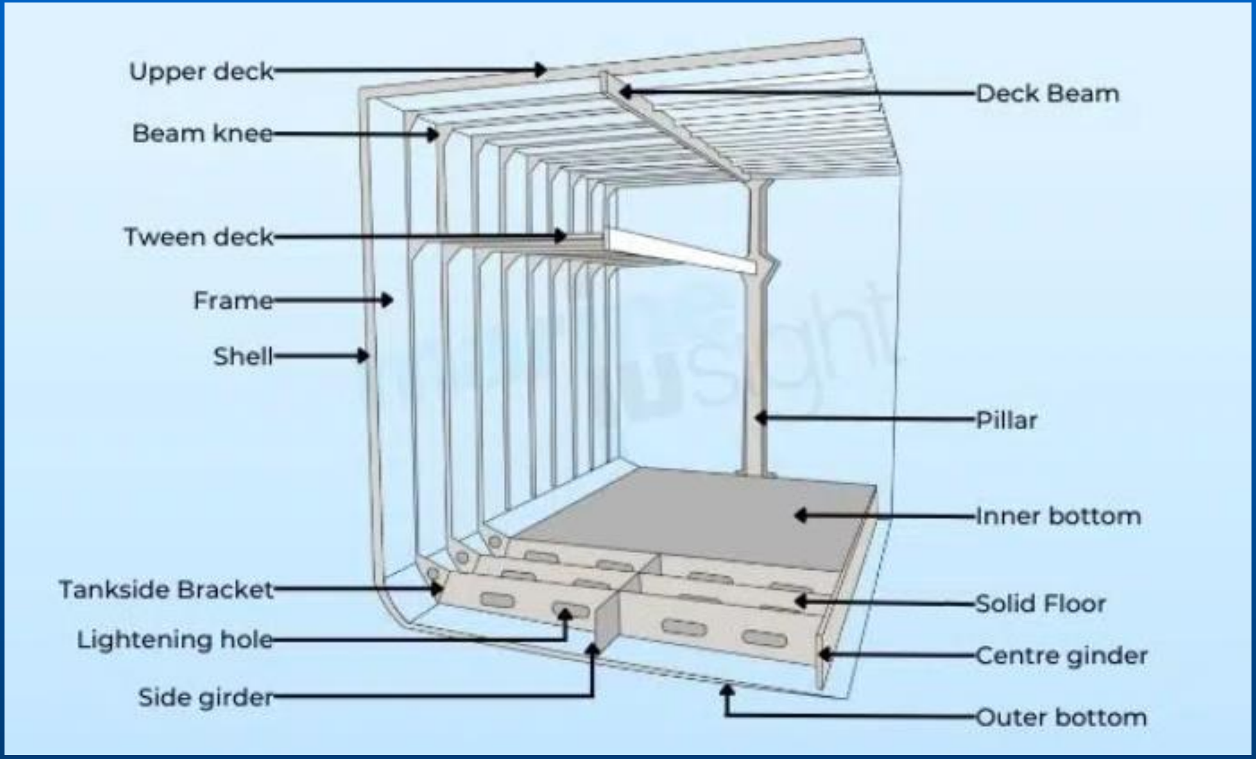


Plate floors have openings mainly used to reduce unnecessary weight and free passage of fluids like fuel, lubes, or water as required. Bracket floors have large openings and are primarily constructed of brackets fitted at ends. They are used in areas where there is a lesser requirement of strength.

So, floors are essentially the lower components of a frame that extend from the bilge strake to the keel on either side. Besides stiffening the bottommost or outer shell plating, they also serve as foundations for supporting the inner bottom plating (for double bottom constructions) and tank boundaries or machinery foundations.

Nomenclatura Estrutural

Floors can be of three types: Solid Floors, Plate Floors and Bracket Floors.



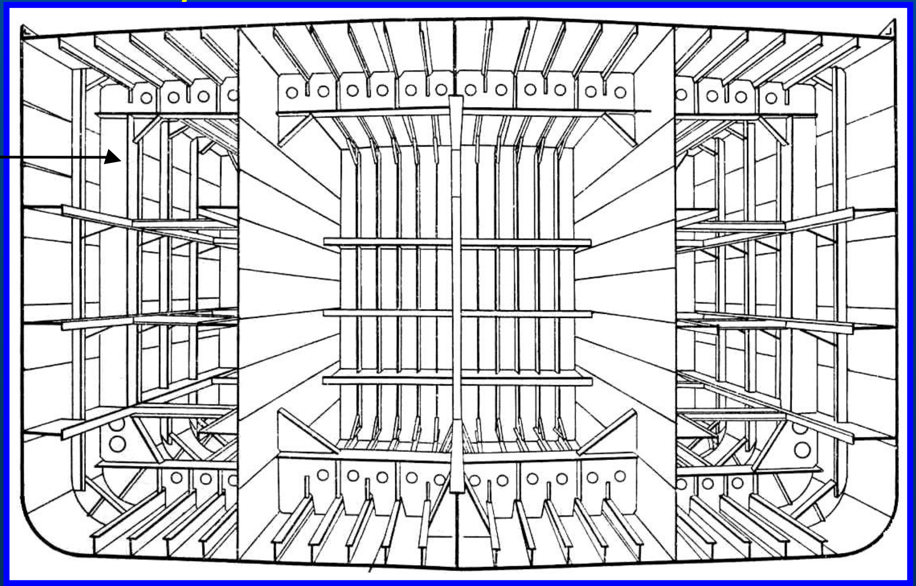
The type of floor is chosen based on the requirement and the modulus of loading in that particular region of consideration. The depth of the floor is also decided based on the strength requirements.

Nomenclatura Estrutural

Side Frames

The upper part of the frames welded to the side shell and run vertically is also known as *side frames*. For tank construction, the part of the side frame associated with the tank or hold region is also known as the holding frame, and the part of this frame above the upper tank boundary, which continues to the main deck level, is known as the tween frame.

These side frames are mainly composed of bulb plates or L-beams. The scantlings of these frames depend on the area of disposition and the estimated extent of transverse loading that may incur.

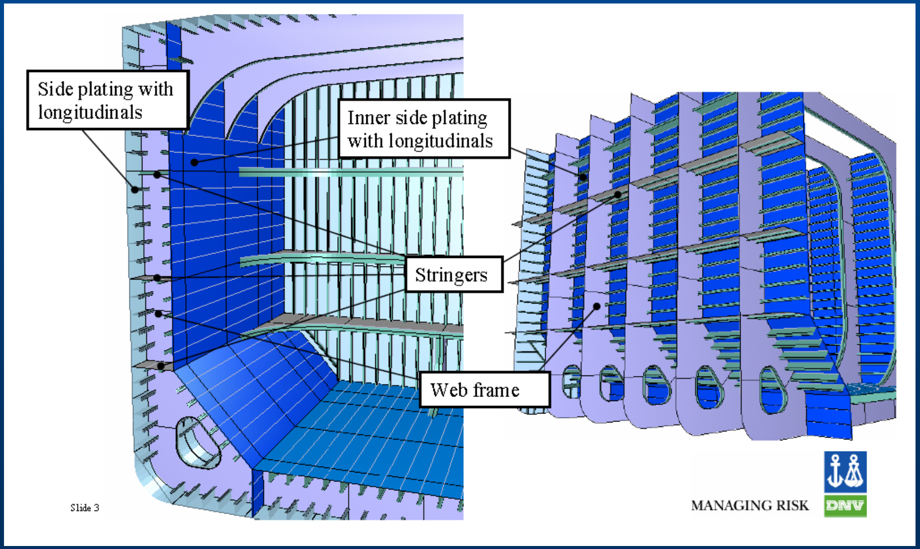


Nomenclatura Estrutural

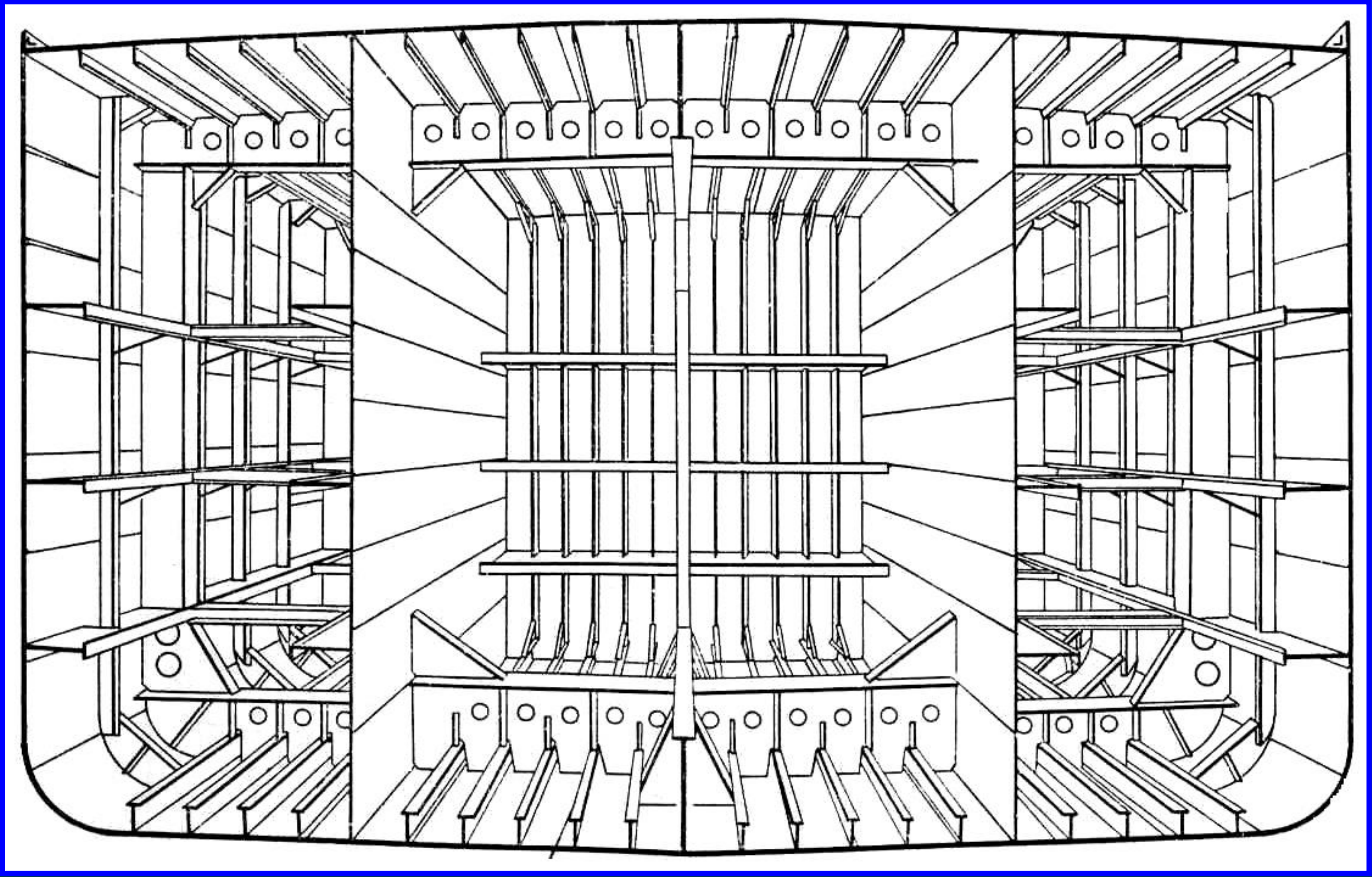
Web Frames

They are special types of frames that are heavier in scantlings and generally have greater depths and thicknesses. They consist of plate web and face flat, the web being much deeper than conventional frames. They occur after every 4 or 5 normal frames for all practical purposes. Still, they may have a higher occurrence in high-strength regions like machinery spaces or in the forward and the aft regions to increase the structural rigidity.

The frames are disposed of along the vessel's length regularly for all practical purposes. The distance between two successive frames is known as frame spacing and is also highly considered for several purposes by the designer. This is at least 600 mm or more for most sea-going cargo ships, depending on the requirement.



Seção Mestra Típica

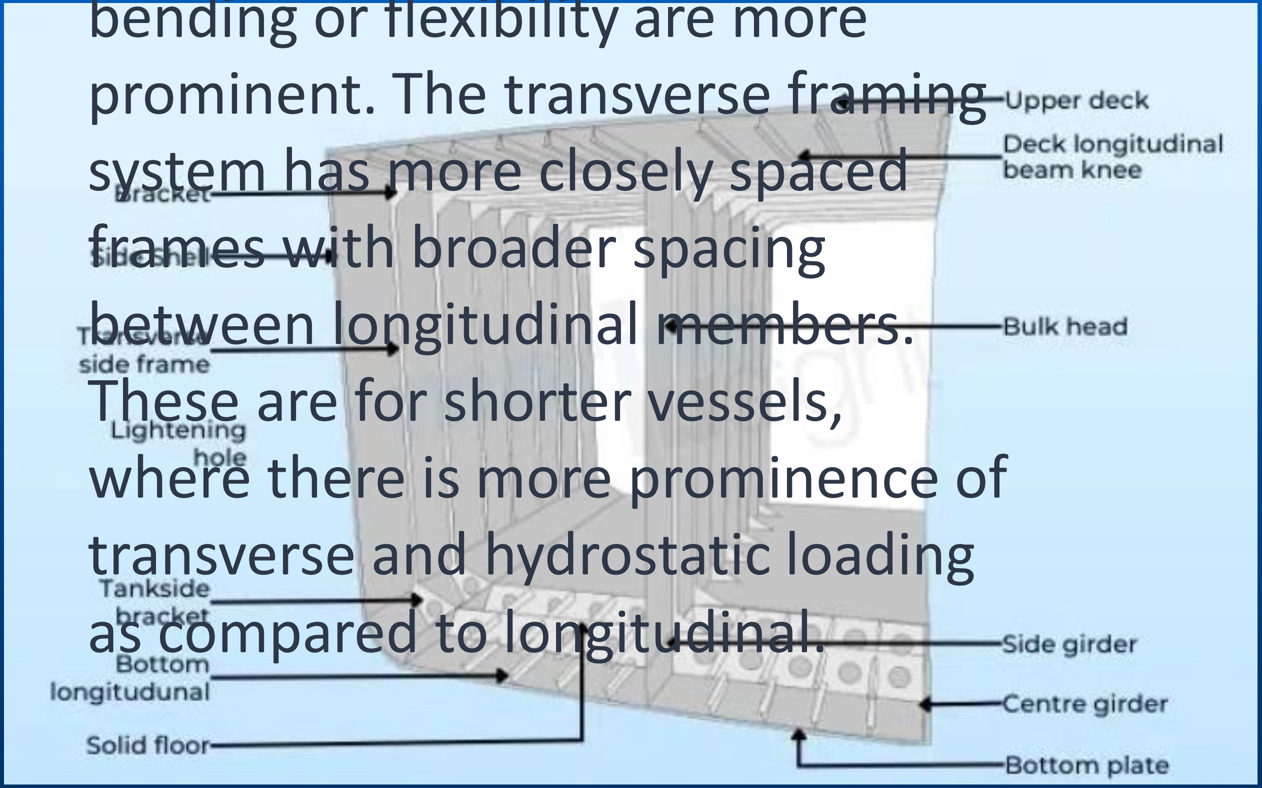


Seção Mestra Típica

Longitudinal And Transverse Framing

In a longitudinal frame, there are more closely spaced longitudinal members than transverse ones.

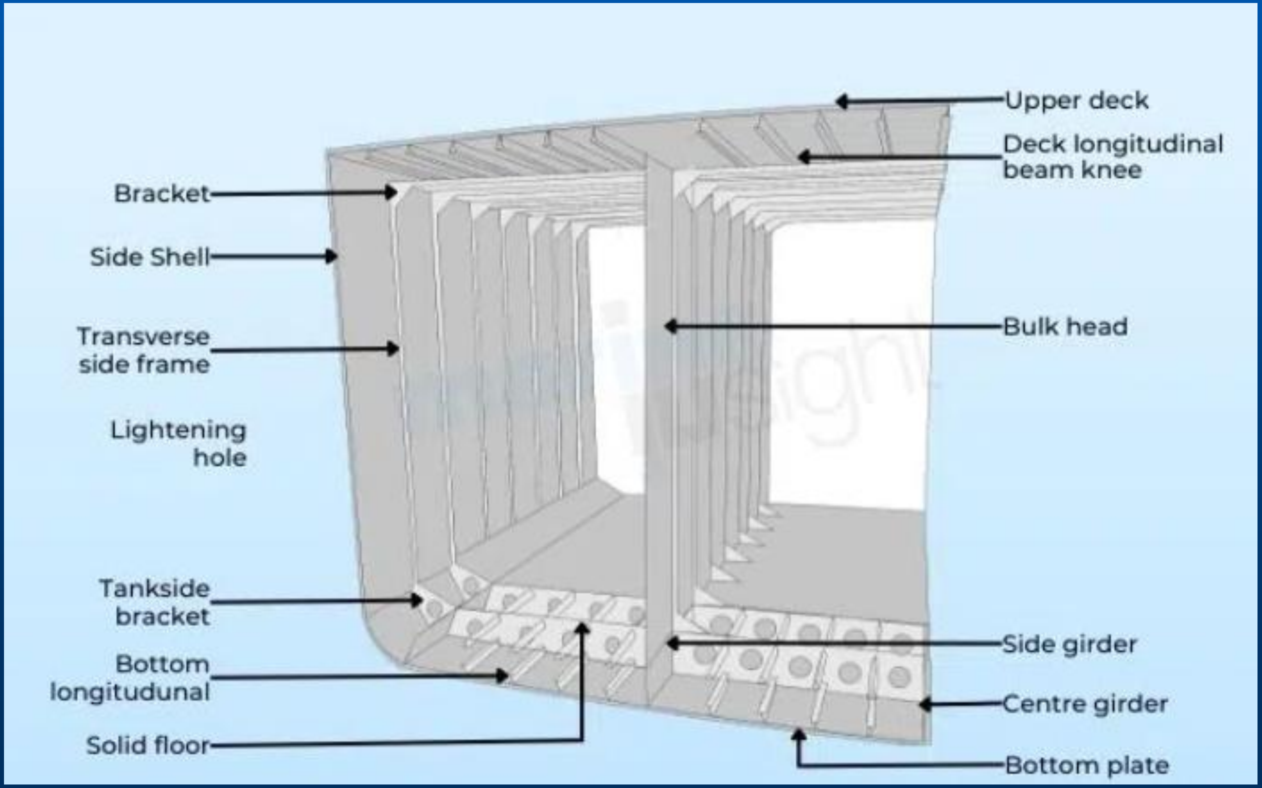
They are primarily for longer ships where longitudinal effects like bending or flexibility are more prominent. The transverse framing system has more closely spaced frames with broader spacing between longitudinal members. These are for shorter vessels, where there is more prominence of transverse and hydrostatic loading as compared to longitudinal.



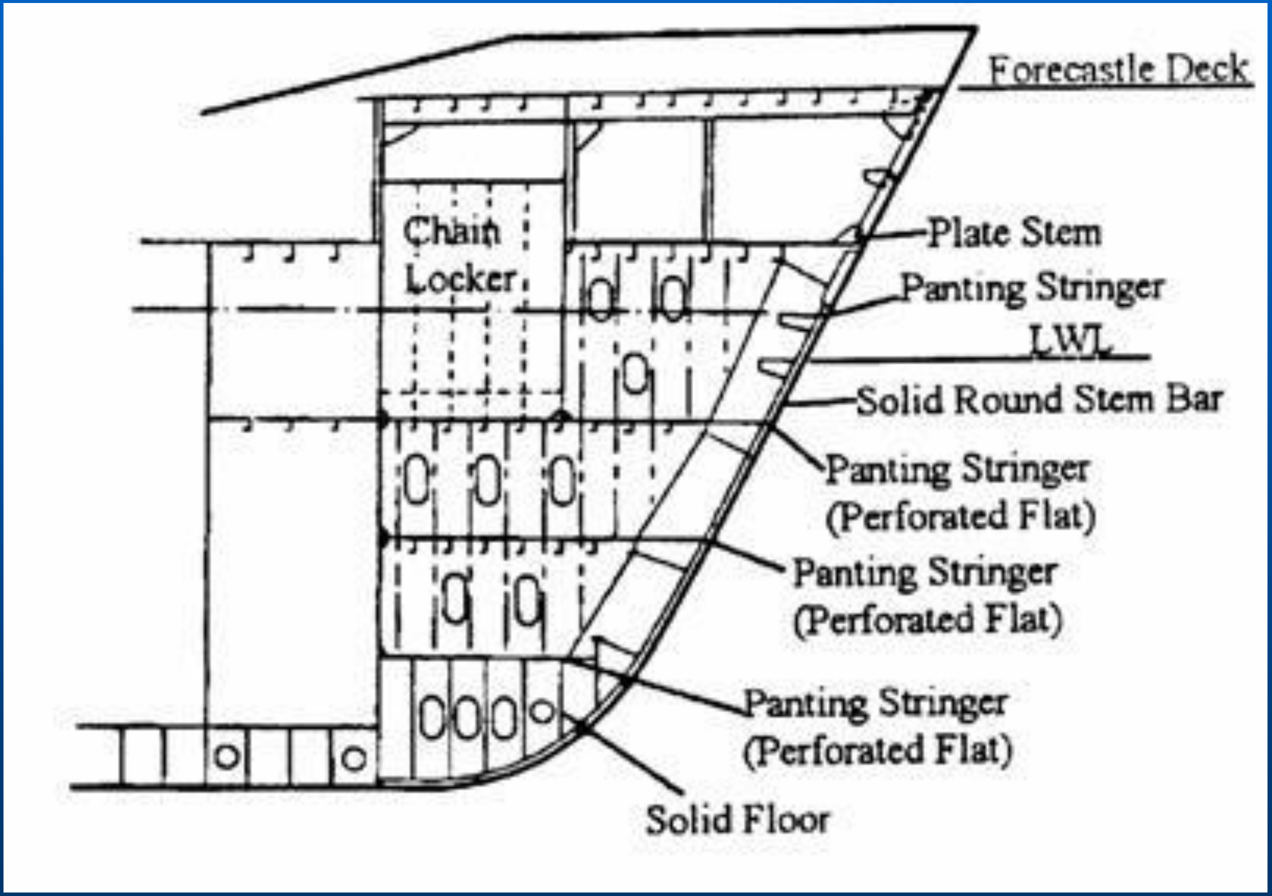
Seção Mestra Típica

Longitudinal And Transverse Framing

Long. frames are primarily for longer ships where longitudinal effects like bending or flexibility are more prominent. The transverse framing system has more closely spaced frames with broader spacing between longitudinal members. These are for shorter vessels, where there is more prominence of transverse and hydrostatic loading as compared to longitudinal.



