UNIVERSIDADE DA CORUÑA

Escola Politécnica Superior

Trabajo Fin de Grado

CURSO 2021/22

BUQUE OCEANOGRÁFICO 55 m
MAR AURORA

Grado en Ingeniería Naval y Oceánica

ALUMNO

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FECHA

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Escola Politécnica Superior

UNIVERSIDADE DA CORUÑA

GRADO EN INGENIERÍA NAVAL Y OCEÁNICA
TRABAJO FIN DE GRADO

CURSO 2.021-2.022

PROYECTO NÚMERO 2022-GENO-14

TIPO DE BUQUE: Buque oceanográfico con capacidad polar para operar en zonas árticas y antárticas. 55 m de eslora entre perpendiculares

CLASIFICACIÓN, COTA Y REGLAMENTOS DE APLICACIÓN: DNVGL, SOLAS + MARPOL+ exigibles en este tipo de buques. POLAR CODE TIPO B ICE CLAS I-B SPS. CLEAN DESIGN. NAUT O EQUIVALENTE

CARACTERÍSTICAS DE LA CARGA: 300 m^2 de capacidad para laboratorios de investigación. 100 m^2 de superficie libre en cubierta

VELOCIDAD Y AUTONOMÍA: velocidad máxima de 14 nudos y velocidad de crucero de 12 nudos con una autonomía de 40 días

SISTEMAS Y EQUIPOS DE CARGA / DESCARGA: 2 grúas de carga a cada costado del buque.

PROPULSIÓN: propulsión eléctrica mediante 2 motores eléctricos, mas 4 generadores diésel de diferentes potencias, más el generador de emergencia. Navegación en zona ECA con LNG.

TRIPULACIÓN Y PASAJE: capacidad para 20 científicos más 8-12 tripulantes

OTROS EQUIPOS E INSTALACIONES: laboratorio en frío (-25 º C), nivel mínimo de vibraciones y ruidos transmitidos a la mar, robot submarino a bordo además de embarcaciones menores tales como 2 Zodiacs a disposición del personal. Helipuerto.

ALUMNO: **D. David Martín Argibay**

RESUMEN BUQUE OCEANOGRÁFICO 55 M MAR AURORA

Castellano

A lo largo del presente Trabajo Fin de Grado se realizará el anteproyecto de un buque oceanográfico de 55 metros de eslora. Se trata de un buque que podrá navegar en aguas polares a 12 nudos con propulsión diésel-eléctrica, 40 días de autonomía, capacidad de navegación con LNG en zona ECA y que poseerá 300 m^2 de laboratorios mas 100 m^2 de superficie libre en cubierta para el estudio llevado a cabo por los 20 científicos que podrán ir a bordo del mismo.

El proyecto consta de un estudio preliminar de oceanográficos semejantes para, posteriormente, desarrollar las formas del buque, estudiar su flotabilidad y estabilidad en distintas condiciones, la potencia necesaria a bordo, la disposición general, el cálculo estructural de la cuaderna maestra, así como el estudio del francobordo, cámara de máquinas, planta eléctrica y equipos y servicios necesarios a bordo para concluir con el estudio del presupuesto y viabilidad de construcción del buque.

Galego

Ao longo deste Traballo Fin de Grao realizarase o anteproxecto dun buque oceanográfico de 55 metros de eslora. Trátase dun buque que poderá navegar en augas polares a 12 nudos con propulsión diésel-eléctrica, 40 días de autonomía, capacidade de navegación con LNG na zona ECA e que contará con 300 m^2 de laboratorios máis 100 m^2 de superficie libre na cuberta para o estudo realizado polos 20 científicos que poderán subir a bordo.

O proxecto consiste nun estudo preliminar de oceanográficos similares para posteriormente desarrollar as formas do buque, estudar a súa flotabilidade e estabilidade en diferentes condicións, a potencia necesaria a bordo, a disposición xeral, o cálculo estrutural da cuaderna maestra, así como o estudo do francobordo, cámara de máquinas, planta eléctrica e equipos e servizos necesarios a bordo para concluír co estudo do orzamento e viabilidade de construción do buque.