Nomenclatura Estrutural



Seção 6 - Materiais

1 Steel Grades

1.1 Hull Structural Steel

1.1.1 Scope

1.1.1.1 Materials used during construction are to comply with the Rules for Materials of the individual Classification Society. Use of other materials and the corresponding scantlings will be specially considered.

1.1.2 Strength

1.1.2.1 Steel having a specified minimum yield stress of 235N/mm^2 is regarded as normal strength hull structural steel. Steel having a higher specified minimum yield stress is regarded as higher strength hull structural steel.

1.1.3 Material grades

1.1.3.1 Material grades of hull structural steels are referred to as follows:

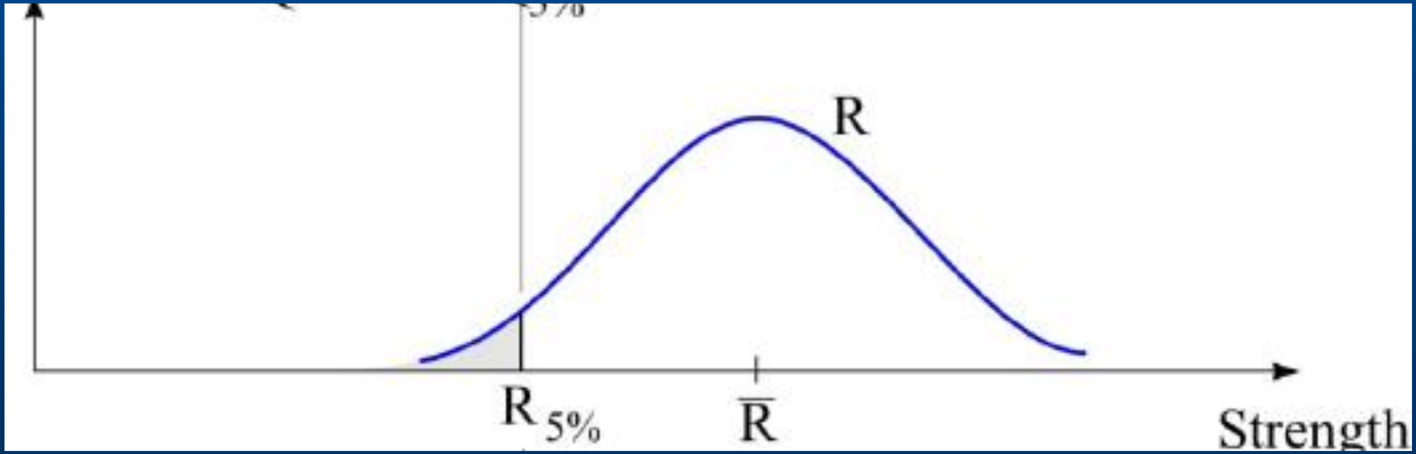
(a) A, B, D and E denote normal strength steel grades

(b) AH, DH and EH denote higher strength steel grades.

Seção 6 - Materiais

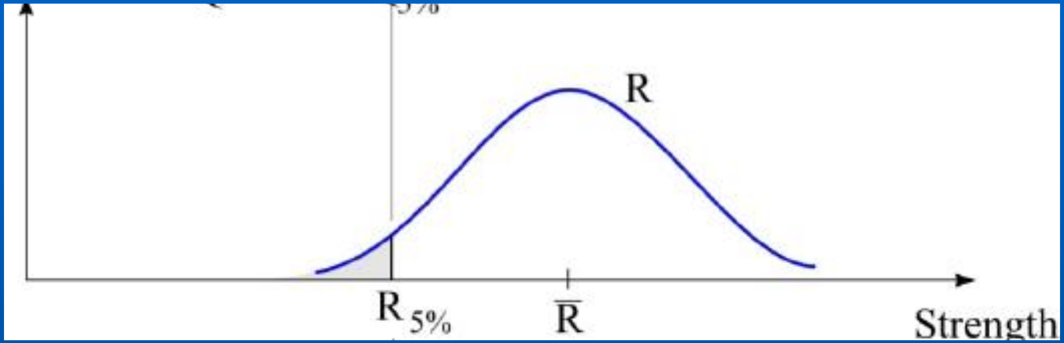
- Valores característicos

This approach is very common in engineering. When we say that steel has a yield strength of 300MPa, we don't mean that the average strength is 300MPa, we mean that no more than 5% of the tested values fall below 300MPa. This is because if more than 5% are below, the steel would fail to be rated at 300MPa. There are cases where none of the samples would be below 300, possibly with a minimum test at 320MPa, but yet the steel is rated as 300MPa.



Seção 6 - Materiais

- Valores característicos



We define values such as the 5% value as Characteristic Values. We might be more specific and call this the 5% characteristic value. In naval architecture we use the term 'significant wave height' which we might call Hs. Hs, is approximately equal to the average of the highest one-third of the waves. This is a 'characteristic value', at about the 10% level (est.).

Note: Hs is calculated precisely using:

$$Hs = 4.0 * \mathrm{sqrt}(m0)$$

where m0 is the variance of the wave displacement time series acquired during the wave acquisition period.

Seção 6 - Materiais

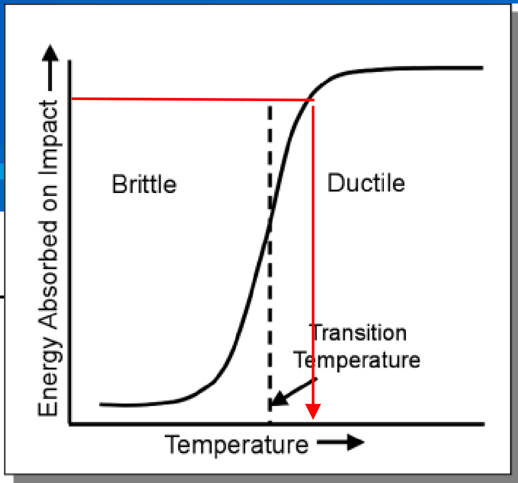
Chemical Composition (ladle analysis, percent %) as specified by Lloyd's rule

Grade	C Max	Mn	P Max	S Max	Si	Al[1]	Nb
A	0,21	[2]	0,035	0,035	0,50 max	-	-
B	0,21	0,80 min	0,035	0,035	0,35 max	-	-
D	0,21	0,60 min	0,035	0,035	0,10- 0,35	0,020 min	-
E	0,18	0,70 min	0,035	0,035	0,10-0,35	0,020 min	-
AH 36[3]	0,18	0,07-1,60[4]	0,035	0,035	0,50 max	0,020 min	0,020 -0,050
DH36[3]	0,18	0,90-1,60	0,035	0,035	0,5 max	0,020 min	0,020- 0,050
EH36[3]	0,18	0,90-1,60	0,035	0,035	0,5 max	0,020 min	0,020- 0,050

Notes:

1. Total Aluminum
2. % manganese not less than 2,5 times % carbon
3. Residual elements are restricted to the following maximum: copper ≤ 0,35%; chromium ≤ 0,20% nickel ≤ 0,40%; molybdenum ≤ 0,08%
4. 0.9% -1. 60 manganese for t ≥ 12.5mm

Seção 6 - Materiais



Mechanical Property Requiremens as specified by Lloyd's rules

Grade	Tensile Strength (MPa)	Minimum Yield stress (MPa)	Minimum Elongation [1,2] (%)	Charpy V –Notch [3] Impact test in the Longitudinal direction	
				Test temperature(°C)	Minimum average energy (J)
A	400-520	235	22	-	-
B	400-520	235	22	0	27
D	400-520	235	22	20	27
E	400-520	235	22	-40	27
AH36	490-620	355	21	0	34
DH36	490-620	355	21	-20	34
EH36	490-620	355	21	-40	34

Notes:

1. Gauge length $5{,}65\sqrt{S_0}$, , where S_0 is the original cross section area of the tensile test specimen
2. Applicable to round tensile specimens only.
3. Longitudinal, full size test specimen.

Seção 6 - Materiais

(b) AH, DH and EH denote higher strength steel grades.

1.1.4 Higher strength steel factor

1.1.4.1 For the determination of hull girder section modulus, where higher strength hull structural steel is used, a higher strength steel factor, k is given in *Table 6.1.1*.

Table 6.1.1
Values of k

Specified minimum yield stress, N/mm^2	k
235	1.00
265	0.93
315	0.78
340	0.74
355	0.72
390	0.68

Note

1. Intermediate values are to be calculated by linear interpolation.

Seção 6 - Materiais

- Aplicação do material

Table 6.1.2 Material Grades			
Thickness, t in mm	Material Class		
	I	II	III
$t \leq 15$	A, AH	A, AH	A, AH
$15 < t \leq 20$	A, AH	A, AH	B, AH
$20 < t \leq 25$	A, AH	B, AH	D, DH
$25 < t \leq 30$	A, AH	D, DH	D, DH
$30 < t \leq 35$	B, AH	D, DH	E, EH
$35 < t \leq 40$	B, AH	D, DH	E, EH
$40 < t \leq 51$	D, DH	E, EH	E, EH

Seção 6 - Materiais

Table 6.1.3
Material Class or Grade of Structural Members

Structural member category	Material Class or Grade	
	Within 0.4*L* Amidships	Outside 0.4*L*
Secondary Longitudinal bulkhead strakes, other than those belonging to primary category Deck plating exposed to weather other than that belonging to primary or special category Side plating	Class I	Grade A[8]/ AH
Primary Bottom plating including keel plate Strength deck plating, excluding that belonging to the special category [10] Continuous longitudinal members above strength deck, excluding longitudinal hatch coamings Uppermost strake in longitudinal bulkheads [10] Vertical strake (hatch side girder) and upper sloped strake in top wing tank	Class II	Grade A[8] / AH
Special Sheer strake at strength deck [1][2][3][10] Stringer plate in strength deck [1][2][3][10] Deck strake at longitudinal bulkhead [2][4][10] Strength deck plating at outboard corners of cargo hatch openings Bilge strake [2][5][6] Continuous longitudinal hatch coamings	Class III	Class II (Class I outside 0.6*L* amidships)
Other Categories Plating for stern frames, rudder horns, rudders and shaft brackets [7]	–	Class II
Strength members not referred to in above categories [9]	Grade A[8] / AH	Grade A[8] / AH

Note
1. Not to be less than E/EH within 0.4*L* amidships in vessels with length, *L*, exceeding 250m.
2. Single strakes required to be of material class III or E/EH are, within 0.4*L* amidships, to have breadths not less than 800 + 5*L* mm, but need not be greater than 1800mm.

Seção 8 - Escantilhões

1. Resistência Longitudinal
   – Loading Guidance
   – Loading Manual
   – Viga Navio (Hull Girder)
      • Resistência à flexão
      • Resistência ao Cisalhamento
      • Flambagem
      • Fadiga
   – Continuidade Estrutural

Seção 8 - Escantilhões

2. **Cargo Tank Region:**

aplica-se a estrutura do navio na região de carga (chapa do fundo, convés, duplo fundo, anteparas, reforços leves e pesados)

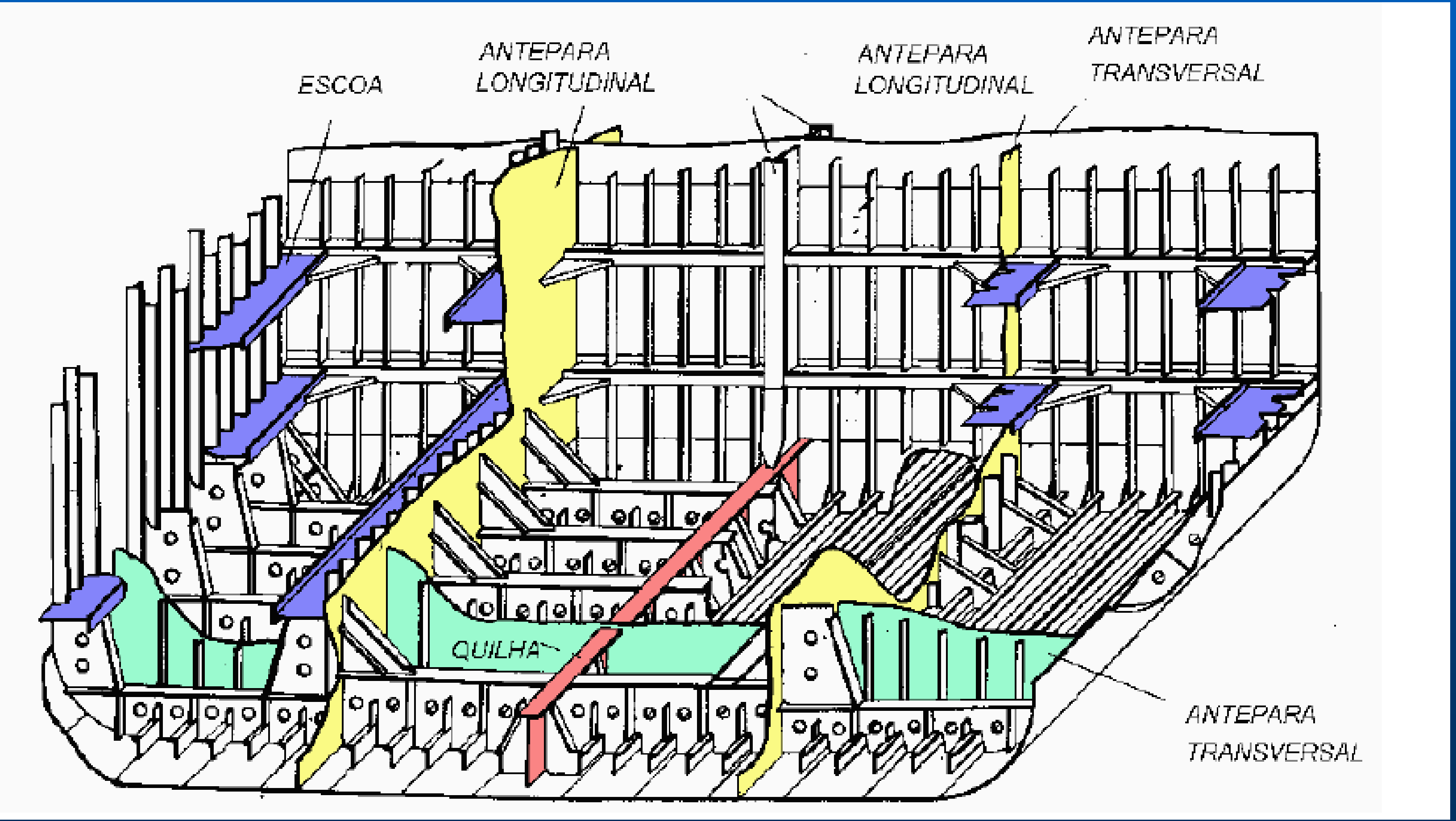
- **Geral**
- **Hull envelope plating**
  - **Keel plating, bottom shell plating, bilge plating, side shell plating, sheer strake, deck plating.**
- **Hull Framing**

Seção 8 - Escantilhões

2. **Cargo Tank Region:**
   - **Inner Bottom**
     - **Plate**
     - **Longitudinals**
   - **Bulkheads**
   - **Membros Primários**

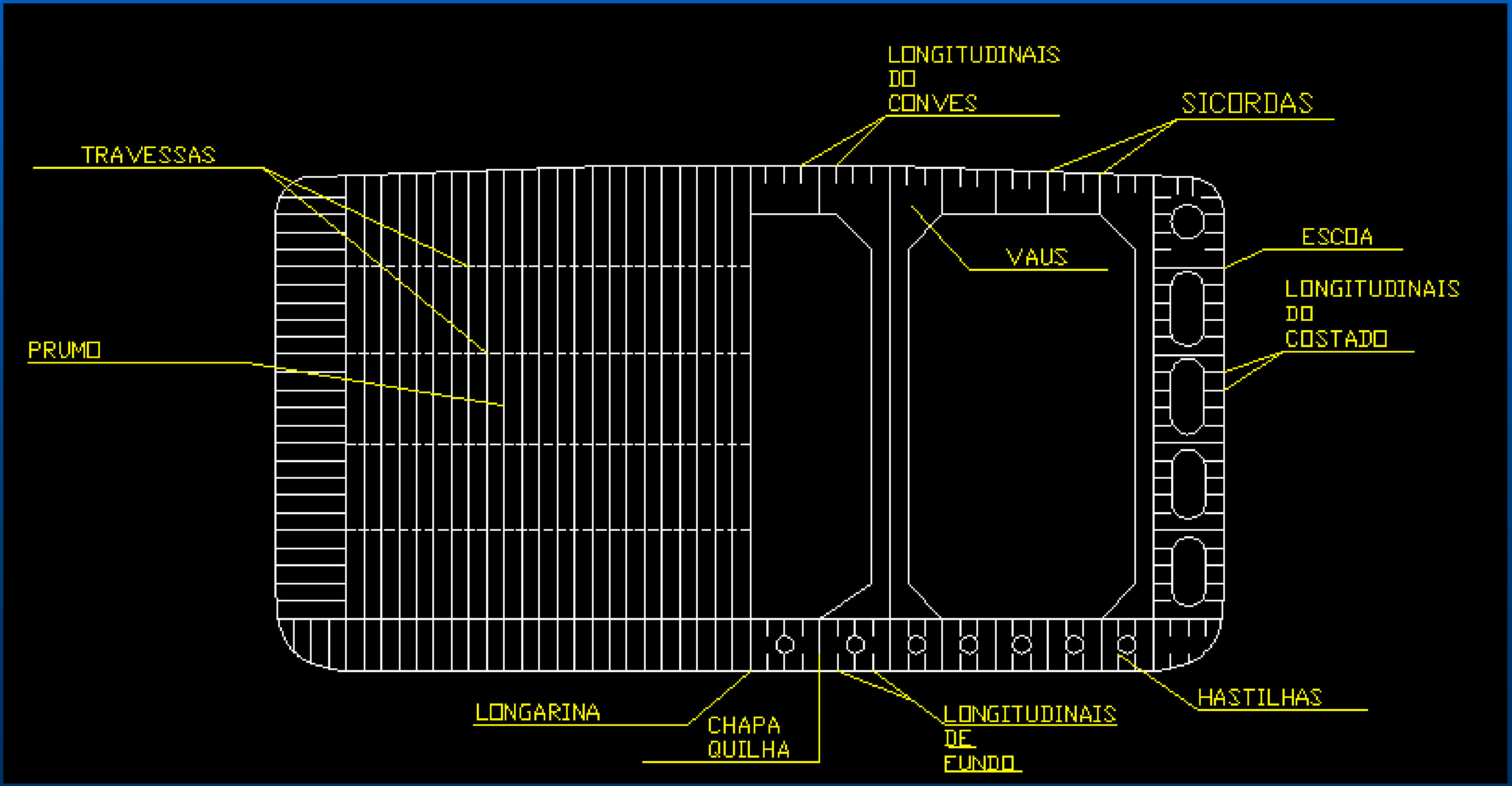
Elementos

- **Navio Petroleiro**



Elementos

- **Arranjo Estrutural**



Modos de falha

2 CRITERIA

2.1 General

2.1.1

Criteria are prescribed in the Rules to check the relevant limit states for the various structural elements. The strength assessments included in the Rules are defined in terms of yield check, buckling check, ultimate strength check, and fatigue check as indicated in Table 2.

Table 2 : Structural assessment

Structural Elements [1]		Yielding check	Buckling check	Ultimate strength check	Fatigue check
Local Structures	Stiffeners	Y	Y	Y [2]	Y
	Plating	Y	Y	Y [3]	-
Primary supporting members		Y	Y	Y [2]	Y
Hull girder		Y	Y [4]	Y	-

(1) "Y" indicates that the structural assessment is to be carried out.
(2) The ultimate strength check is included in the buckling check.
(3) The ultimate strength check of plating is included in the yielding check formula of plating.
(4) The buckling check of stiffeners and plating taking part in hull girder strength is performed against stress due to hull girder bending moment and hull girder shear force.

Design Load

Table 1 : Design load sets

Item	Design load set	Load component	Draught	Design load	Loading condition
External shell and exposed deck	SEA-1	P_{ex}, P_D	T_{SC}	S+D	Full Load condition [1]
	SEA-2	P_{ex}	T_{SC}	S	Harbour condition [2]
Water ballast tank (oil tanker and bulk carrier)	WB-1	$P_{in} - P_{ex}$ [3]	T_{BAL}	S+D	Normal ballast condition
	WB-2	$P_{in} - P_{ex}$ [3]	T_{BAL}	S+D	Normal ballast condition Water ballast exchange
	WB-3	$P_{in} - P_{ex}$ [3]	$0.25T_{SC}$	S	Harbour/test condition

Item	Design load set	Load component	Draught	Design load	Loading condition
Water ballast tank (bulk carrier) and bulk cargo hold assigned as ballast hold	WB-4	$P_{in} - P_{ex}$ [3]	T_{BAL-H} [7]	S+D	Heavy ballast condition
	WB-5 [4]	$P_{in} - P_{ex}$ [3]	T_{BAL-H} [7]	S+D	Heavy ballast condition Water ballast exchange
	WB-6 [5]	P_{in}	-	S	Harbour/test condition
Cargo oil tank	OT-1	P_{in}	T_{SC}	S+D	Full Load condition
	OT-2	P_{in}	$0.6T_{SC}$	S+D	Partial load condition
	OT-3	P_{in}	-	S	Harbour/Test condition
	BC-1	P_{in}	T_{SC}	S+D	Homogeneous loading, fully filled
	BC-2	P_{in}	-	S	
	BC-3	P_{in}	T_{SC}	S+D	Homogeneous heavy cargo, partially filled (BC-A, B ships)
	BC-4	P		S	

Section 8

- **Longitudinal Strength**
  - **Loading Guidance**
  - **Loading Manual**

1.2.2.2 At the midship cross section the net vertical hull girder section modulus, $Z_{v\text{-}min}$, at the deck and keel is not to be less than the rule minimum hull girder section modulus, $Z_{v\text{-}min}$, defined as:

$$Z_{v-min} = 0.9 k C_{wv} L^2 B (C_b + 0.7) \cdot 10^{-6} \quad m^3$$

Where:

k	higher strength steel factor, as defined in *Section 6/1.1.4*
C_{wv}	wave coefficient as defined in *Table 8.1.2*
L	rule length, in m, as defined in *Section 4/1.1.1.1*
B	moulded breadth, in m, as defined in *Section 4/1.1.3.1*
C_b	block coefficient, as defined in *Section 4/1.1.11.1* but is not to be taken as less than 0.70

Seção 8

- **Resistência Longitudinal**

$$Mw(+) = +0.19 C_1 C_2 L_1^2 B C_b' \qquad \text{(kN-m)}$$

$$Mw(-) = -0.11 C_1 C_2 L_1^2 B (C_b' + 0.7) \qquad \text{(kN-m)}$$

where

$Mw(+)$: the wave bending moment of hogging
$Mw(-)$: the wave bending moment of sagging
C_1: the parameter determined by ship length

$$C_1 = \begin{cases} 10.75 - \left(\dfrac{300 - L_1}{100}\right)^{1.5} & \mathrm{L_1} \le 300\,\mathrm{m} \\ 10.75 & 300\,\mathrm{m} \le \mathrm{L_1} \le 350\,\mathrm{m} \\ 10.75 - \left(\dfrac{L_1 - 350}{100}\right)^{1.5} & 350\,\mathrm{m} \le \mathrm{L_1} \end{cases}$$

C_2: distribution factor along ship length as specified in Fig. 2.2.2
L_1: ship length (m)
B: ship breadth (m)
C_b': block coefficient

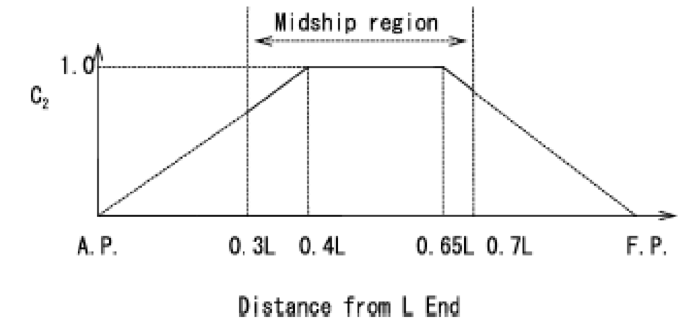


Fig. 2.2.2 Coefficient C2 : distribution factor

Seção 8

- **Resistência Longitudinal**

106 The design stillwater bending moments amidships (sagging and hogging) are normally not to be taken less than:

$$M_S = M_{SO} \quad \text{(kNm)}$$

$M_{SO} = -0.065\, C_{WU}\, L^2 B\, (C_B + 0.7)$ (kNm) in sagging

$= C_{WU}\, L^2 B\, (0.1225 - 0.015\, C_B)$ (kNm) in hogging

$C_{WU} = C_W$ for unrestricted service.

Ship Length L	*Wave Coefficient C*
$90 \leq L < 300$ m	$10.75 - [(300 - L)/100]^{3/2}$
$300 \leq L < 350$ m	10.75
$350 \leq L$	$10.75 - [(300 - L)/150]^{3/2}$

Seção 8

- **Resistência Longitudinal**

TABLE 18.II Reference Horizontal Bending Moments

Class Society	M_{WH} *[N · m]*
ABS (8)	$180\ C_1L^2DC_B$
BV (9) RINA (10)	$1600\ L^{2.1}\ TC_B$
DNV (11)	$220\ L^{9/4}(T + 0.3B)C_B$
NKK (12)	$320\ L_2C\ \ T\sqrt{L - 35 / L}$

TABLE 18.III Examples of Reference Values for Wave Torque

Class Society	Q_w *[N · m] (at mid-ship)*
ABS (bulk carrier)	$2700\,LB^2T\left[(C_W - 0.5)^2 + 0.1\right]\left[0.13 - \frac{e}{D}\left(\frac{0.14}{T}\right)^{0.5}\right]$ (e = vertical position of shear center)
BV RINA	$190\,LB^2C_W^2\left[8.13 - \left(\frac{250 - 0.7L}{125}\right)^3\right]$

Instabilidade

1.4.2 Buckling assessment

1.4.2.1 The buckling assessment of plate panels and longitudinals is to be determined according to *Section 10/3.1* with hull girder stresses calculated on net hull girder sectional properties.

1.4.2.2 The buckling strength for the buckling assessment is to be derived using local net scantlings, t_{net}, as follows:

$$t_{net} = t_{grs} - 1.0 t_{corr} \quad \text{mm}$$

Where:

t_{grs} gross plate thickness, in mm

t_{corr} corrosion addition, in mm, as defined in *Section 6/3.2*

1.4.2.3 The hull girder compressive stress due to bending, $\sigma_{hg\text{-}net50}$, for the buckling assessment is to be calculated using net hull girder sectional properties and is to be taken as the greater of the following:

$$\sigma_{hg-net50} = \left| \frac{(z - z_{NA-net50})(M_{sw-perm-sea} + M_{wv-v})}{I_{v-net50}} \right| 10^{-3} \quad \text{N/mm}^2$$

$$\sigma_{hg-net50} = \frac{30}{k} \quad \text{N/mm}^2$$

Where:

$M_{sw\text{-}perm\text{-}sea}$ permissible still water bending moment for seagoing operation, in kNm, as defined in *Section 7/2.1.1*, with signs

Fadiga

1.5.1.3 The fatigue life for the deck structure as required by *Section 9/3* and *Appendix C* is normally satisfied providing the net vertical hull girder section modulus at the moulded deck line at side, $Z_{v\text{-}net50}$, as defined in *Section 4/2.6.1.1*, is not less than the required hull girder section modulus, $Z_{v\text{-}fat}$, defined as:

$$Z_{v-fat} = \frac{M_{wv-hog} - M_{wv-sag}}{1000 R_{al}} \quad \text{m}^3$$

Where:

$M_{wv\text{-}hog}$ hogging vertical wave bending moment for fatigue, in kNm, as defined in *Section 7/3.4.1*

$M_{wv\text{-}sag}$ sagging vertical wave bending moment for fatigue, in kNm, as defined in *Section 7/3.4.1*

R_{al} allowable stress range, in N/mm^2

$= 0.17L + 86$ for class F-details

$= 0.15L + 76$ for class F2-details

L rule length, in m, as defined in *Section 4/1.1.1.1*

Região dos Tanques de Carga

8.1.1.1 - Espaçamento de Cavernas

8.1.1.1.1 - O espaçamento de cavernas transversais, desde **0,2.L** à ré da PPAV até a antepara de colisão à ré, deve ser determinado através da seguinte fórmula:

$$a_o = L/500 + 0{,}48 \quad [m];\ a_{oMAX} = 1{,}0\ m$$

8.1.1.1.2 - À vante da antepara de colisão de vante e à ré da antepara de colisão à ré, o espaçamento de cavernas não deve, geralmente, exceder 600mm.

Região dos Tanques de Carga

C Shell Plating

C.1 Minimum thickness

The minimum thickness t_{min} of the shell plating is defined as:

$$t_{min} = 3.5 \text{ mm}$$

C.2 Bottom plating

C.2.1 The thickness t_B of bottom plating is not to be less than determined by the following formula:

$$t_B = 1.3 \cdot \frac{\mathbf{a}}{a_0} \cdot \sqrt{\frac{\mathbf{L} \cdot \mathbf{T}}{\mathbf{H}}} \quad [\text{mm}] \qquad \text{with } t_B \geq t_{min}$$

a_0 : standard frame spacing [m], defined as:

$$\boxed{a_0 = \frac{\mathbf{L}}{500} + 0.48}$$

t_{min} : minimum thickness according to C.1

Região dos Tanques de Carga

C.6.2 Plate floors

C.6.2.1 The floor spacing should, in general, not exceed 5 times the mean longitudinal frame spacing.

C.3 Side girders

C.3.1 Arrangement

At least one side girder is to be fitted in the engine room and in way of 0.25 **L** aft of F.P. In the other parts of the double bottom, one side girder is to be fitted where the horizontal distance between ship's side and centre girder exceeds 4.5 m. Two side girders are to be fitted where the distance exceeds 8 m, and three side girders where it exceeds 10.5 m. The distance of the side girders from each other and from centre girder and ship's side respectively is not to be greater than:

1.8 m	in the engine room within the engine seatings
4.5 m	where one side girder is fitted in the other parts of double bottom
4.0 m	where two side girders are fitted in the other parts of double bottom
3.5 m	where three side girders are fitted in the other parts of double bottom

Região dos Tanques de Carga

8.2.3.8 - Se os escantilhões de longitudinais forem determinados por cálculos de resistência, a tensão total resultante das tensões devidas à flexão local e das tensões normais devidas à flexão longitudinal, não deve exceder.

$$\sigma_t = 230/k\ [N/mm^2]$$

A tensão de flexão local não deve exceder:

σ_{bm} = 150/k [N/mm^2], para aqueles carregamentos para os quais, conforme 8.2.3.1, o fator n = 0,55
σ_{bm} = 120/k [N/mm^2], para aqueles carregamentos para os quais, conforme 8.2.3.1, o fator n = 0,70.

8.2.3.9 - Quando escoras, conforme a Seção 7, item 7.2.7.6, são colocadas entre longitudinais do fundo e do teto do fundo duplo, os módulos de seção das longitudinais podem ser reduzidos em 40%.

8.2.4 - Cavernas Laterais Gigantes

8.2.4.1 - O módulo de seção de cavernas laterais gigantes suportando longitudinais do costado, não deve ser menor que:

$$W = 0,57\ .\ k\ .\ e\ .\ m^2\ .\ p\ [cm^3]$$

e = espaçamento de cavernas laterais gigantes, em [m]
m = vão, sem apoio, em [m], conforme Seção 2, 2.3.

Área seccional mínima da alma:

$$f = 0,058\ .\ k\ .\ e\ .\ m\ .\ p\ [cm^2]$$

8.2.4.2. - Se as cavernas laterais gigantes estão dimensionadas com base em cálculos de resistência, as seguintes tensões não devem ser excedidas:

σ_b = 140/k [N/mm]
τ = 80/k [N/mm]

Região dos Tanques de Carga

C 600 Transverse frames

601 The section modulus requirement of bottom and inner bottom frames is given by:

$$Z = \frac{0.63\, l^2 s\, p\, w_k}{f_1} \quad (\text{cm}^3)$$

p = p_1 to p_{15} (when relevant) as given in Table B1.

602 Struts fitted between bottom and inner bottom frames are in general not to be considered as effective supports for the frames.

The requirements given in 601, however, may be reduced after special consideration. When bottom and inner bottom frames have the same scantlings, a Z-reduction of 35% will be accepted if strut at middle length of span.

603 The thickness of web and flange shall not be less than the larger of:

$$t = 4.5 + k + t_k \ (\text{mm})$$

$$= 1.5 + \frac{h_w \sqrt{f_1}}{g} + t_k$$

k = $0.015\, L_1$
= 5.0 maximum

h_w = web height in mm

g = 75 for flanged profile webs
= 41 for bulb profiles
= 22 for flat bar profiles.

Região dos Tanques de Carga

C 700 Bottom longitudinals

701 The section modulus requirement is given by:

$$Z = \frac{83\, l^2\, s\, p\, w_k}{\sigma} \quad (\mathrm{cm}^3)$$

p = p_1 to p_3 (when relevant) as given in Table B1

σ = allowable stress (maximum 160 f_1) given by:

B. Design loads

B 100 Local loads on side structures

101 All generally applicable local loads on side structures are given in Table B1, based upon the general loads given in Sec.4. In connection with the various local structures, reference is made to this table, indicating the relevant loads in each case.

Table B1 Design loads

Load type		*P (kN/m²)*
External	Sea pressure below summer load waterline	$p_1 = 10\, h_0 + p_{dp}$ 1)
	Sea pressure above summer load waterline	$p_2 = (p_{dp} - (4 + 0.2\, k_s)\, h_0)$ 1) minimum $6.25 + 0.025\, L_1$
Internal	Ballast, bunker or liquid cargo in side tanks in general	$p_3 = \rho\,(g_0 + 0.5\, a_v)\, h_s - 10\, h_b$ $p_4 = \rho\, g_0\, h_s - 10\, h_b + p_o$ $p_5 = 0.67\,(\rho\, g_0\, h_p + \Delta\, p_{dyn}) - 10\, h_b$
	Above the ballast waterline at ballast, bunker or liquid cargo tanks with a breadth > 0.4 B	$p_6 = \rho g_0 [0.67(h_s + \phi b) - 0.12\sqrt{H \phi b_t}]$
	Above the ballast waterline and towards ends of tanks for ballast, bunker or liquid cargo with length > 0.15 L	$p_7 = \rho g_0 [0.67(h_s + \theta l) - 0.12\sqrt{H \theta l_t}]$
	In tanks with no restriction on their filling height 2)	$p_8 = \rho\left[3 - \frac{B}{100}\right] b_b$

1) For ships with service restrictions, p_2 and the last term in p_1 may be reduced by the percentages given in Sec.4 B202.
2) For tanks with free breadth b_s > 0.56 B the design pressure will be specially considered according to Sec.4 C305.

h_0 = vertical distance in m from the waterline at draught T to the load point
T = rule draught in m, see Sec.1 B
z = vertical distance from the baseline to the load point, maximum T (m)
p_{dp}, k_s = as given in Sec.4 C201
L_1 = ship length, need not be taken greater than 300 (m)
a_v = vertical acceleration as given in Sec.4 B600
h_s = vertical distance in m from load point to top of tank, excluding smaller hatchways.

h_p = vertical distance in m from the load point to the top of air pipe
h_b = vertical distance in m from the load point to the minimum design draught, which may normally be taken as 0.35 T for dry cargo vessels and 2 + 0.02 L for tankers. For load points above the ballast waterline $h_b = 0$
p_o = 25 in general
= 15 in ballast holds in dry cargo vessels
= tank pressure valve opening pressure when exceeding the general value
ρ = density of ballast, bunker or liquid cargo in t/m³, normally not to be taken less than 1.025 t/m³ (i.e. $\rho\, g_0 \approx 10$)
Δp_{dyn} = as given in Sec.4 C300

Região dos Tanques de Carga

2.1.5 Minimum thickness for plating and local support members

2.1.5.1 The thickness of plating and stiffeners in the cargo tank region is to comply with the appropriate minimum thickness requirements given in *Table 8.2.1*.

Table 8.2.1
Minimum Net Thickness for Plating and Local Support Members in the Cargo Tank Region

Scantling Location			Net Thickness (mm)
Plating	**Hull envelope up to T_{sc} + 4.6m**	Keel plating	$5.5+0.03L_2$
		Bottom shell/bilge/side shell	$3.5+0.03L_2$
	Hull envelope above T_{sc} + 4.6m	Side shell/upper deck	$4.5+0.02L_2$
	Hull internal structure	Hull internal tank boundaries	$4.5+0.02L_2$
		Non-tight bulkheads, bulkheads between dry spaces and other plates in general	$4.5+0.01L_2$
Local support members	Local support members on tight boundaries		$3.5+0.015L_2$
	Local support members on other structure		$2.5+0.015L_2$
Tripping brackets			$5.0+0.015L_2$

Where:
T_{sc} as defined in *Section 4/1.1.5.5*
L_2 rule length, L, as defined in *Section 4/1.1.1.1*, but need not be taken greater than 300m

Região dos Tanques de Carga

2.1.5 Minimum thickness for plating and local support members

2.1.5.1 The thickness of plating and stiffeners in the cargo tank region is to comply with the appropriate minimum thickness requirements given in *Table 8.2.1*.

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	Hull envelope above T_{sc} + 4.6m	Side shell/upper deck	$4.5+0.02L_2$
	Hull internal structure	Hull internal tank boundaries	$4.5+0.02L_2$
		Non-tight bulkheads, bulkheads between dry spaces and other plates in general	$4.5+0.01L_2$
Local support members	Local support members on tight boundaries		$3.5+0.015L_2$
	Local support members on other structure		$2.5+0.015L_2$
Tripping brackets			$5.0+0.015L_2$

Where:
T_{sc} as defined in *Section 4/1.1.5.5*
L_2 rule length, L, as defined in *Section 4/1.1.1.1*, but need not be taken greater than 300m

Região dos Tanques de Carga

Table 8.2.2
Minimum Net Thickness for Primary Support Members in Cargo Tank Region

Scantling Location	Net Thickness (mm)
Double bottom centreline girder	$5.5+0.025L_2$
Other double bottom girders	$5.5+0.02L_2$
Double bottom floors, web plates of side transverses and stringers in double hull	$5.0+0.015L_2$
Web and flanges of vertical web frames on longitudinal bulkheads, horizontal stringers on transverse bulkhead and deck transverses (above and below upper deck)	$5.5+0.015L_2$

Where:

L_2 rule length, L, as defined in *Section 4/1.1.1.1*, but need not be taken greater than 300m

Região dos Tanques de Carga

2.2 Hull Envelope Plating

2.2.1 Keel plating

2.2.1.1 Keel plating is to extend over the flat of bottom for the complete length of the ship. The breadth, b_{kl}, is not to be less than:

$$b_{kl} = 800 + 5L_2 \quad \text{mm}$$

Where:

L_2 rule length, L, as defined in *Section 4/1.1.1.1*, but not to be taken greater than 300m

2.2.1.2 The thickness of the keel plating is to comply with the requirements given in *2.2.2*.

2.2.2 Bottom shell plating

2.2.2.1 The thickness of the bottom shell plating is to comply with the requirements in *Table 8.2.4*.

2.2.3 Bilge plating

2.2.3.1 The thickness of bilge plating is not to be less than that required for the adjacent bottom shell, see *2.2.2.1*, or adjacent side shell plating, see *2.2.4.1*, whichever is the greater.

2.2.3.2 The net thickness of bilge plating, t_{net}, without longitudinal stiffening is not to be less than:

$$t_{net} = \frac{\sqrt[3]{r^2 S_t P_{ex}}}{100} \quad \text{mm}$$

Região dos Tanques de Carga

2.2.4 Side shell plating

2.2.4.1 The thickness of the side shell plating is to comply with the requirements in *Table 8.2.4*.

2.2.4.2 The net thickness, t_{net}, of the side plating within the range as specified in *2.2.4.3* is not to be less than:

$$t_{net} = 26\left(\frac{s}{1000} + 0.7\right)\left(\frac{BT_{sc}}{\sigma_{yd}^{\ 2}}\right)^{0.25} \quad \text{mm}$$

Where:

s stiffener spacing, in mm, as defined in *Section 4/2.2*

B moulded breadth, in m as defined in *Section 4/1.1.3.1*

T_{sc} scantling draught, in m, as defined in *Section 4/1.1.5.5*

σ_{yd} specified minimum yield stress of the material, in N/mm²

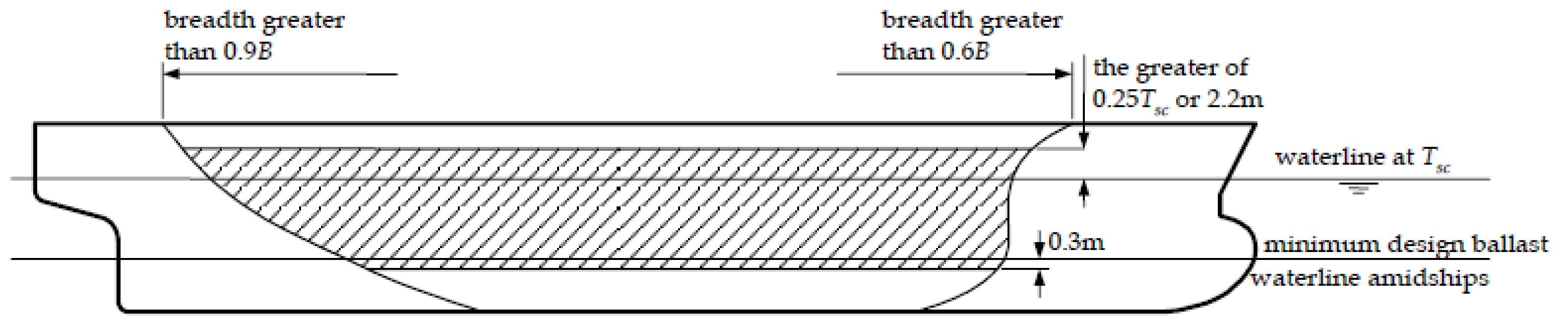
Região dos Tanques de Carga

- between a section aft of amidships where the breadth at the waterline exceeds 0.9B, and a section forward of amidships where the breadth at the waterline exceeds 0.6B

(b) vertical extent:

- between 300mm below the minimum design ballast waterline, T_{bal}, amidships to 0.25T_{sc} or 2.2m, whichever is greater, above the draught T_{sc}.