English

Throughout this Final Degree Project, the preliminary design of a research vessel of 55 meters in length will be carried out. It is a ship that will be able to navigate in polar waters at 12 knots with diesel-electric propulsion, 40 days of autonomy, navigation capacity with LNG in ECA zone and that will have 300 m^2 of laboratories plus 100 m^2 of free surface on deck for the study carried out by the 20 scientists that will be able to go on board.

The project consists of a preliminary study of similar research vessels an then, develop the vessel's forme, study its buoyancy and stability in different conditions, the power required on board, the general layout, the structural calculation of the master frame, as well as the study of the freeboard, engine room, electrical plant and equipment and services required on board to conclude with the study of the budget and viability of building the vessel.

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Trabajo Fin de Grado
CURSO 2021/22

BUQUE OCEANOGRÁFICO 55 m
MAR AURORA

Grado en Ingeniería Naval y Oceánica

CUADERNO 8

CUADERNA MAESTRA

ÍNDICE

1. INTRODUCCIÓN

A lo largo de este Cuaderno 8: "Cuaderna Maestra", realizaremos todos los cálculos estructurales para el dimensionamiento de la cuaderna maestro de nuestro buque en base a las reglas que establece las sociedades de clasificación, en nuestro caso, Det Norske Veritas o DNV.

Las medidas principales para su cálculo serán las siguientes:

Lpp (m)	B (m)	D (m)	T (m)	Fn
55	11,50	7,80	4,80	0,2657

CB	CM	CP	CF
0,57	0,97	0,59	0,80

Tabla 1: dimensiones principales

Además de las dimensiones principales expuestas, consideraremos el calado de máxima carga de verano, obtenido en el Cuaderno 5, de 4,75 m por lo que el escantillonado y los cálculos estructurales que realizaremos en este cuaderno los hallaremos para un calado máximo de 5 m dejando un margen de 0,25 m de seguridad, o lo que es lo mismo, un 5%.

2. DEFINICIÓN DE LA ESTRUCTURA DEL BUQUE

La estructura de un buque puede ser de tres tipos:

- Estructura longitudinal
- Estructura transversal
- Estructura mixta

Un buque con una estructura longitudinal es aquel que tiene sus refuerzos orientados en sentido longitudinal a lo largo de la eslora del buque (longitudinales, esloras, vagras, etc.), sin embargo, un buque con estructura transversal es aquel que tiene los refuerzos estructurales en sentido transversal (baos, bulárcamas, etc.).

En el caso del Mar Aurora, presentará una estructura:

- ✓ Mixta en el doble fondo con varengas, longitudinales y esloras
- ✓ Transversal en los costados con cuadernas y bulárcamas
- ✓ Mixta en el entrepuente y cubiertas con baos y refuerzos longitudinales

3. DISEÑO CONCEPTUAL DE LA CUADERNA MAESTRA

3.1. Doble fondo

Mostramos como será la disposición del doble fondo del buque:

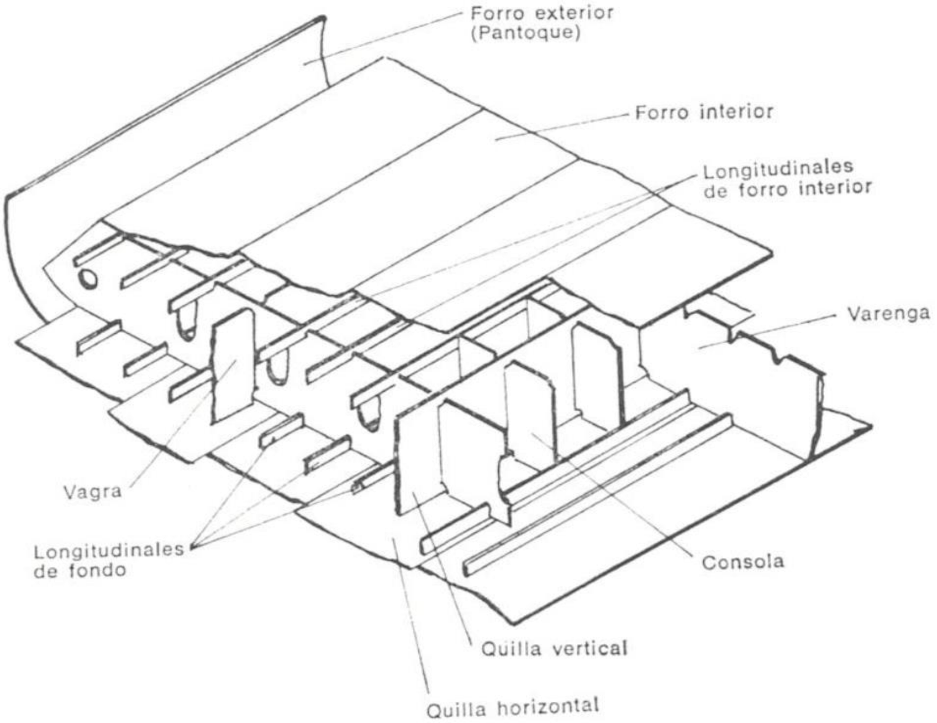


Ilustración 1: estructura tipo doble fondo

El doble fondo, como vemos en la Ilustración 1, presentará una estructura fundamentalmente transversal, aunque tendrá refuerzos longitudinales tales como perfiles, así como esloras o refuerzos longitudinales primarios para una mayor resistencia longitudinal, por lo que la estructura será mixta en el doble fondo como hemos dicho anteriormente.

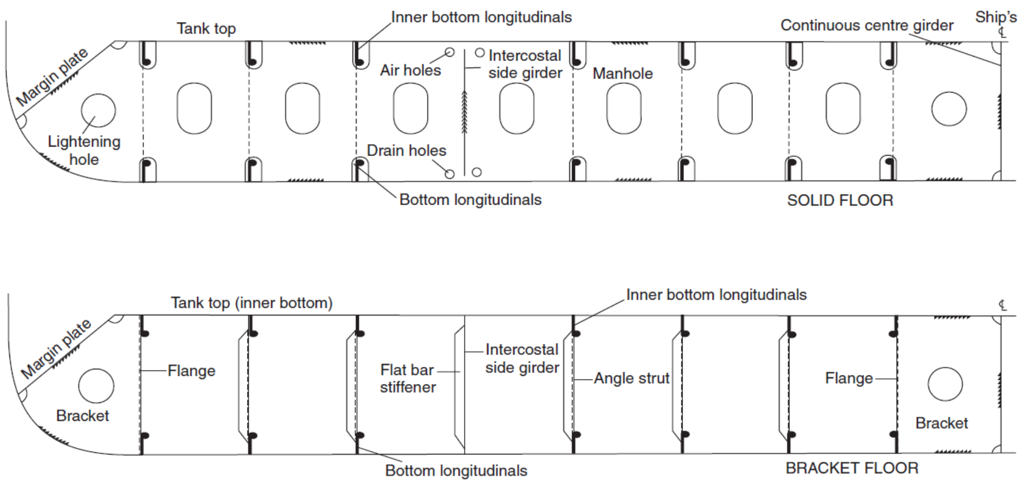


Ilustración 2: doble fondo tipo

3.2. Costado

En el costado el buque presentará un tipo de estructura totalmente transversal como podemos ver en la Ilustración 3:

Shell Plating and Framing

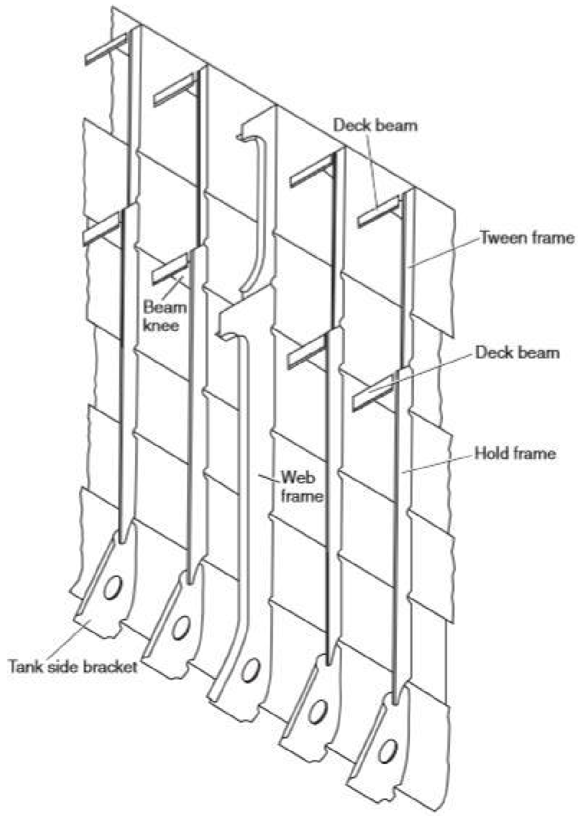


FIGURE 17.2 Side shell with transverse framing

Ilustración 3: estructura del costado tipo del buque

Como podemos apreciar en la Ilustración 3, el buque dispondrá de una estructura transversal en los costados con cuadernas y bulárcamas o refuerzos primarios para dotar de rigidez al costado.

3.3. Cubiertas

En lo referente a las cubiertas, el buque tendrá una estructura de tipo mixta como podemos ver en la Ilustración 4:

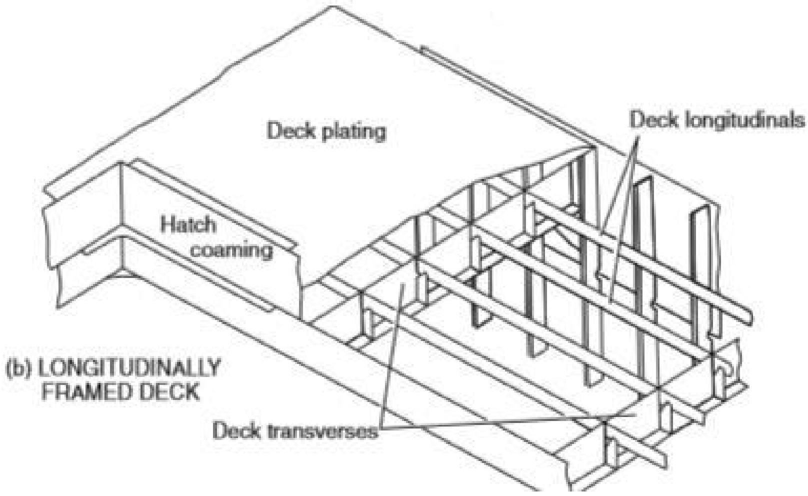


Ilustración 4: estructura tipo en la cubierta del buque

Como podemos observar en la Ilustración 4, el buque contará con una estructura mixta en la cubierta y entrepuente con refuerzos secundarios o perfiles de llanta bulbo en sentido longitudinal, y con refuerzos primarios transversales o baos para dotar de rigidez a la estructura.

4. DIMENSIONES PRINCIPALES Y MATERIALES

4.1. Dimensiones principales

4.1.1. Eslora de escantillonado

El DNV define la eslora de reglamento o escantillonado, para buques que no tenga mecha del timón, como el 97 % de la eslora de flotación al calado de escantillonado:

$$\boldsymbol{L = 55,29\ m}$$

4.1.2. Calado de escantillonado

El calado de escantillonado será aquel calado para el que se diseña la estructura a plena carga del buque.

Tras lo obtenido en el Cuaderno 5 “Condiciones de Carga”, calcularemos la estructura para un calado máximo de 5 m, dejando un pequeño margen de seguridad del 5% por posibles fluctuaciones de peso a la hora de la construcción del buque y que éste cale más de los 4,75 m obtenidos en el Cuaderno 5.

$$\boldsymbol{T_{SC} = 5\ m}$$

4.1.3. Manga de escantillonado

La manga de escantillonado será la mayor manga medida en el buque para el calado de escantillonado:

$$\boldsymbol{B = 11,5\ m}$$

4.1.4. Puntal de escantillonado

El puntal de escantillonado es la distancia vertical medida en metros, desde la línea base hasta la cubierta continua más alta:

$$\boldsymbol{D = 7,8\ m}$$

4.1.5. Coeficiente de bloque al T_{SC}

Obtenemos de las hidrostáticas el coeficiente de bloque del buque, CB, al calado de escantillonado de 5 m, y de la siguiente fórmula proporcionada por el reglamento:

$$CB = \frac{\Delta_{T_{SC}}}{1{,}025\ x\ L\ x\ B\ x\ T_{SC}}$$

	Measurement	Value	Units
1	Displacement	1964	t
2	Volume (displace	1916,510	m^3
3	Draft Amidships	5,000	m
4	Immersed depth	5,013	m
5	WL Length	57,206	m
6	Beam max extent	11,500	m
7	Wetted Area	997,168	m^2
8	Max sect. area	55,584	m^2
9	Waterpl. Area	533,228	m^2
10	Prismatic coeff. (	0,603	
11	Block coeff. (Cb)	0,581	
12	Max Sect. area c	0,979	
13	Waterpl. area coe	0,811	
14	LCB length	25,804	from z
15	LCF length	21,679	from z
16	LCB %	45,107	from z
17	LCF %	37,896	from z
18	KB	2,875	m
19	KG fluid	0,000	m
20	BMt	2,661	m
21	BML	56,265	m
22	GMt corrected	5,536	m
23	GML	59,140	m
24	KMt	5,536	m
25	KML	59,140	m
26	Immersion (TPc)	5,466	tonne/
27	MTc	21,123	tonne.
28	RM at 1deg = GM	189,806	tonne.
29	Length:Beam rati	4,974	

Tabla 2: hidrostáticas al calado de escantillonado

Siguiendo la tabla 2, hidrostáticas al calado de escantillonado, y la fórmula del reglamento presentada anteriormente, el CB del buque será:

$$CB = 0,6$$

4.1.6. Claras entre cuadernas, varengas y separación entre longitudinales

La separación entre cuadernas será de:

- ✓ 600 mm entre cuadernas

La disposición de las varengas será cada 4 claras, por lo tanto:

- ✓ 2400 mm entre varengas

La separación entre los longitudinales será de:

- ✓ 700 mm entre longitudinales

4.2. Material

El acero escogido para la construcción del buque será un acero estándar con un límite elástico de 235 N/mm^2. Por lo tanto, siguiendo el DNV:

2.2 Material factor, *k*

Unless otherwise specified, the material factor *k*, of normal and higher strength steel for hull girder strength and scantling purposes shall be taken as defined in Table 2.

For intermediate values of R_{eH}, *k* is obtained by linear interpolation.

Table 2 Material factor *k*

Specified minimum yield stress R_{eH}, in N/mm^2	*k*
235	1.00
315	0.78
355	0.72
390	0.66/0.68[1)]
460	0.62

Ilustración 5: factor del material, K, DNV

Siguiendo la ilustración 5, el factor de material, 'K', utilizado de aquí en adelante será:

$$\boldsymbol{K = 1}$$

5. MOMENTOS FLECTORES Y TENSIÓN LONGITUDINAL

5.1. Momentos flectores

Calculamos los momentos flectores en la Cuaderna Maestra de nuestro buque siguiendo el DNV:

2.2 Vertical still water bending moment

2.2.1 Still water bending moment in seagoing condition

As guidance values, at a preliminary design stage, the still water bending moments, in kNm, for hogging and sagging respectively, in seagoing condition may be taken as:

Hogging conditions:

$$M_{sw\text{-}h\text{-}min} = f_{sw}\left(171C_w L^2 B\left(C_B + 0.7\right)10^{-3} - M_{wv\text{-}h\text{-}mid}\right)$$

Sagging conditions:

$$M_{sw\text{-}s\text{-}min} = -0.85 f_{sw}\left(171C_w L^2 B\left(C_B + 0.7\right)10^{-3} + M_{wv\text{-}s\text{-}mid}\right)$$

where:

$M_{wv\text{-}h\text{-}mid}$ = vertical wave bending moment for strength assessment amidships in hogging condition, as defined in [3.1.1] using f_p and f_m equal to 1.0

$M_{wv\text{-}s\text{-}mid}$ = vertical wave bending moment for strength assessment amidships in sagging condition, as defined in [3.1.1] using f_p and f_m equal to 1.0

f_{sw} = distribution factor along the ship length, shall be taken as, see Figure 1:

$f_{sw} = 0.0$ for $x \leq 0$

$f_{sw} = 0.15$ at $x = 0.1\,L$

$f_{sw} = 1.0$ for $0.3\,L \leq x \leq 0.7\,L$

$f_{sw} = 0.15$ at $x = 0.9\,L$

$f_{sw} = 0.0$ for $x \geq L$.