Figure 8.2.2
Extent of Side Shell Plating



Região dos Tanques de Carga

- **Cavernamento**

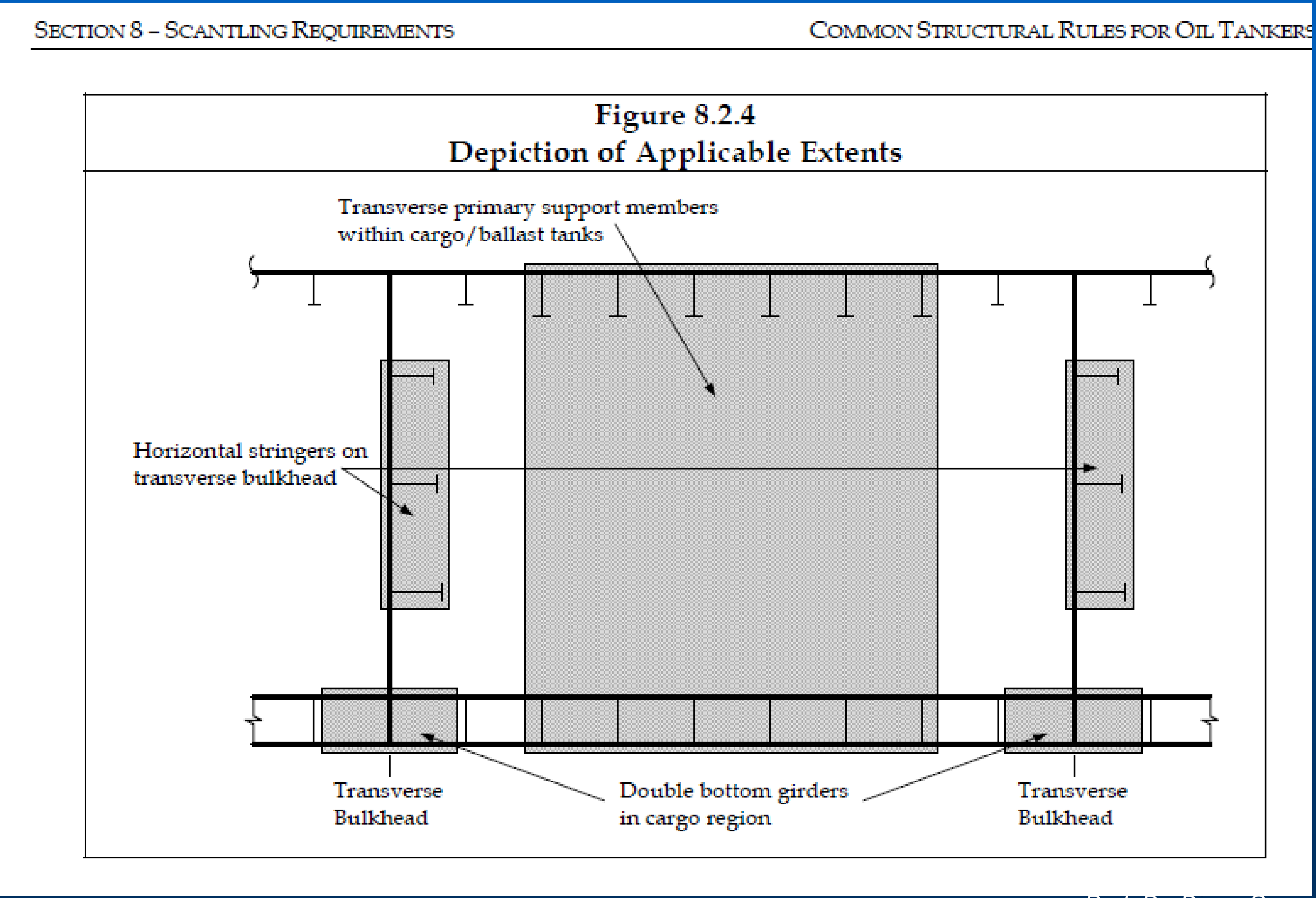
2.3 Hull Envelope Framing

2.3.1 General

2.3.1.1 The bottom shell, inner bottom and deck are to be longitudinally framed in the cargo tank region. The side shell, inner hull bulkheads and longitudinal bulkheads are generally to be longitudinally framed. Where the side shell is longitudinally framed, the inner hull bulkheads are to be similarly constructed. Suitable alternatives which take account of resistance to buckling will be specially considered.

Região dos Tanques de Carga

- Membros Primários



Caverna Vertical Gigante

2.6.6.2 The net section modulus, Z_{net50}, of the vertical web frame is not to be less than:

$$Z_{net50} = \frac{1000\,M}{C_{s-pr}\,\sigma_{yd}} \quad \text{cm}^3$$

Where:

M design bending moment, in kNm, as follows:

$= c_u P S l_{bdg-vw}{}^2$ for upper part of the web frame

$= c_l P S l_{bdg-vw}{}^2$ for lower part of the web frame

where a cross tie is fitted and $l_{bdg-vw-ct}$ is greater than $0.7 l_{bdg-vw}$, then l_{bdg-vw} in the above formula is to be taken as $l_{bdg-vw-ct}$.

P design pressure for the design load set being considered, calculated at mid point of the effective bending span, l_{bdg-vw}, of the vertical web frame located at mid tank, in kN/m²

l_{bdg-vw} effective bending span of the vertical web frame on the longitudinal bulkhead, between the deck transverse and the bottom structure, in m, see *Section 4/2.1.4* and *Figure 8.2.7*.

$l_{bdg-vw-ct}$ effective bending span of the vertical web frame on longitudinal bulkhead, between the deck transverse and mid depth of the cross tie on ships with two longitudinal bulkheads, in m, see *Section 4/2.1.4*

S primary support member spacing, in m, as defined in *Section 4/2.2.2*

Reforçadore sob pressão lateral

IACS 2023

1 STIFFENERS SUBJECT TO LATERAL PRESSURE

1.1 Yielding check

1.1.1 Web plating

The minimum net web thickness, t_w in mm, is not to be taken less than the greatest value calculated for all applicable design load sets as defined in Ch 6, Sec 2, [2], given by:

$$t_w = \frac{f_{shr}\,|P|\,s\,\ell_{shr}}{d_{shr}\,\chi\,C_t\,\tau_{eH}}$$ with $\chi\,C_t$ not to be taken greater than 1.0.

where:

f_{shr} : Shear force distribution factor taken as:

- For continuous stiffeners with fixed ends, f_{shr} is not to be taken less than:
  - f_{shr} = 0.5 for horizontal stiffeners and upper end of vertical stiffeners.
  - f_{shr} = 0.7 for lower end of vertical stiffeners.
- For stiffeners with reduced end fixity, variable load or being part of grillage, the requirement in [1.2] applies.

C_t : Permissible shear stress coefficient for the design load set being considered, taken as:

- C_t = 0.75 for acceptance criteria set AC-S.
- C_t = 0.90 for acceptance criteria set AC-SD.

Prof. Dr. Diego Sarzosa Burgos- 2023

Reforçadore sob pressão lateral

IACS 2023

1.1.2 Section modulus

The minimum net section modulus, Z in cm³, is not to be taken less than the greatest value calculated for all applicable design load sets as defined in Ch 6, Sec 2, [2.1.3], given by:

$$Z = \frac{|P|\, s\, \ell_{bdg}^2}{f_{bdg}\, \chi\, C_s\, R_{eH}}$$

with $\chi\, C_s$ not to be taken greater than 1.0.

where:

f_{bdg} : Bending moment factor taken as:

- For continuous stiffeners with fixed ends, f_{bdg} is not to be taken higher than:
  - f_{bdg} = 12 for horizontal stiffeners and upper end of vertical stiffeners.
  - f_{bdg} = 10 for lower end of vertical stiffeners.
- For stiffeners with reduced end fixity, variable load or being part of grillage, the requirement in [1.2] applies.

C_s : Permissible bending stress coefficient as defined in Table 1 for the design load set being considered.

σ_{hg} : Hull girder bending stress, in N/mm², as defined in Ch 6, Sec 2, [1.1], calculated at the load calculation point as defined in Ch 3, Sec 7, [3.2].

β_s : Coefficient as defined in Table 2.

α_s : Coefficient as defined in Table 2.

$C_{s\text{-}max}$: Coefficient as defined in Table 2.

Table 1 : Definition of C_s

Sign of hull girder bending stress, σ_{hg}	Lateral pressure acting on	Coefficient C_s
Tension (positive)	Stiffener side	$C_s = \beta_s - \alpha_s \frac{\lvert\sigma_{hg}\rvert}{R_{eH}}$ but not to be taken greater than $C_{s\text{-}max}$
Compression (negative)	Plate side	
Tension (positive)	Plate side	$C_s = C_{s\text{-}max}$
Compression (negative)	Stiffener side	

Table 2 : Definition of β_s, α_s and $C_{s\text{-}max}$

Acceptance criteria set	Structural member	β_s	α_s	$C_{s\text{-}max}$
AC-S	Longitudinal strength member	0.85	1.0	0.75
	Transverse or vertical member	0.75	0	0.75
AC-SD	Longitudinal strength member	1.0	1.0	0.9
	Transverse or vertical member	0.9	0	0.9

Span

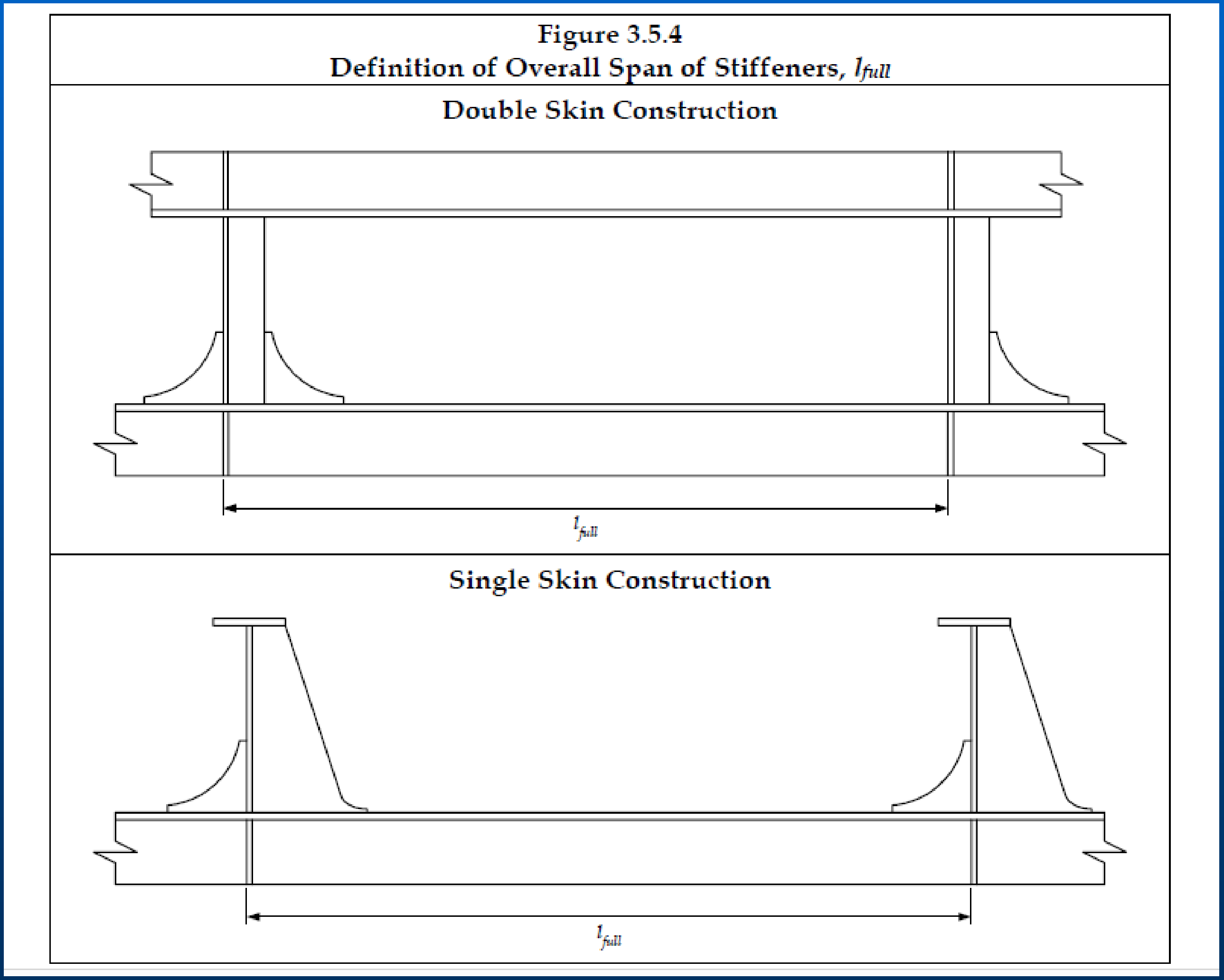


Figure 3.5.4
Definition of Overall Span of Stiffeners, l_{full}
Double Skin Construction
l_{full}
Single Skin Construction
l_{full}

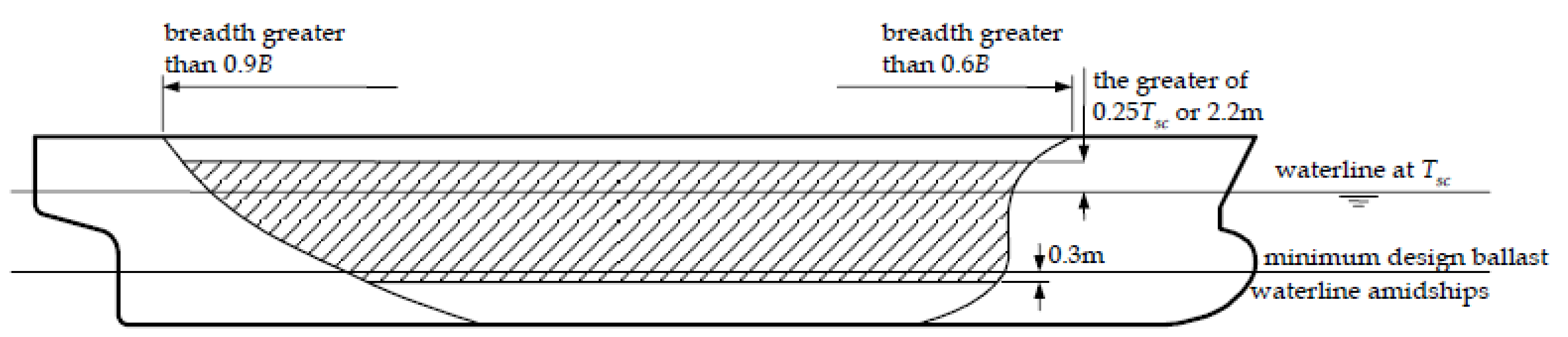
Região dos Tanques de Carga

- between a section aft of amidships where the breadth at the waterline exceeds $0.9B$, and a section forward of amidships where the breadth at the waterline exceeds $0.6B$

(b) vertical extent:

- between 300mm below the minimum design ballast waterline, T_{bal}, amidships to $0.25T_{sc}$ or 2.2m, whichever is greater, above the draught T_{sc}.

Figure 8.2.2
Extent of Side Shell Plating



Estudo de Caso

Navios Mega Petroleiro

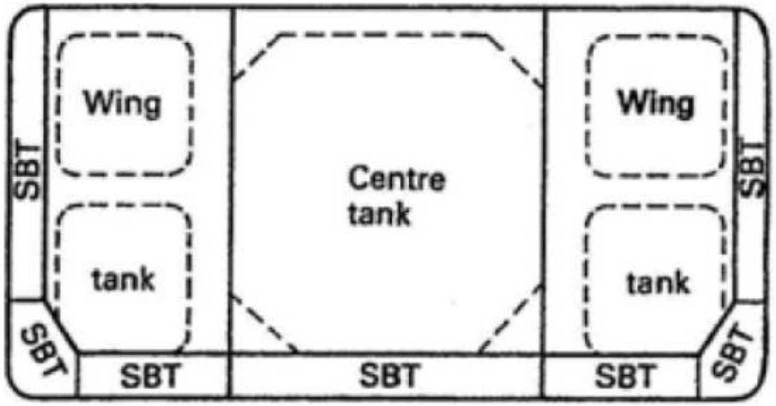
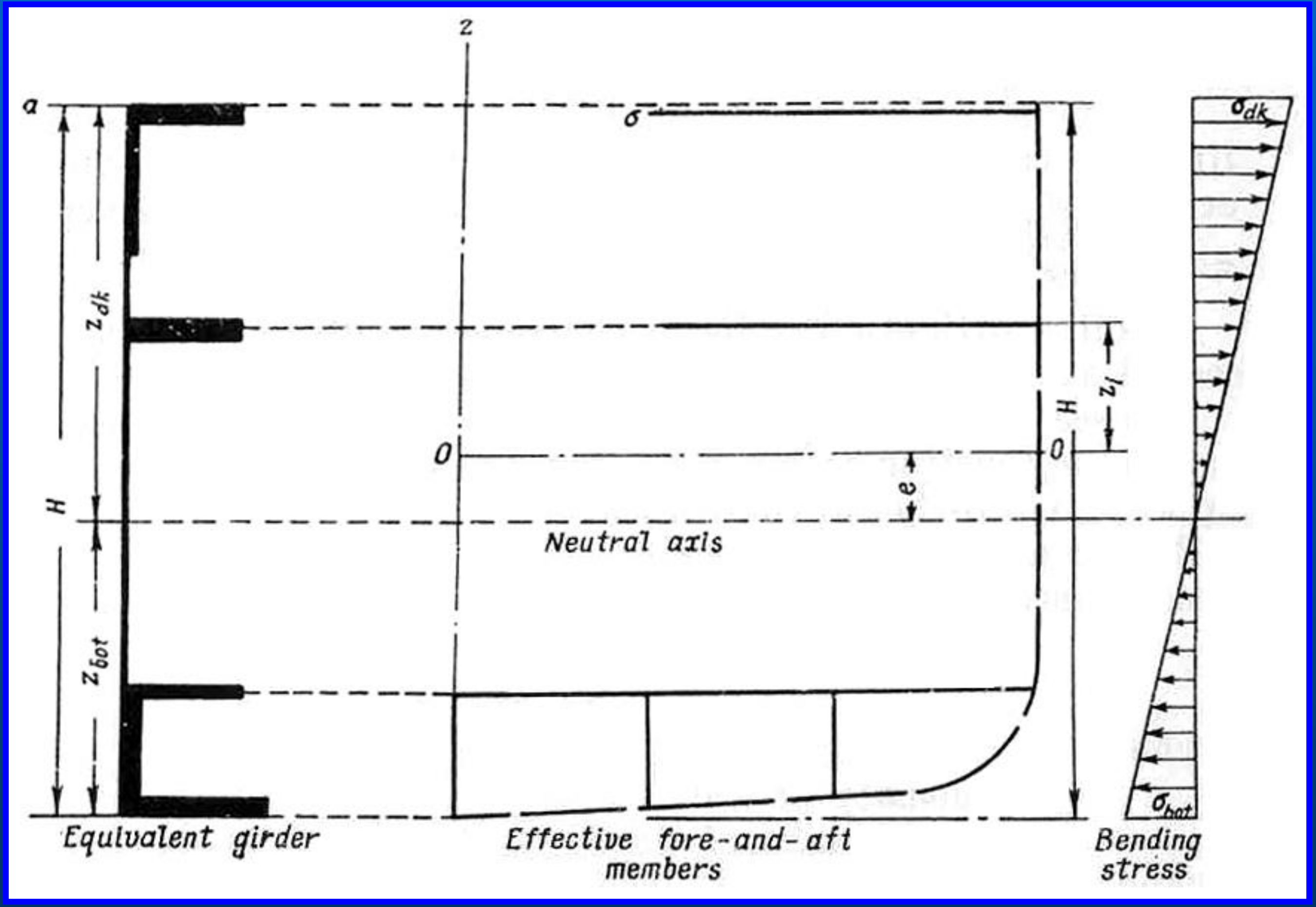


FIGURA 3.3: Secção de um Petroleiro com Duplo Casco

Cálculo Seção Mestra



Fadiga

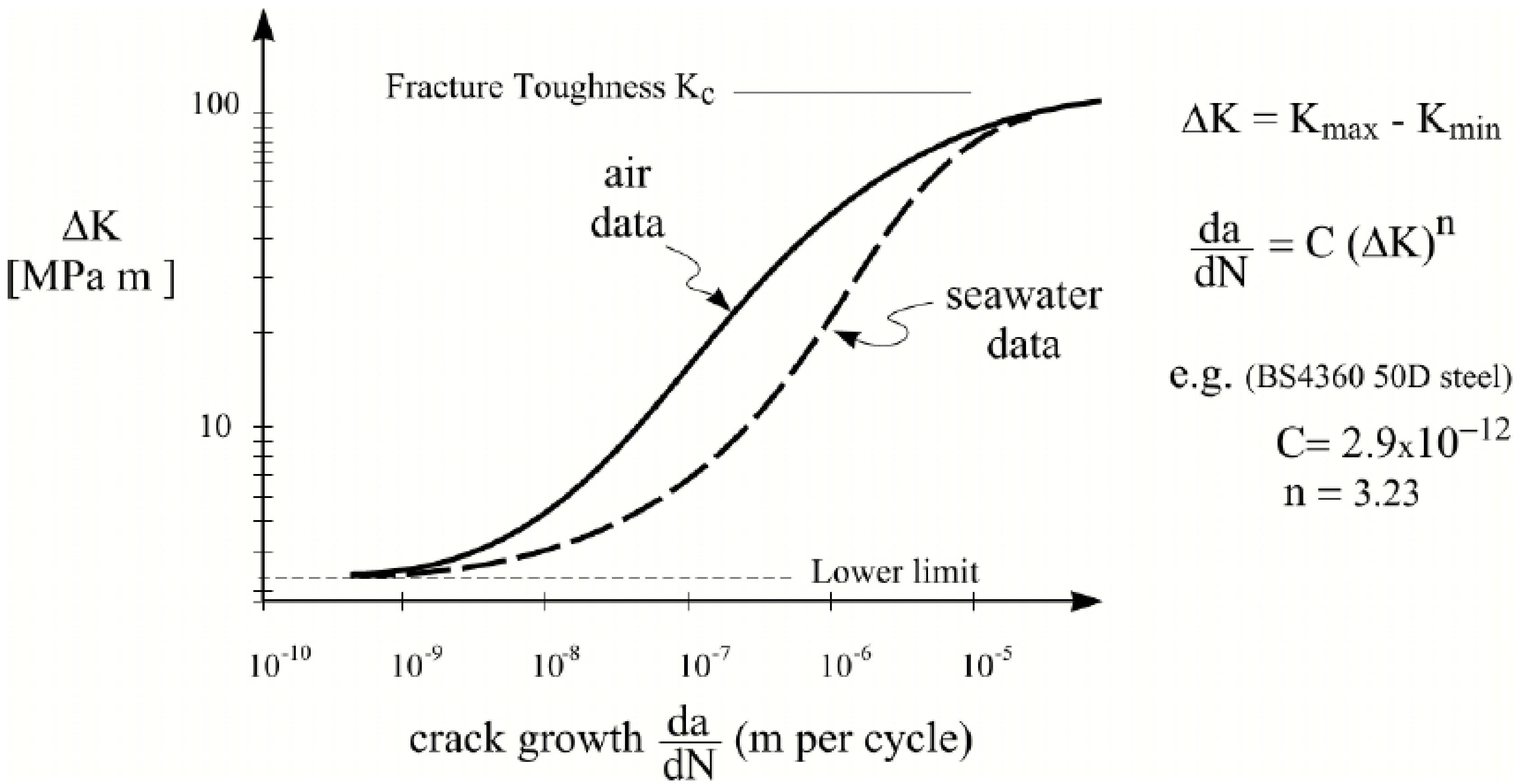


Figure 6. Crack growth diagrams (Paris Law)

FEA MODEL

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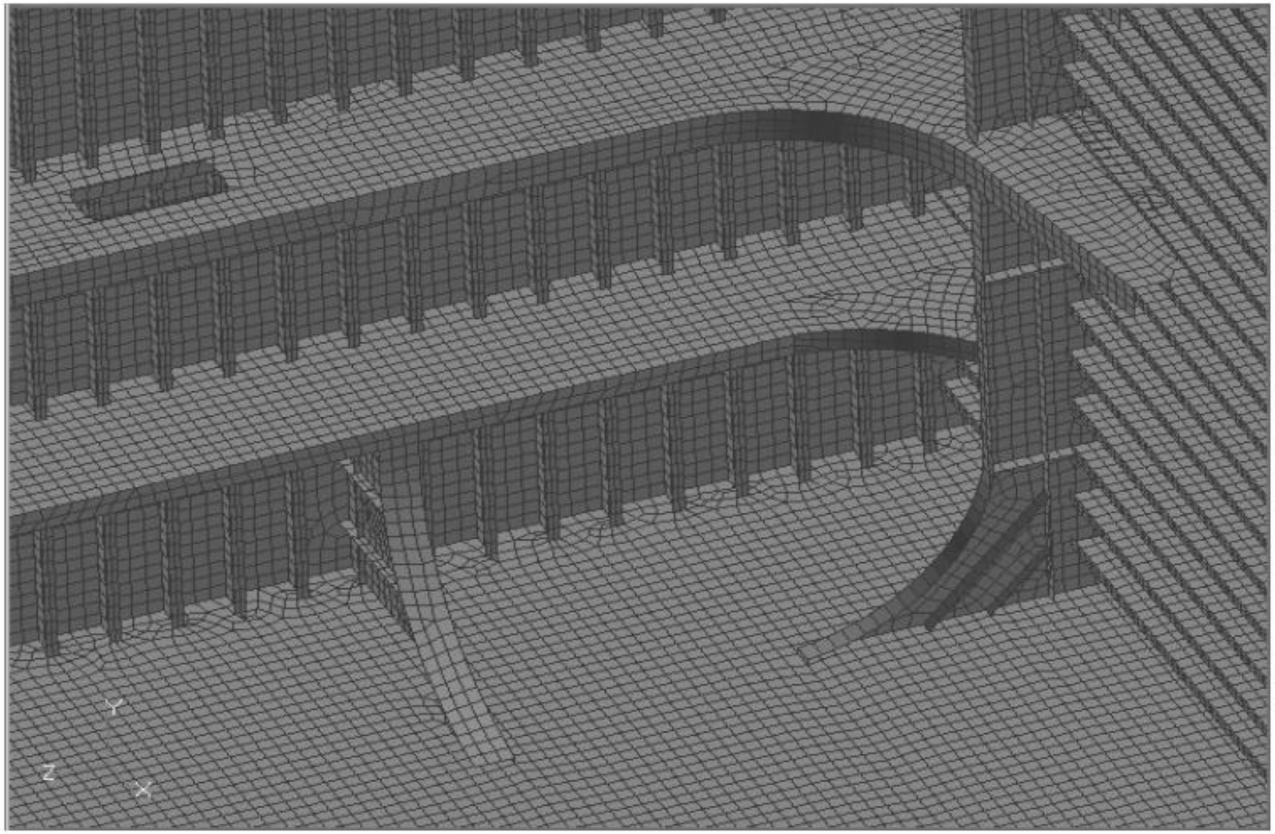
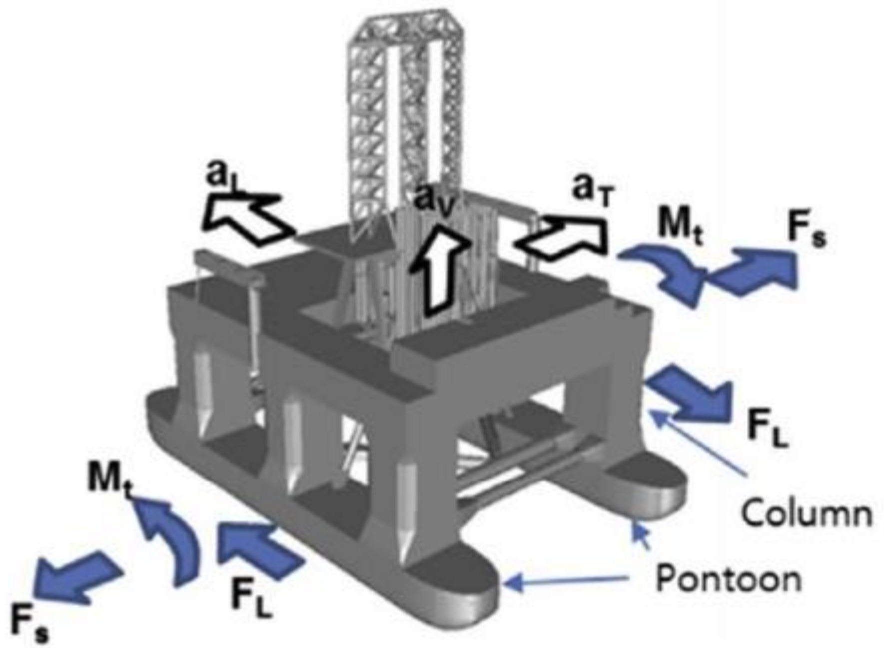


A Local Zoom Model with Stiffeners Modeled as Plate Members generated by Auto-Mesher



F_L : Longitudinal shear force between the pontoons
F_S : Split force between the pontoons
M_T : Torsional moment about a transverse horizontal axis
a_L : Longitudinal acceleration of deck mass
a_T : Transverse acceleration of deck mass
a_V : Vertical acceleration of deck mass

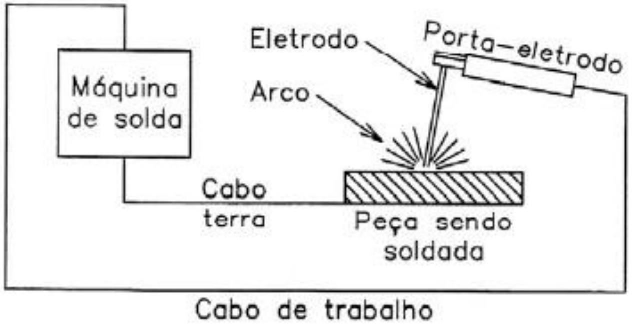
SOLDAGEM

- Processo de junção de **2** peças pela criação de uma forte **ligação** metalúrgica entre as mesmas seja por calor, pressão ou calor+pressão.
- O material fundido deve ser **isolado** do ambiente para evitar a deposição de impurezas na solda

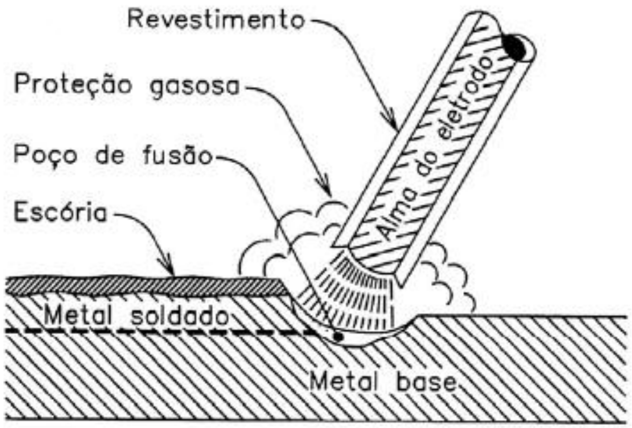
Processo de Soldagem

Arco Elétrico com Eletrodo revestido:

SMAW - Shielded Metal Arc Welding



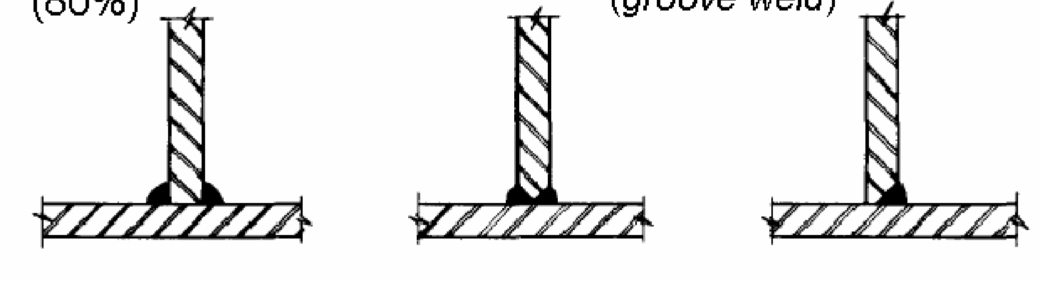
O revestimento é consumido junto com o eletrodo, transformando-se parte em gases inertes, parte em escória.

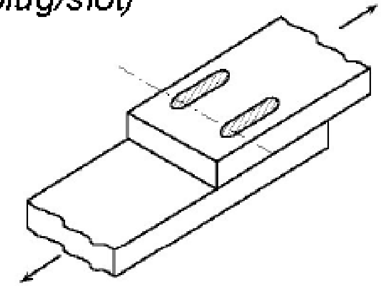


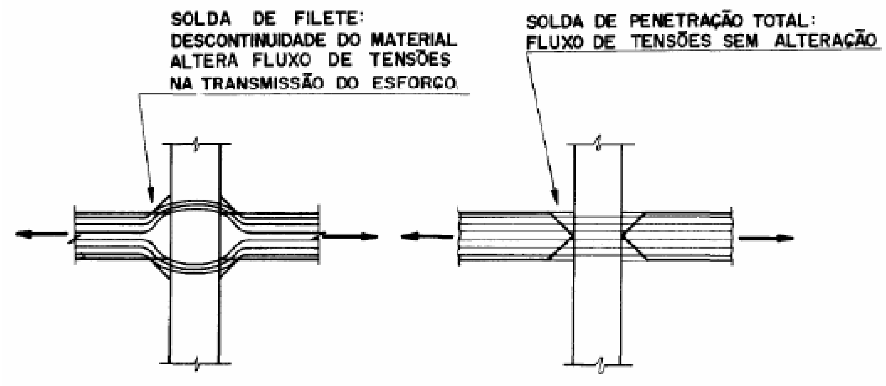
Ref: "Curso Básico de Estruturas de Aço", Péricles Barreto de Andrade, Ed. IEA, 1994.

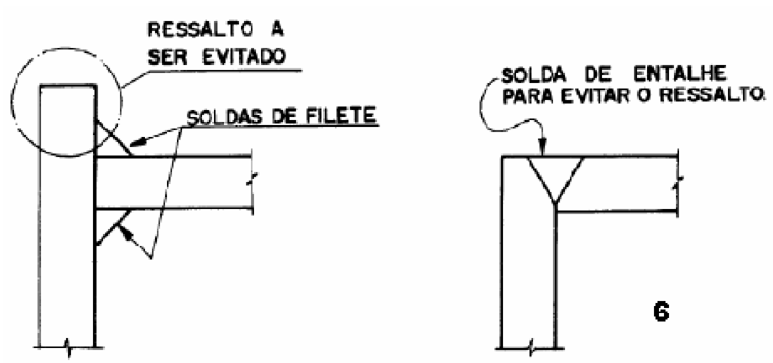
Classificação

Solda de FILETE (*fillet*) (80%) — Solda de ENTALHE (*groove weld*) — Solda de TAMPÃO (*plug/slot*)









Ref: "Ligações em Estruturas Metálicas", Instituto Brasileiro de Siderurgia, IBS/CBCA, 2004.

Material de Solda

Compatibilidade do metal-base com o metal da solda:

	Metal base		Metal da solda compatível			
	ABNT	ASTM	Arco elétrico com eletrodo revestido (SMAW)	Arco submerso (SAW)	Arco elétrico com proteção gasosa (GMAW)	Arco elétrico com fluxo no núcleo (FCAW)
Grupo I	NBR 6648 (CG-24 - $t \leq 20$ mm) NBR 6648 (CG-26 - $t \leq 20$ mm) NBR 6649 (CF-24) NBR 6649 (CF-26) NBR 6650 (CF-24) NBR 6650 (CF-26) NBR 7007 (MR 250 - $t \leq 20$ mm)	A36 ($t \leq 20$ mm) A500 Grau A A500 Grau B A570 Grau 40 A570 Grau 45	AWS A5.1 - E60XX, E70XX AWS A5.5 [5)]- E70XX-X	AWS A5.17 - F6XX-EXXX, F6XX-ECXXX, F7XX-EXXX, F7XX-ECXXX AWS A5.23 [5)] - F7XX-EXXX-XX, F7XX-ECXXX-XX	AWS A5.18 - ER70S-X, E70C-XC, E70C-XM (exceto -GS) AWS A5.28 [5)] - ER70S-XXX, E70C-XXX	AWS A5.20 - E6XT-X, E6XT-XM, E7XT-X, E7XT-XM (exceto -2, -2M, -3, -10, -13, -14 e -GS e exceto -11 com espessura superior a 12 mm) AWS A5.29 [5)] - E6XTX-X, E6XT-XM, E7XTX-X, E7XTX-XM

Tabela 7 – NBR 8800 AWS D1.1

Material de Solda

Compatibilidade do metal-base com o metal da solda:

	Metal base		Metal da solda compatível			
	ABNT	ASTM	Arco elétrico com eletrodo revestido (SMAW)	Arco submerso (SAW)	Arco elétrico com proteção gasosa (GMAW)	Arco elétrico com fluxo no núcleo (FCAW)
Grupo II	NBR 5000 (G-30) NBR 5000 (G-35) NBR 5004 (F32/Q32) NBR 5004 (F35/Q35) NBR 5008 (Classes 1, 2 e 2A - $t \leq 100$ mm) [4)] NBR 5920 [4)] NBR 5921 [4)] NBR 7007 (AR-290) NBR 7007 (AR-345) NBR 7007 (AR-COR 345 A ou B) [4)] NBR 8261 (Graus B e C)	A36 ($t > 20$ mm) A570 Grau 50 A570 Grau 55 A572 Grau 42 A572 Grau 50 A572 Grau 55 A588 ($t \leq 100$ mm) [4)] A913 Grau 50 A992	AWS A5.1 - E7015, E7016, E7018, E7028 AWS A5.5 [5)] - E7015-X, E7016-X, E7018-X	AWS A5.17 - F7XX-EXXX, F7XX-ECXXX AWS A5.23 [5)] - F7XX-EXXX-XX, F7XX-ECXXX-XX	AWS A5.18 - ER70S-X, E70C-XC, E70C-XM (exceto -GS) AWS A5.28 [5)] - ER70S-XXX, E70C-XXX	AWS A5.20 - E7XT-X, E7XT-XM (exceto -2, -2M, -3, -10, -13, -14 e -GS e exceto -11 com espessura superior a 12 mm) AWS A5.29 [5)] - E7XTX-X, E7XTX-XM

Tabela 7 – NBR 8800 AWS D1.1

Material de Solda

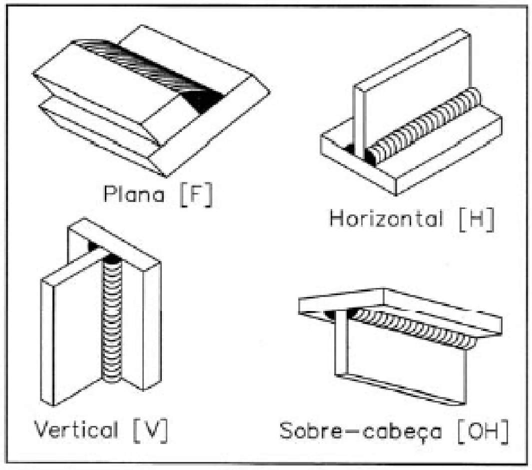
Os materiais utilizados na solda têm resistência à ruptura superior à dos aços para os quais são especificados.

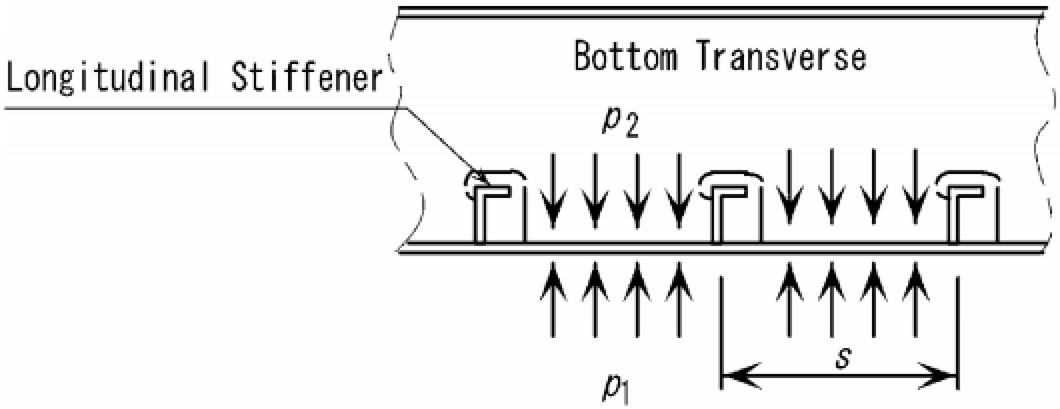
$$E60 \Rightarrow f_w = 60 \text{ ksi} = 415 \text{ MPa}$$
$$E70 \Rightarrow f_w = 70 \text{ ksi} = 485 \text{ MPa}$$

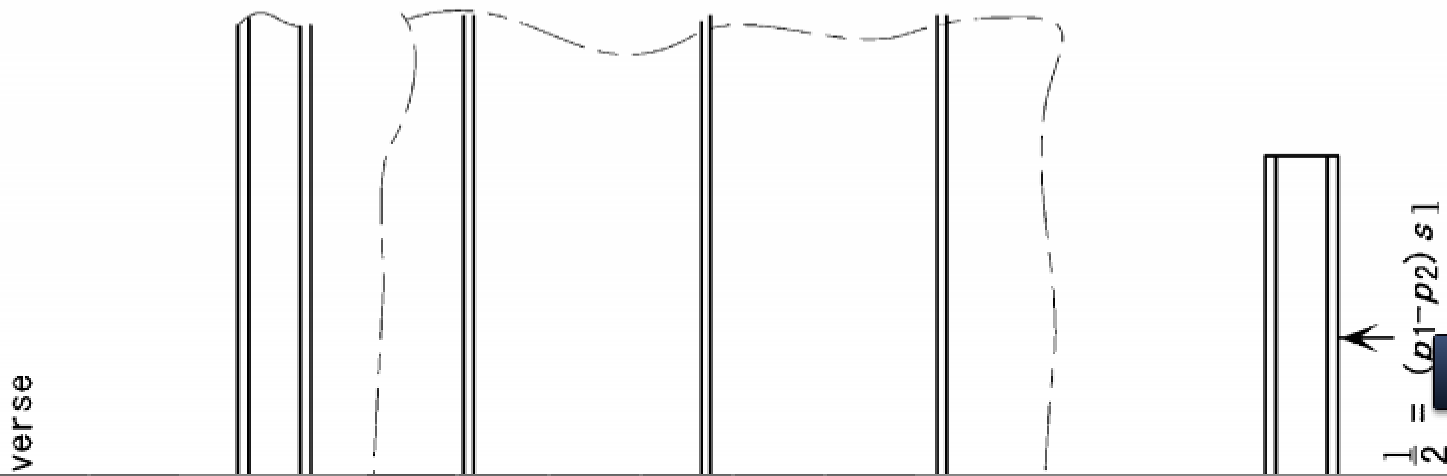
Em solda por arco com eletrodo revestido:

E 70 X Y

- Y → tipo de corrente e de revestimento
- X → posição de soldagem: 1 - qualquer; 2 - pos horiz
- 70 → f_w em ksi
- E → Eletrodo