Intermediate values of f_{sw} may be obtained by linear interpolation.

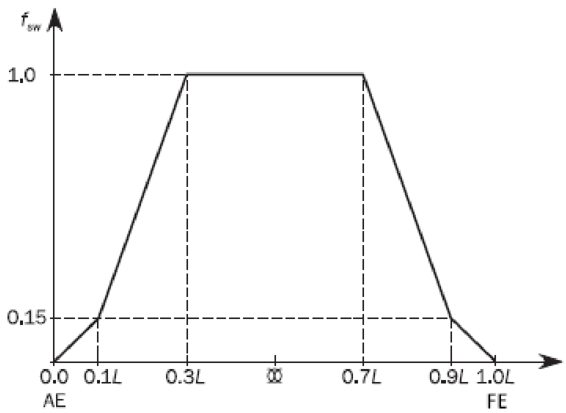


Ilustración 6: momento flector en aguas tranquilas en condiciones de navegación, DNV

3.1 Vertical wave bending moment

3.1.1 The vertical wave bending moments at any longitudinal position, in kNm, shall be taken as:

Hogging condition:

$$M_{wv\text{-}h} = 0.19 \cdot \frac{f_R}{0{,}85} f_{n\ell\text{-}vh} f_m f_p C_w L^2 B C_B$$

Sagging condition:

$$M_{wv\text{-}s} = -0.19 \cdot \frac{f_R}{0{,}85} f_{n\ell\text{-}vs} f_m f_p C_w L^2 B C_B$$

where:

$f_{n\ell\text{-}vh}$ = coefficient considering non-linear effects applied to hogging, shall be taken as:
$f_{n\ell\text{-}vh}$ = 1.0 for strength and fatigue assessment

$f_{n\ell\text{-}vs}$ = coefficient considering non-linear effects applied to sagging, shall be taken as:

$f_{n\ell\text{-}vs} = 0.5789\left(\frac{C_B + 0.7}{C_B}\right)$ for strength assessment

$f_{n\ell\text{-}vs} = 1.0$ for fatigue assessment

f_R = factor related to the operational profile, to be taken as:
= 0.85 for strength assessment
= as given in Ch.9 Sec.4 [4.3] for fatigue assessment

f_p = coefficient shall be taken as:

$f_p = f_{ps}$ for strength assessment

$f_p = f_{fa} \cdot f_{vib}[0.27 - (6 + 4f_T)\, L \cdot 10^{-5}]$ for fatigue assessment

f_{vib} = correction for minimum contribution from hull girder vibration
= 1.10 for $B \leq 28$ m
= 1.20 for $B > 40$ m
= 1.15 for $B > 40$ m when North Atlantic is specified for other ships than ships with large deck openings, as defined in Ch.1 Sec.4 Table 7.
= linear interpolation shall be applied in-between.

f_m = distribution factor for strength assessment for vertical wave bending moment along the ship's length, shall be taken as:

$f_m = 0.0$ for $x \leq 0$

$f_m = 1.0$ for $0.4\, L \leq x \leq 0.65\, L$

$f_m = 0.0$ for $x \geq L$.

Intermediate values of f_m shall be obtained by linear interpolation (see Figure 2).
= distribution factor for fatigue assessment for vertical wave bending moment along the ship's length, shall be taken as shown in Table 1 with linear interpolation in-between.

Ilustración 7: momento en aguas tranquilas, DNV

Primeramente, calculamos el momento flector vertical ($M_{wv\text{-}h}$) tal y como indica el DNV:

- f_R

$$f_R = 0{,}85$$

- $f_{nl\text{-}vh}$

$$f_{nl-vh} = 1$$

- f_m

$$f_m = 1$$

- f_p

$$f_p = f_{ps} = 1$$

- C_w: calculado más adelante y con valor de:

$$C_w = 4{,}733$$

- $f_{nl\text{-}vs}$

$$f_{nl-vs} = 1{,}254$$

Por lo que el momento flector vertical es:

$$M_{wv-h} = 18.967{,}77\ kNm$$

$$M_{wv-s} = -23.790{,}95\ kNm$$

Calculamos a continuación el momento flector en aguas tranquilas en condiciones de navegación ($M_{sw\text{-}h\text{-}min}$):