Longitudinal Stiffener
Bottom Transverse
p2
p1
s


verse
1/2 = (p1−p2) s

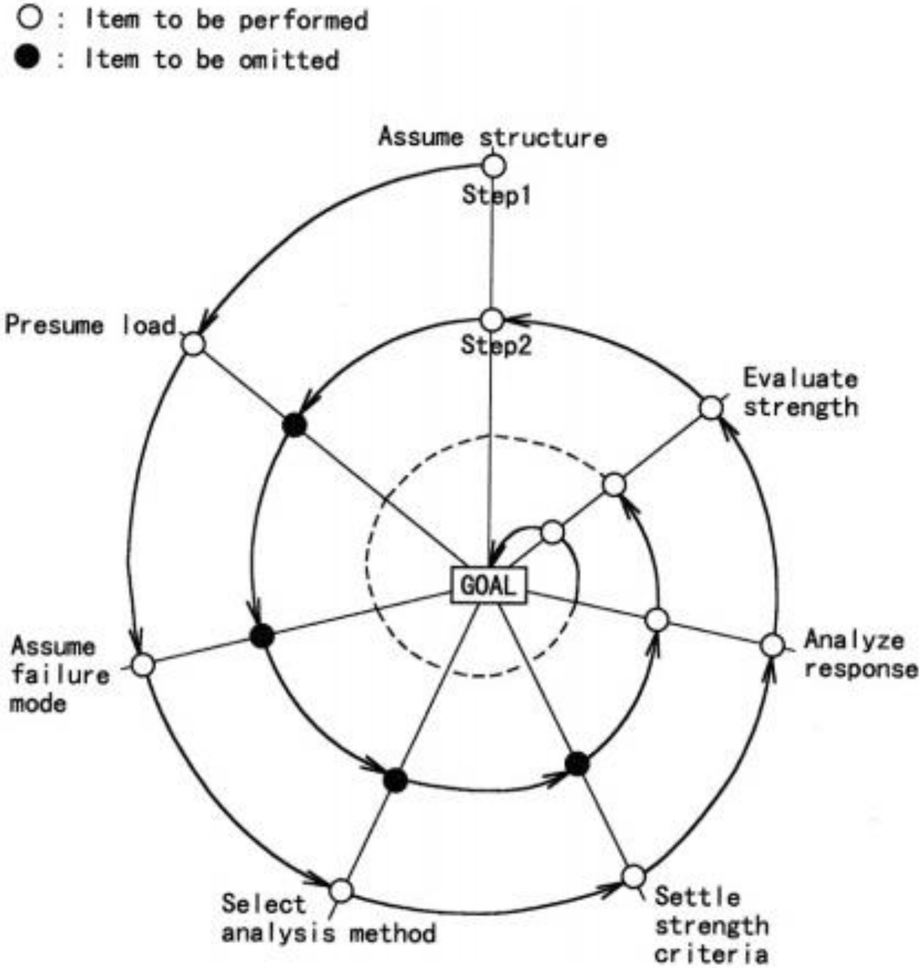
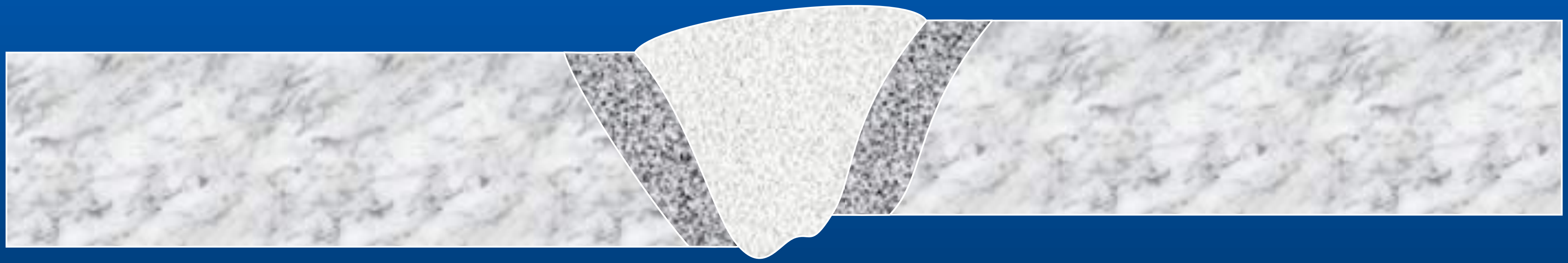


Fig. 3.1.2 Procedure of FEM structure analysis

Defeitos em Juntas Soldadas (I)

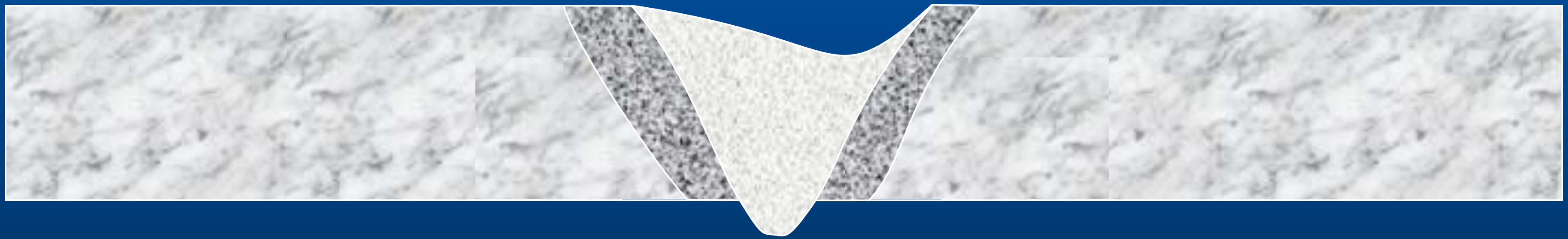
Defeitos em Juntas Soldadas (II)

Desalinhamento



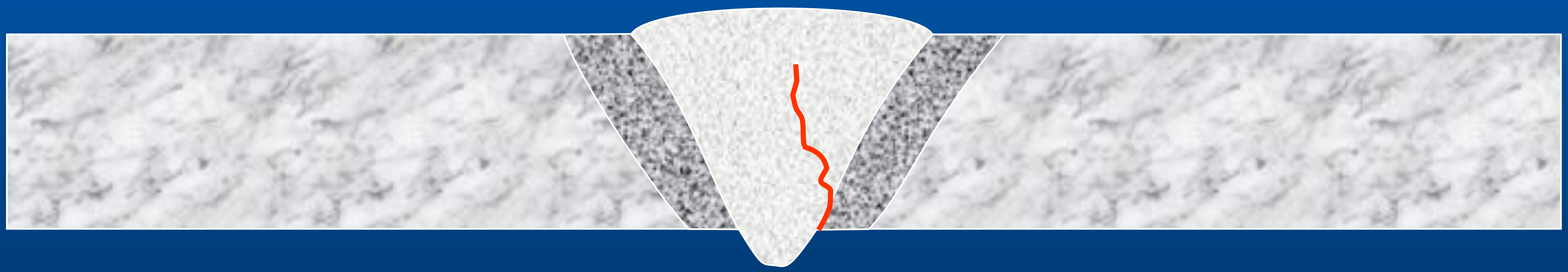
Defeitos em Juntas Soldadas (III)

Deposição Incompleta



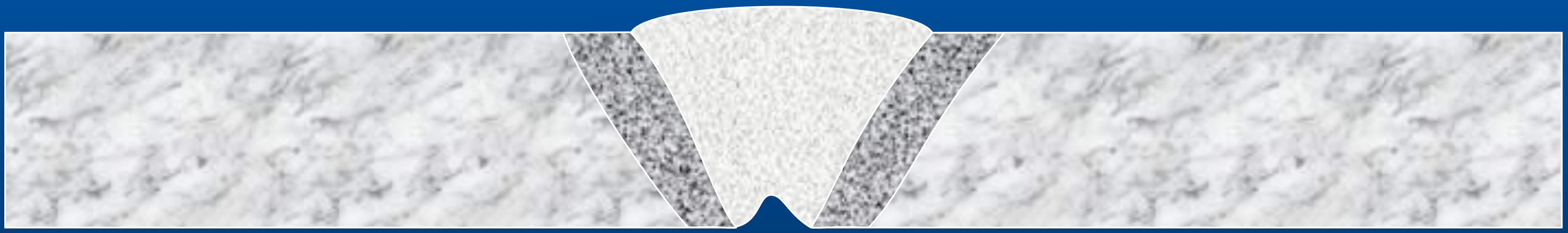
Defeitos em Juntas Soldadas (IV)

Trinca de Raiz



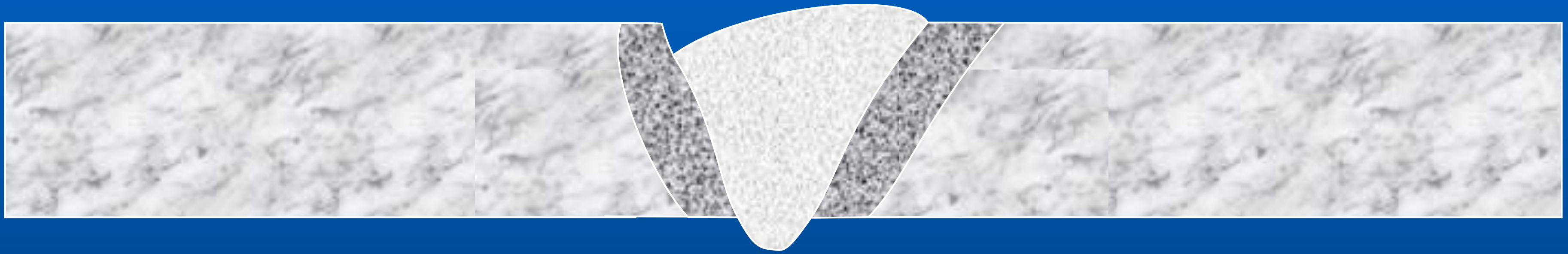
Defeitos em Juntas Soldadas (V)

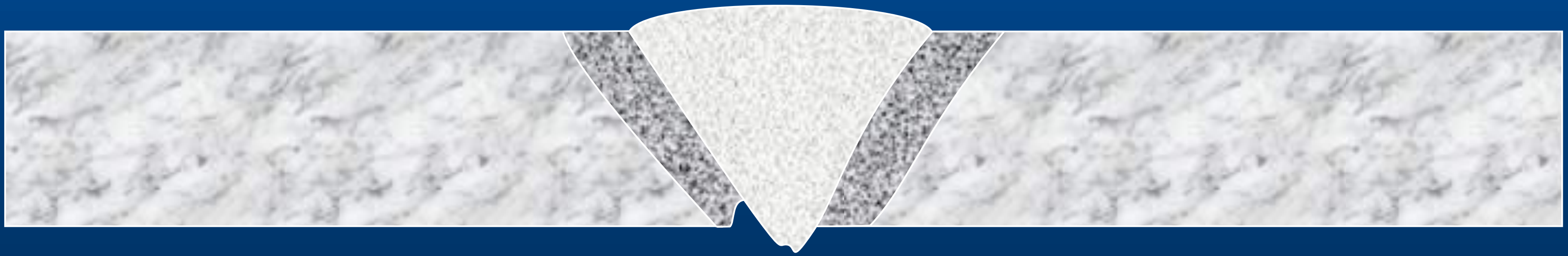
Concavidade na Raiz



Defeitos em Juntas Soldadas (VI)

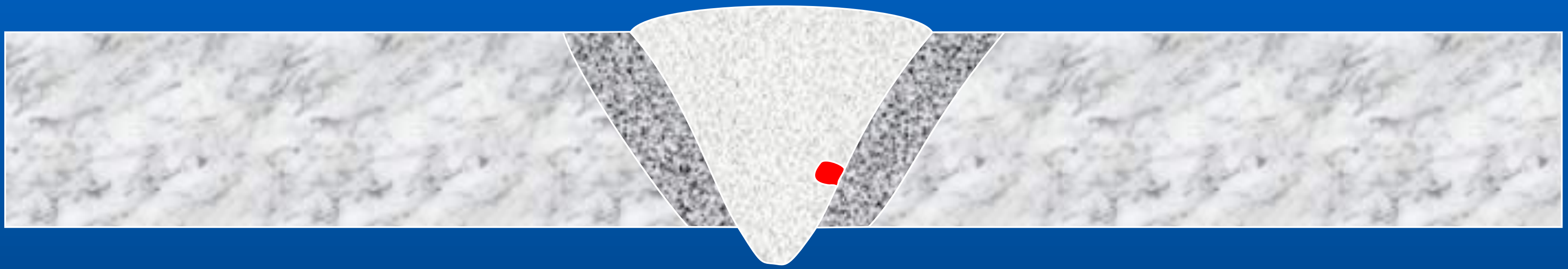
"Mordeduras"

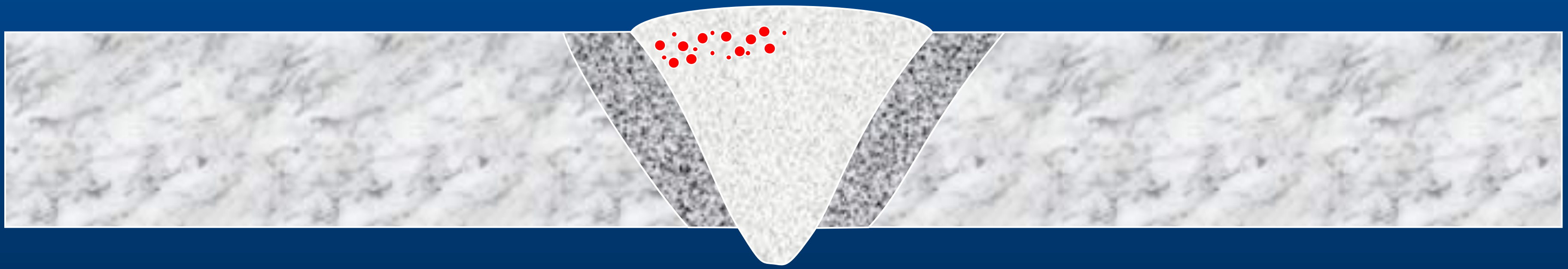




Defeitos em Juntas Soldadas (VII)

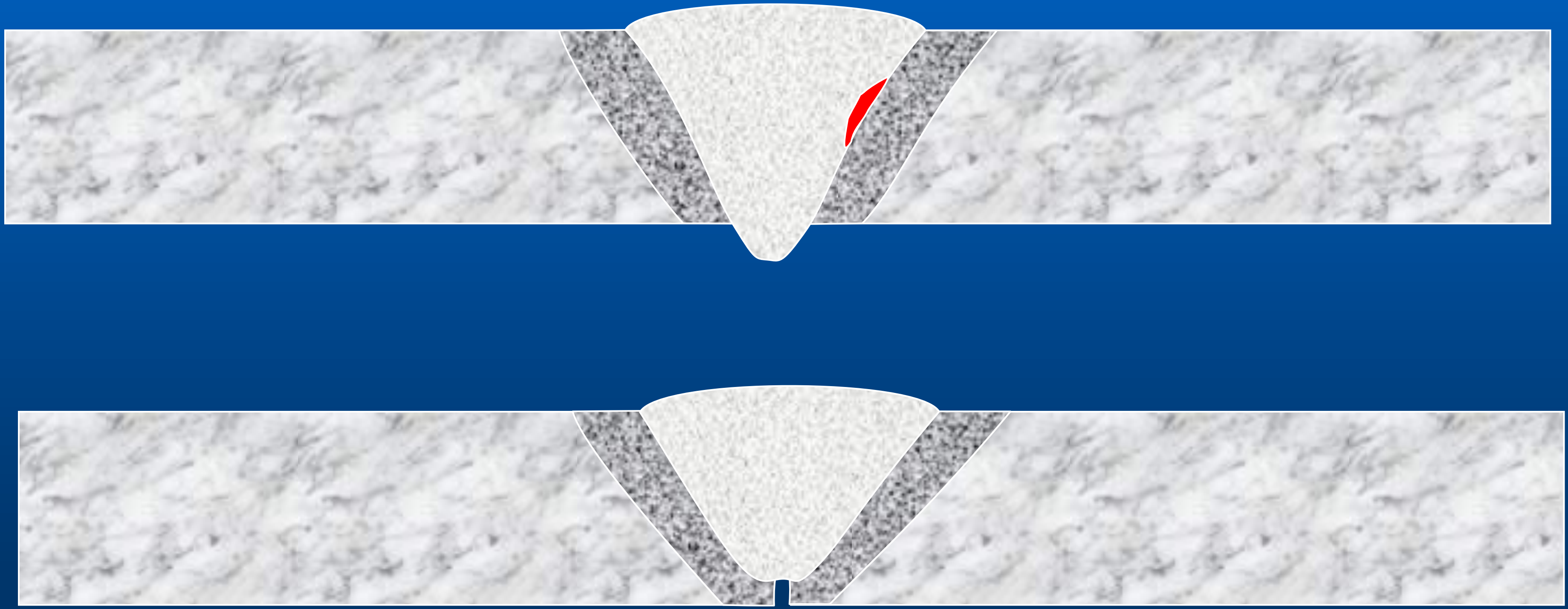
Porosidades





Defeitos em Juntas Soldadas (VIII)

Falta de Penetração



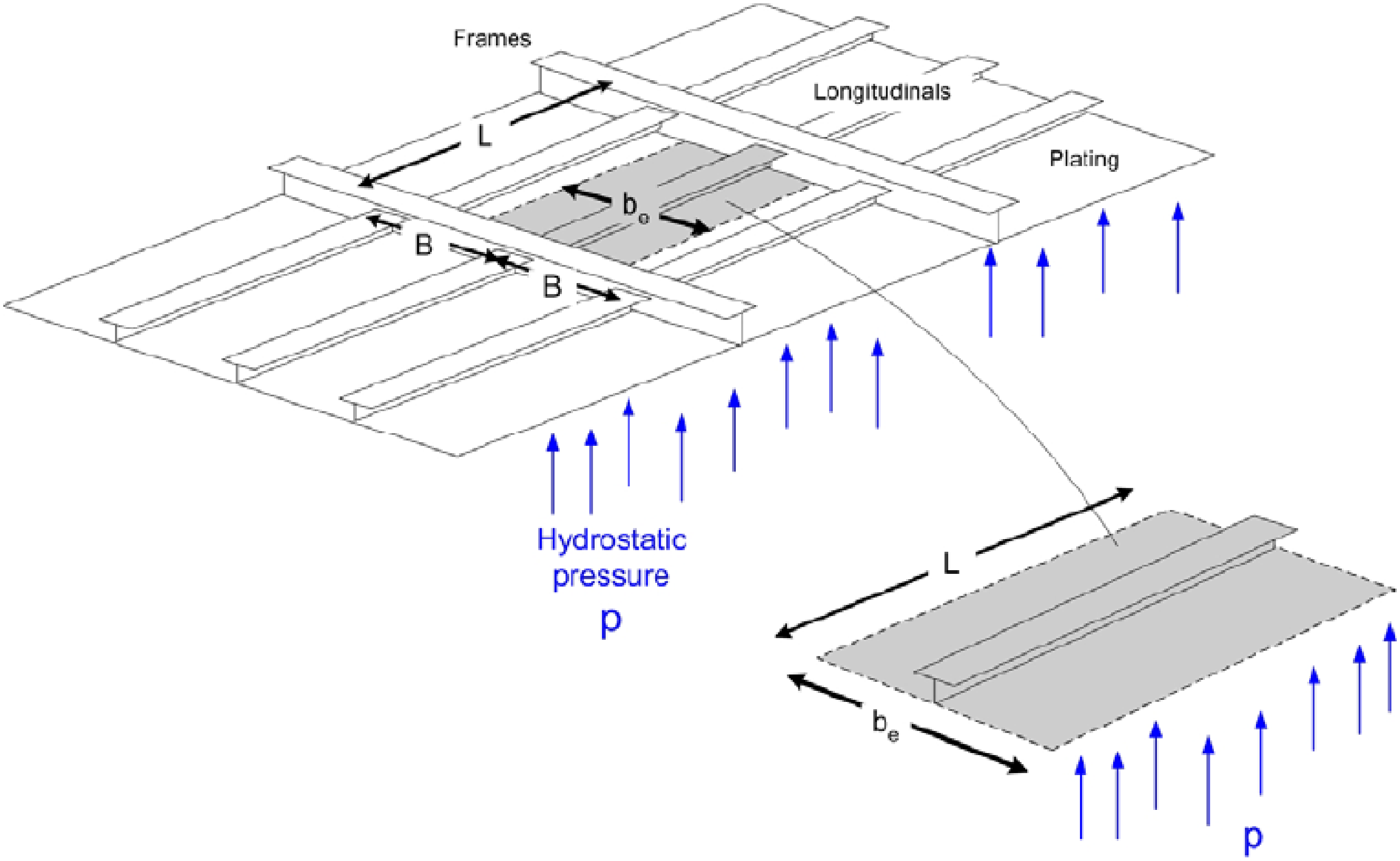
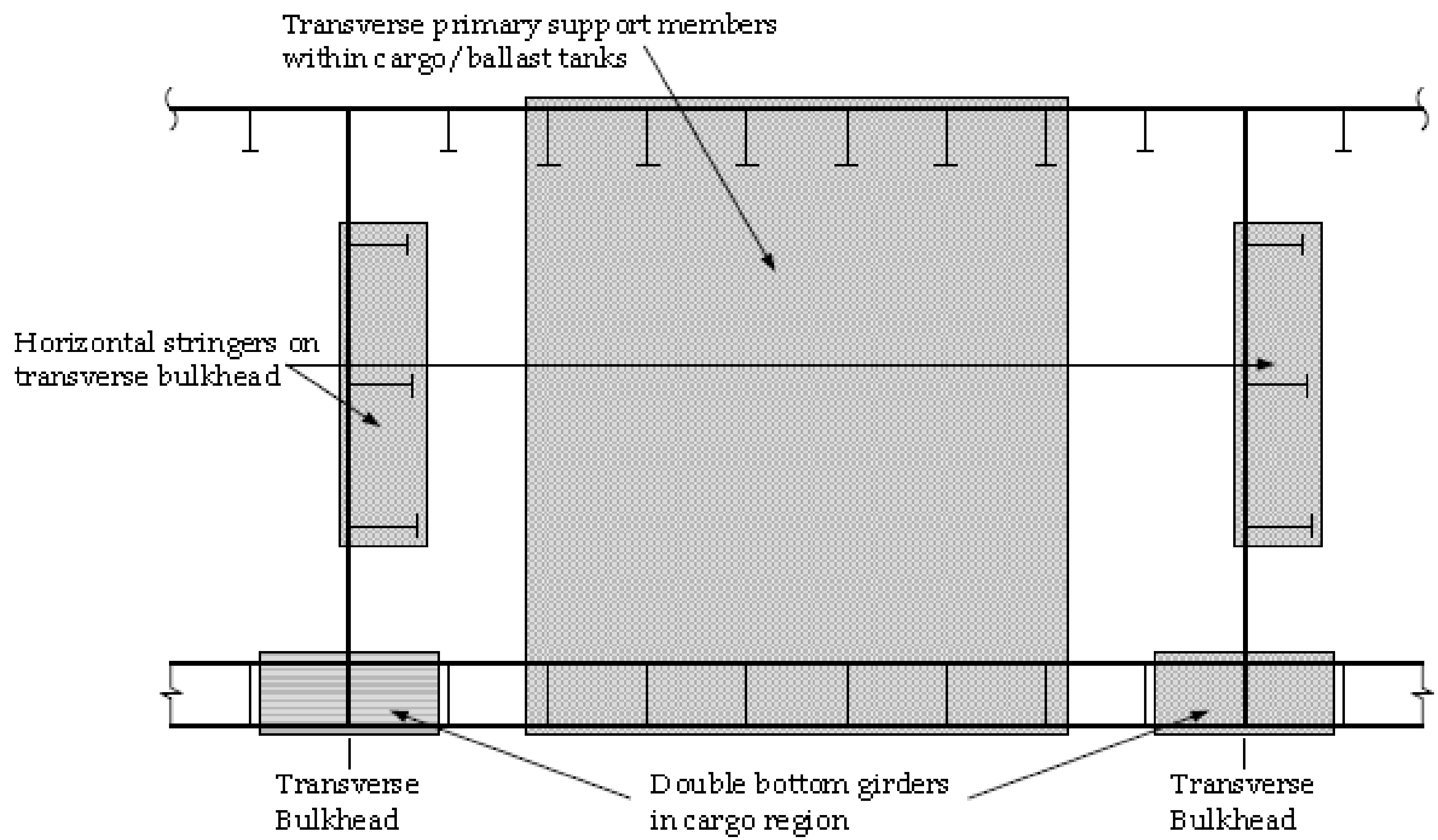

Frames
Longitudinals
Plating
L
b_e
B
B
Hydrostatic
pressure
p
L
b_e
p

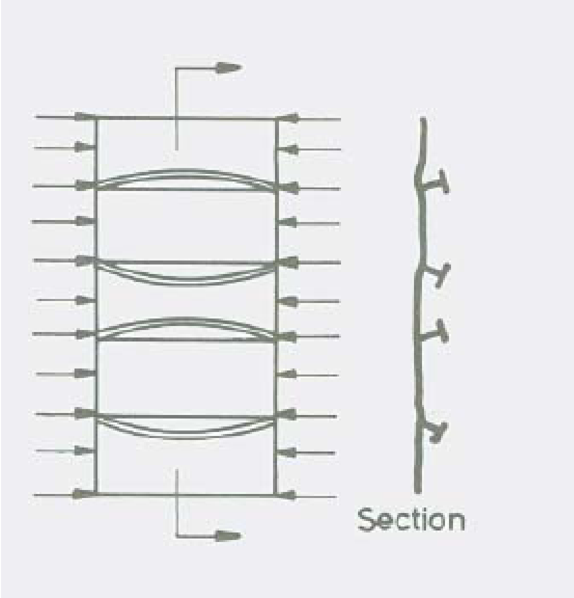
Figure 8.2.4
Depiction of Applicable Extents



Flambagem de Reforços

Torsional Buckling of Stiffeners – Tripping

A stiffener may buckle by twisting (or *rotating*) about its line of attachment to the plating. This is referred to as tripping. This is not the same as the column or beam-column type of buckling we have discussed previously for stiffeners, and it is not the same as local compressive buckling of the web or buckling of the flange. Tripping of several stiffeners in a uniaxially-loaded panel is illustrated in the below figure. Note that the plate may also rotate to some extent to accommodate the stiffener rotation – this is not plate buckling, but rather part of the stiffener tripping phenomenon. Tripping could be elastic or plastic, but usually plastic and catastrophic.



$$\sigma_{cr-tripping} = \frac{1}{I_{sp}}\left[\pi^2 E\left(\frac{h}{a}\right)^2 I_{sz}\right]$$

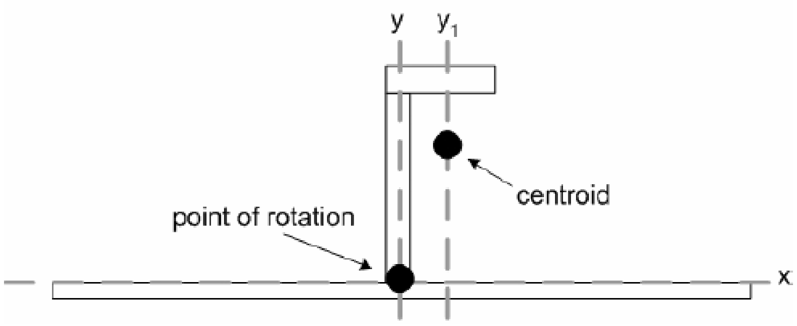
Tripping

A slightly simplified solution for stiffener tripping is presented in Hughes. The result is that for stiffener tripping due to a uni-axial compression:

$$\sigma_{cr-tripping} = \frac{1}{I_{sp}}\left[\pi^2 E\left(\frac{h}{a}\right)^2 I_{sz}\right]$$

where

h = distance (height) from plate to *shear center* of stiffener
A_x = stiffener area (flange + web)
I_{sp} = *polar* moment of inertia of stiffener about *center of rotation* ($I_x + I_y$)
I_{sz} = moment of inertia of stiffener about axis t*hrough centroid of stiffener and parallel to web* (I_{y1})



Painel Reforçado

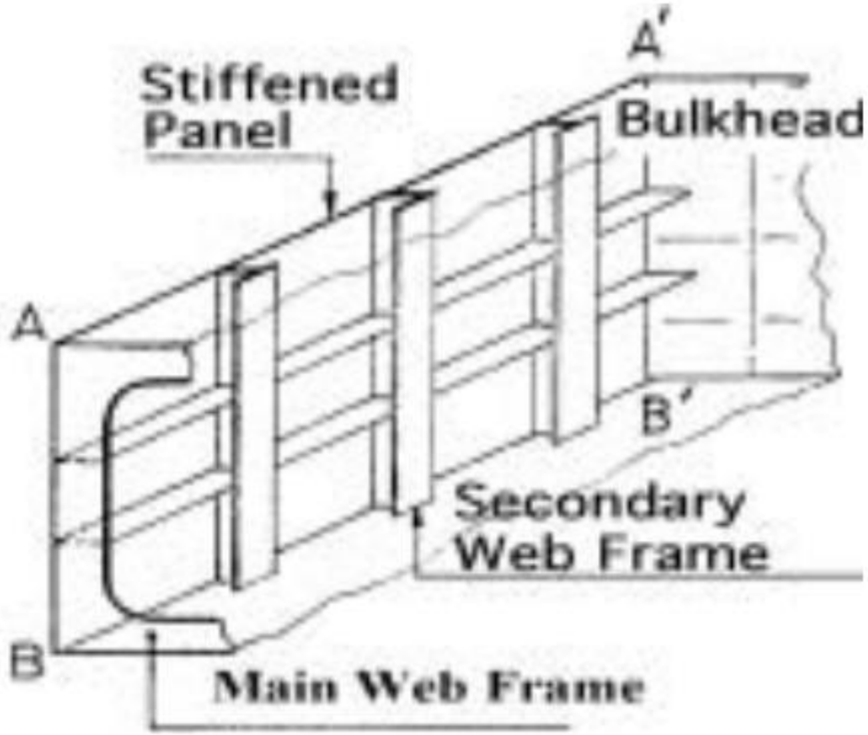


Figure 18.22 A Standard Stiffened Panel

Painel Reforçado

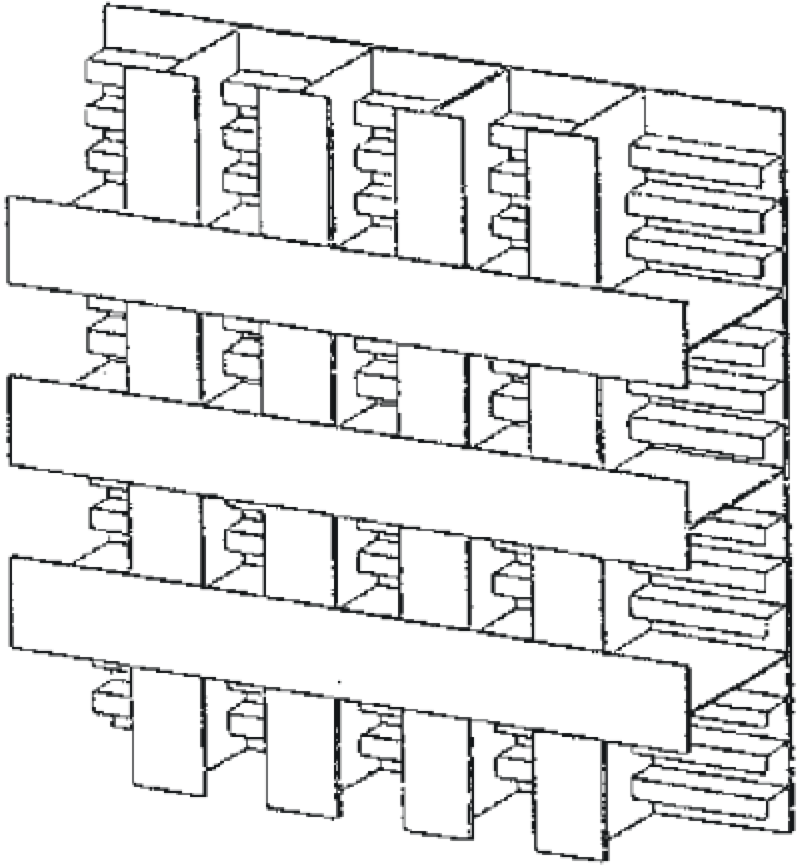
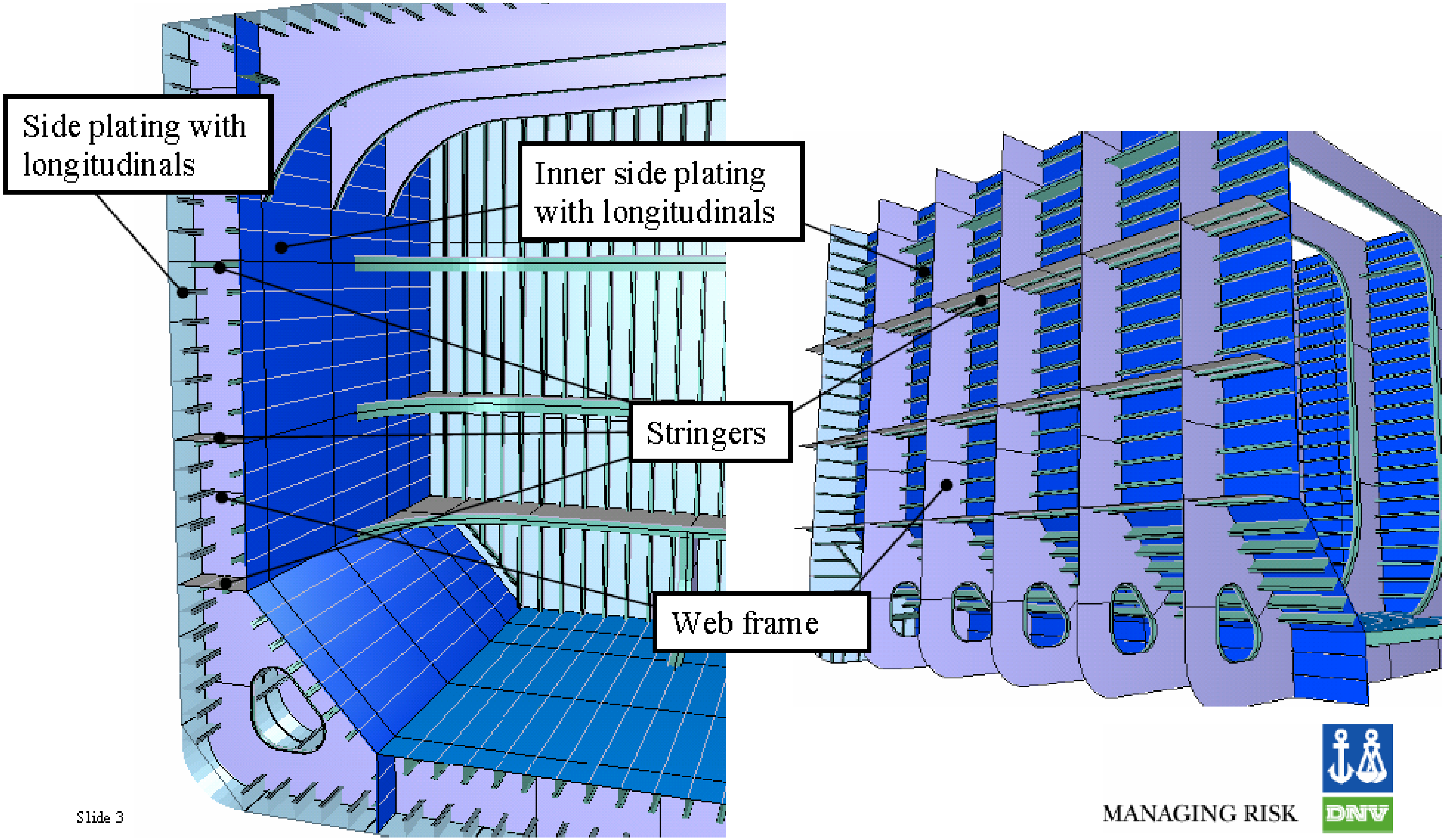
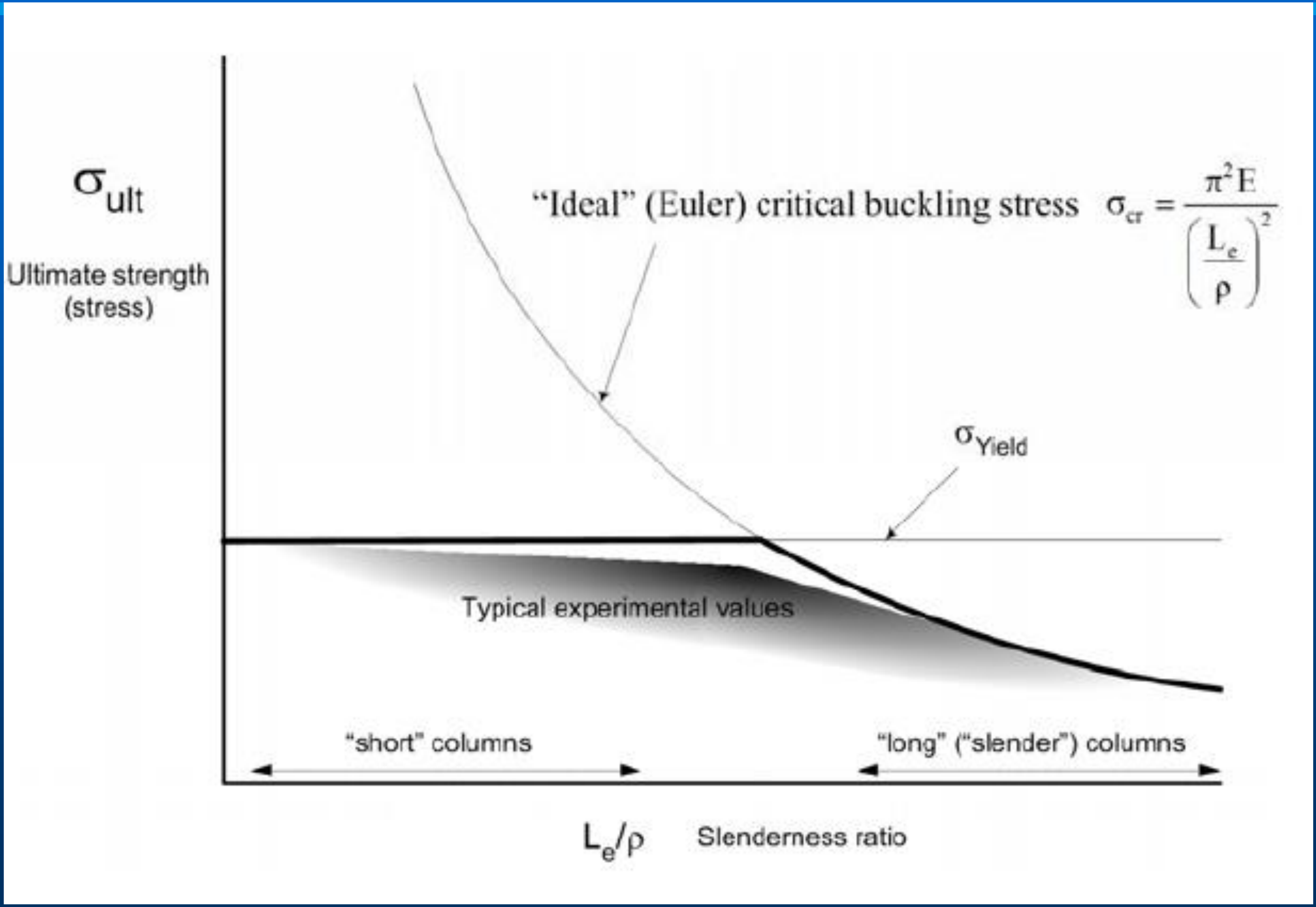


Figure 18.36 A Stiffened Panel with Uniformly Distributed Longitudinals, 4 Webframes, and 3 Girders.


Side plating with longitudinals
Inner side plating with longitudinals
Stringers
Web frame

Flambagem

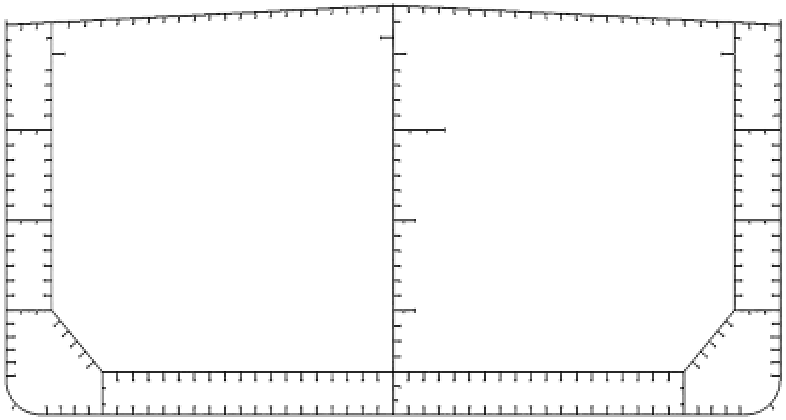


σ_{ult}
Ultimate strength (stress)
"Ideal" (Euler) critical buckling stress $\sigma_{cr} = \frac{\pi^2 E}{\left(\frac{L_e}{\rho}\right)^2}$
σ_{Yield}
Typical experimental values
"short" columns
"long" ("slender") columns
L_e/ρ Slenderness ratio

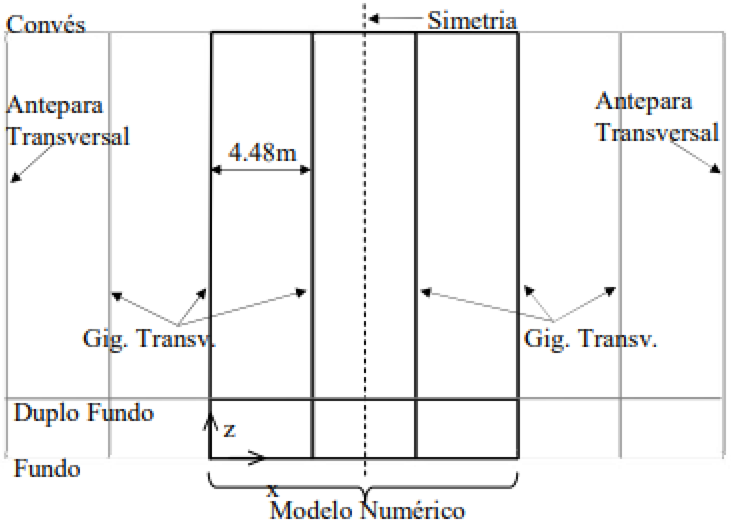
Comportamento estrutural de navio sob flexão

- Modelo numérico de uma navio tanque suezmax – Compartimento entre gigantes transversais a meia-nau
  - Características principais do navio:
    - Comprimento Total (Loa) = 254 m
    - Comprimento entre perpendiculares (Lpp) = 244 m
    - Boca (B) = 42 m
    - Pontal (T) = 15 m
    - Deslocamento = 126.000 ton
  - A região analisada foi um espaçamento entre gigantes transversais de um porão típico a meia-nau de dimensões:
    - Comprimento do porão: 31,36 m
    - Espaçamento entre gigantes transversais: 4,48 m
    - Altura do duplo fundo: 2,3 m
    - Largura do dulho costado: 2,5 m

- Elementos longitudinais da seção estudada

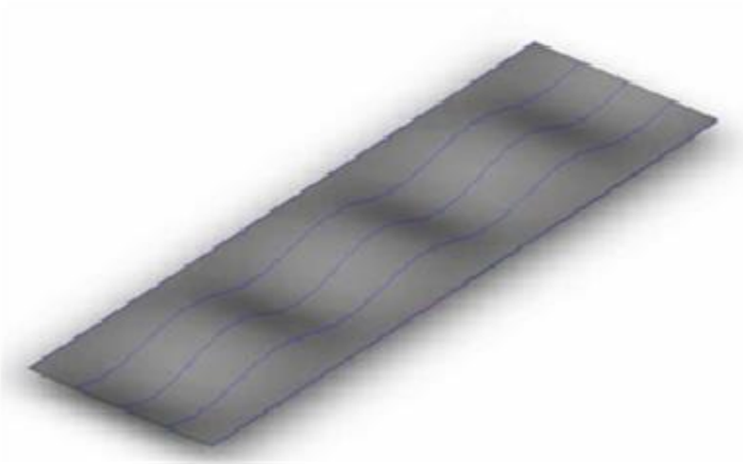


- Posição da região analisada no navio

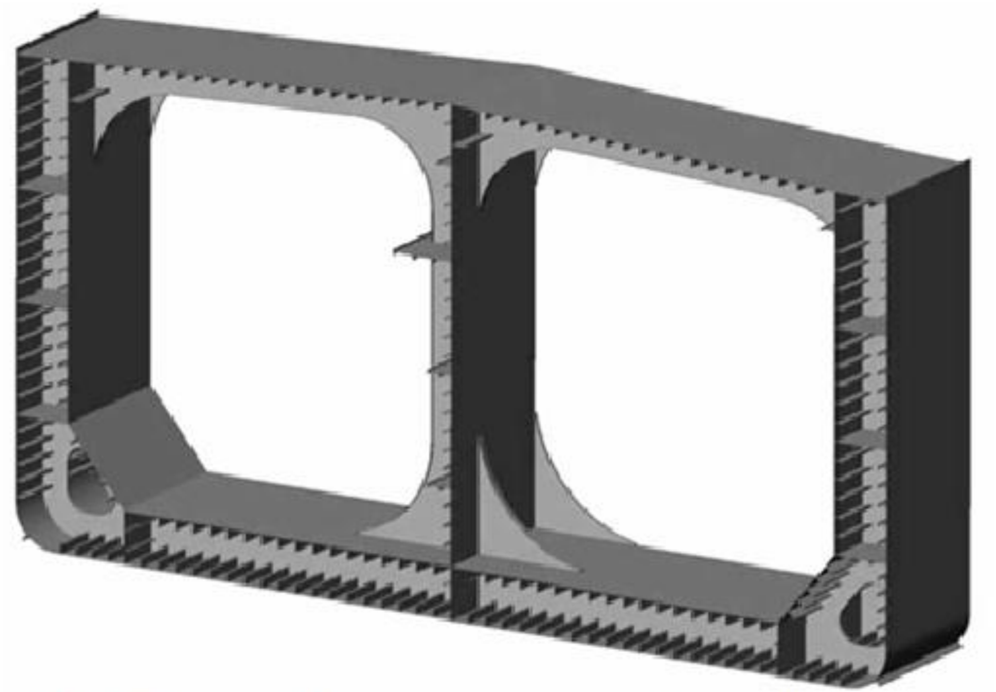


- Imperfeição geométrica inicial representada pela expressão:

$$w(x,y) = w_{\max} \cdot \sin\left(\frac{m \cdot x \cdot \pi}{a}\right) \cdot \sin\left(\frac{n \cdot y \cdot \pi}{b}\right)$$



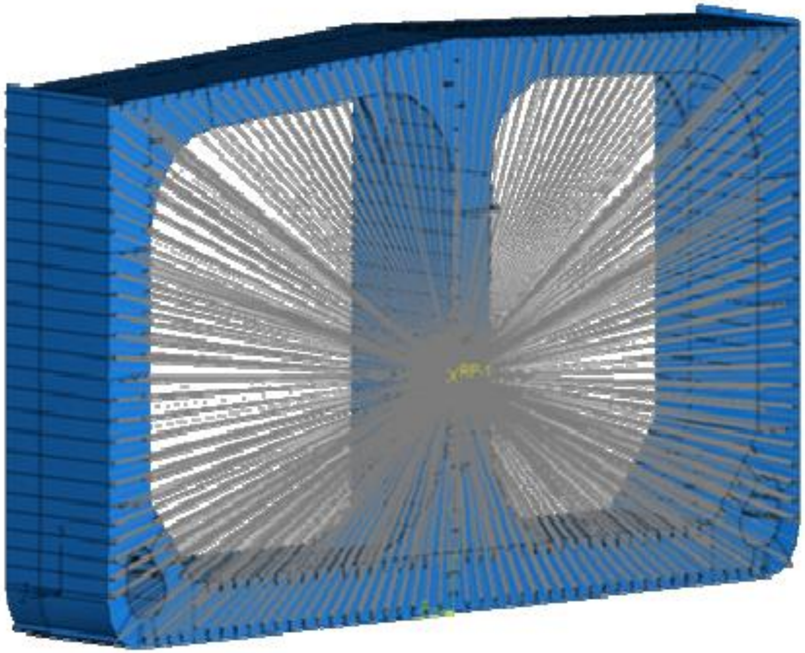
Painel construído em CAD



Modelo geométrico com simetria longitudinal

Comportamento estrutural de navio sob flexão

- Condição de carregamento
  - A condição de carregamento de tosamento e alquebramento são efetuadas através de rotações incrementais controladas aplicadas em todos os nós da extremidade do modelo;
  - Rotações incrementais são aplicadas em um ponto de referência e transmitida a toda extremidade de carga;
  - O ponto de referência foi posicionado no eixo neutro inicial. A extremidade de carga permanece plana e normal a linha neutra durante o carregamento.



Comportamento estrutural de navio sob flexão

- Condições de contorno
  - Ponto de referência
    - $U_y = U_z = 0$
    - $\theta_x = 0$
  - Simetria longitudinal

- Propriedades do aço
  - $\sigma_0 = 235$ N/mm²
  - $E = 210{,}000$ N/mm²;
  - $v = 0.3$

3.4 Boundary conditions

3.4.1 Centerline plane

3.4.1.1 For symmetrical structural configuration and load cases (e.g. conditions 1, 2, 3 and 6), half breadth FE model (e.g. port) may be taken, with following symmetrical restraint conditions applied to all nodes on longitudinal centerline plane (in Figure 3.4.1):

Restraint of displacement along transverse axis, i.e. $\delta_y = 0$;

Restraint of rotation around longitudinal axis, i.e. $\theta_x = 0$;

Restraint of rotation around vertical axis, i.e. $\theta_z = 0$.

3.4.2.2 All nodes within the fore and aft end planes of the model (see figure 3.4.1) are restrained as follows:

Plane A: Restraint of displacement along ship's longitudinal axis, i.e. $\delta_x = 0$;

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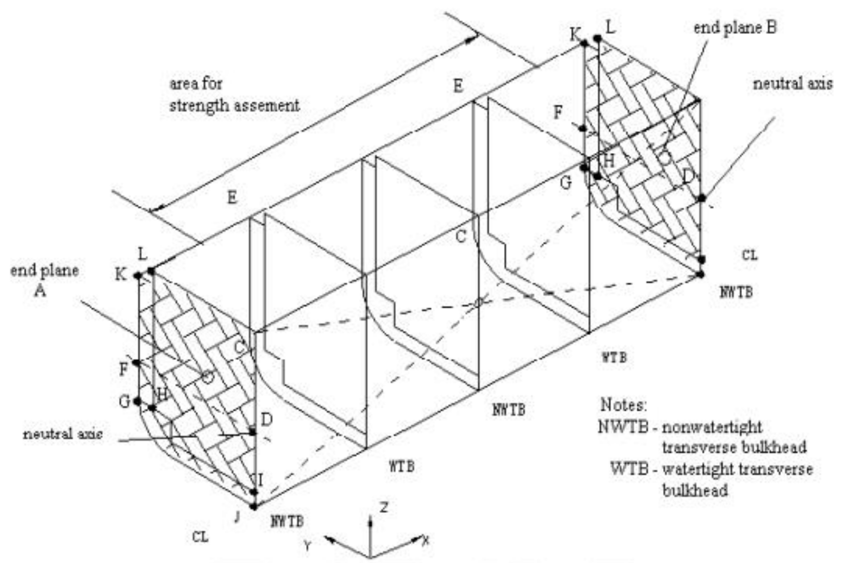


Figure 3.4.1 Symbols for Boundary Conditions for Calculation Conditions

Restraint of rotation around ship's transverse axis, i.e. $\theta_y = 0$;

Restraint of rotation around ship's vertical axis. i.e. $\theta_z = 0$.

Plane B: Restraint of rotation around ship's transverse axis, i.e. $\theta_y = 0$;

Restraint of rotation around ship's vertical axis. i.e. $\theta_z = 0$.

Comportamento estrutural de navio sob flexão

- Análises
  - Magnitude das imperfeições baseada na máxima amplitude recomendada pela DNV;

$$w_{\max} = 0.005\,b$$

  - Para estes modelos ambos reforçadores e reforços transversais foram assumidos como geometria sem imperfeições

3.3.3 The overall longitudinal bending moment of hull girder consists of still water bending moment and wave bending moment. The still water bending moment is taken as the maximum permissible hogging moment within 0.4 L amidships under all loading conditions as indicated in loading manual, and the wave bending moment (hogging) is calculated according to Chapter 2, PART TWO of the Rules.

3.3.4 The load components to be included are as follows:

- the light weight;
- the container loads;
- the hydrostatic pressure due to draft;
- the additional pressure due to local wave crest, as stated in paragraph 3.3.5;
- the longitudinal loads acting on containers due to longitudinal acceleration of ship, to be calculated according to paragraph 3.3.7.

3.3.5 The additional wave pressure acting on side and bottom is shown in Figure 3.3.5:

at waterline:	$P_W = k_W \times 3\, C_W$	kN/m²
at baseline:	$P_B = k_B \times 1.5\, C_W$	kN/m²
at side top:	$P_S = 0$	kN/m²

$k_W = 1.1$

$K_B = 1.5$

linear interpolation between P_W and P_B

C_W — wave coefficient:

$C_W = 10.75 - ((300 - L) / 100)^{1.5}$	$90\text{ m} \leqslant L \leqslant 300\text{ m}$
$C_W = 10.75$	$300\text{ m} < L \leqslant 350\text{ m}$
$C_W = 10.75 - ((L - 350) / 150)^{1.5}$	$350\text{ m} < L \leqslant 500\text{ m}$

$P_W = 3.3\, C_W$
$P_B = 2.25\, C_W$
d_s — draft of structure
linear interpolation between P_W and P_B

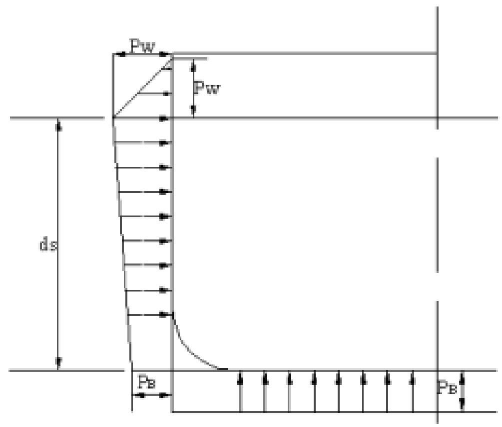
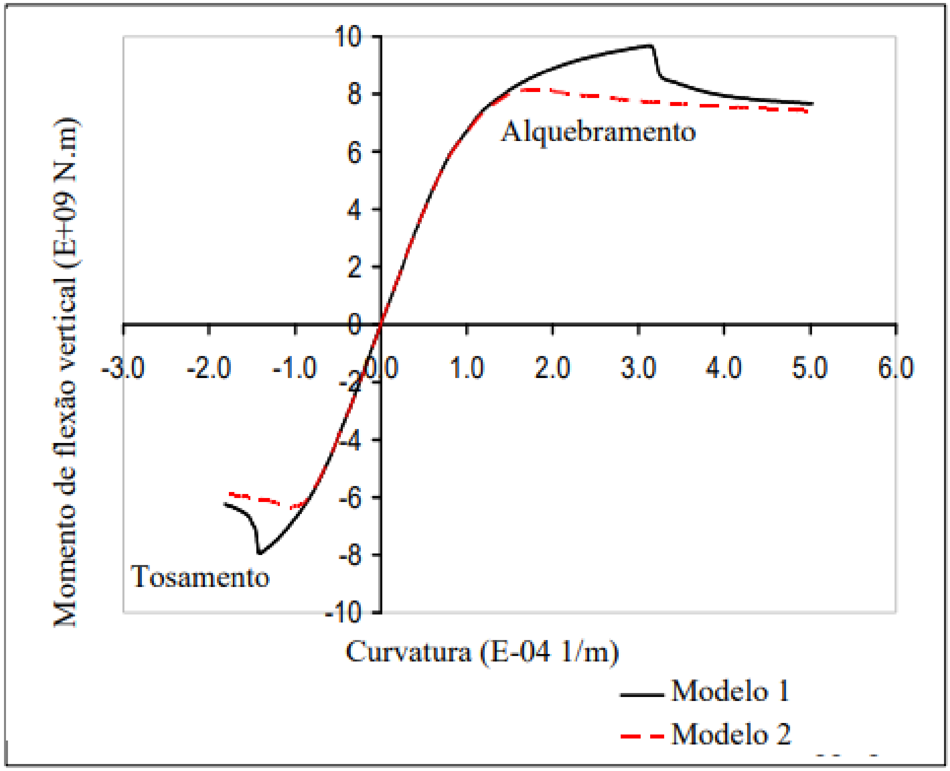


Figure 3.3.5 Distribution of Wave Crest at Side and Bottom of Container Ship

Comportamento estrutural de navio sob flexão

- Resistência última a flexão
  - Relação momento-curvatura obtida para os modelos 1 (m=1) e 2 (m=4 - modo natural de falha) para as contições de tosamento e alquebramento



- Alquebramento – Momento último

  Modelo 1: 9.67 E+09 N.m

  Modelo 2: 8.15 E+09 N.m

  Diferença do 1 para o 2: 15.72%

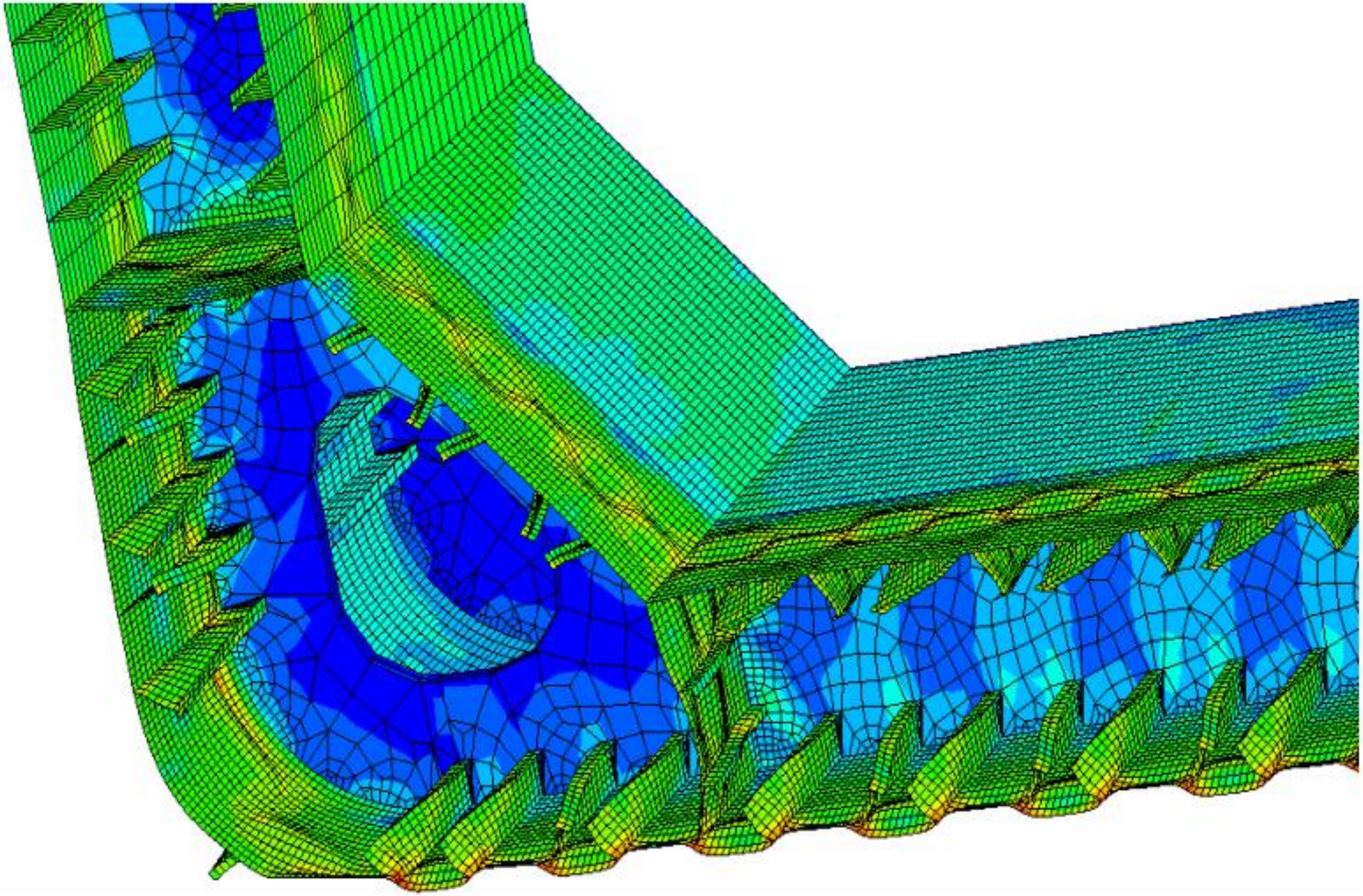
- **Tosamento – Momento último**

  Modelo 1: 7.92 E+09 N.m

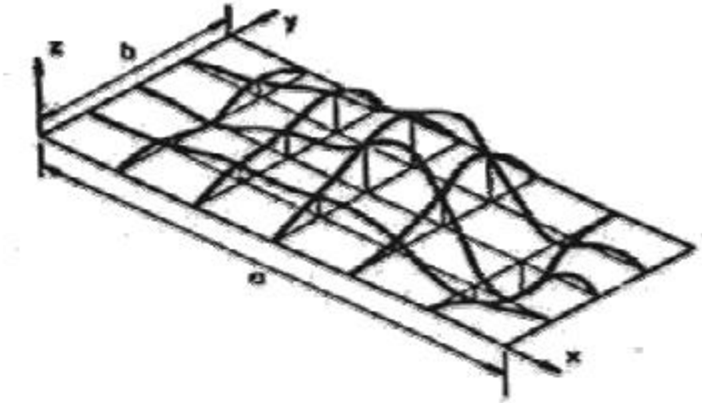
  Modelo 2: 6.34 E+09 N.m

  Diferênça do 1 para o 2: 19.95%

❑ Pós-colapso para o Modelo 1 em alquebramento



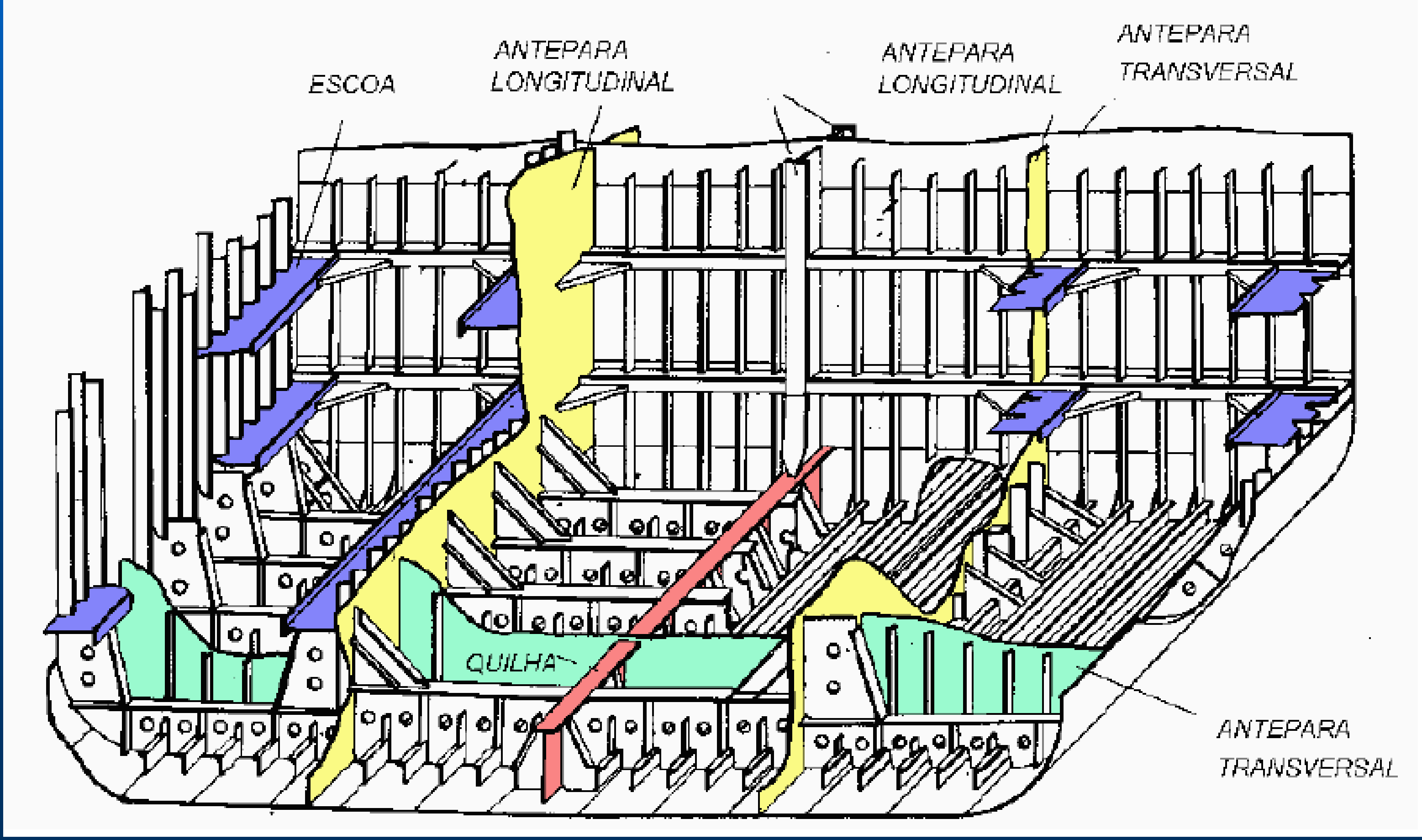
- Imperfeição geométrica inicial foram idealizadas para estudar painéis entre gigantes transversais de uma compartimento característico a meia-nau;
- Ambas amplitude e modo de distribuição das imperfeições são a principal causa de diferentes cargas últimas em painéis nominalmente idênticos;



- Os painéis reforçados são analisados para identificar a iniciação do colapso em um painel particular e a sua influencia na seqüência de falha;
- Interações entre painéis e reforçadores são identificados para melhor descrever o modo de falha global.

Estudo de Caso

- **Navio Petroleiro**



Estudo de Caso

- **Arranjo Estrutural**