- f_{sw}

$$f_{sw} = 1$$

Por lo tanto, con todos los demás parámetros calculados:

$$\boldsymbol{M_{sw-h-min} = 18.019{,}38\ kNm}$$

$$\boldsymbol{M_{sw-s-min} = -11.216{,}76\ kNm}$$

5.2. Tensión longitudinal

Calculamos ahora la tensión longitudinal (σ_{hg}) siguiendo el reglamento:

2 Ships without large deck openings

2.1 Hull girder longitudinal stresses

2.1.1 Definition

For seagoing condition the hull girder longitudinal stress σ_{hg}, in N/mm^2, induced by acting vertical and horizontal bending moments for a dynamic load case at the transverse section being considered is obtained from the following formula:

$$\sigma_{hg} = \sigma_{hg\text{-}sw} + \sigma_{hg\text{-}dyn}$$

where:

$$\sigma_{hg\text{-}sw} = \begin{cases} \sigma_{sw\text{-}h} \\ \sigma_{sw\text{-}s} \end{cases}$$

$$\sigma_{hg\text{-}dyn} = \sigma_{wv\text{-}LC} + \sigma_{wh\text{-}LC}$$

Ilustración 8´: tensión longitudinal, DNV

Para su cálculo, el reglamento nos dirige primero al cálculo de la tensión longitudinal en aguas tranquilas ($\sigma_{hg\text{-}sw}$):

4.1 Longitudinal stress

4.1.1 Longitudinal stresses induced by still water vertical hull girder bending

The longitudinal stresses, in N/mm^2, induced by acting vertical still water bending moment in seagoing condition at the transverse section being considered, are obtained from the following formula:

$$\sigma_{sw\text{-}h} = \frac{M_{sw\text{-}h}}{I_{y\text{-}n50}}(z - z_{n\text{-}n50})10^{-3}$$

$$\sigma_{sw\text{-}s} = \frac{M_{sw\text{-}s}}{I_{y\text{-}n50}}(z - z_{n\text{-}n50})10^{-3}$$

Ilustración 9: tensión longitudinal en aguas tranquilas, DNV

Con el momento flector en aguas tranquilas:

2.2.2 Permissible vertical still water bending moment in seagoing condition

The permissible vertical still water bending moments, M_{sw-h} and M_{sw-s}, in kNm, for hogging and sagging respectively, in seagoing condition at any longitudinal position shall envelop:

— the most severe still water bending moments calculated, in hogging and sagging conditions, respectively, for the seagoing loading conditions defined in Sec.8

— the most severe still water bending moments for the seagoing loading conditions defined in the loading manual.

Ilustración 10: momento flector en aguas tranquilas en condiciones de navegación, DNV

$$M_{sw-h} = M_{sw-h-min} = 18.019{,}38\ kNM$$

Procedemos al cálculo de los demás términos:

- I_{y-n50}

  El momento de inercia será el momento de inercia mínimo, determinado por el reglamento:

  1.5 Minimum moment of inertia midship

  1.5.1 Application

  The requirement in [1.5.2] applies to self propelled ships with length above 90 m.

  1.5.2 Hull girder moment of inertia

  The gross moment of inertia about the horizontal axis, in m^4, at midship point shall not be less than the value obtained from the following formula:

  $$I_{yR\text{-}gr} = 3 f_r C_w L^3 B (C_B + 0.7) 10^{-8}$$

  Ilustración 11: momento de inercia mínimo, DNV

  - f_r (factor de reducción) = 1 (sin reducción)

  $$I_{y-n50} = 0{,}35877\ m^4$$

- z_{n-n50}

  Es la distancia vertical desde la línea base del centro de gravedad de la cuaderna maestra (eje neutro). Lo estimamos en 1/3 del puntal D.

  $$z_{n-n50} = 2{,}6\ m$$

Por lo tanto, calculamos la tensión longitudinal en aguas tranquilas:

- ✓ En el fondo:

$$z = 0\ m$$

$$\boldsymbol{\sigma_{sw-h}(fondo) = \sigma_{hg-sw}\,(fondo) = -130{,}58\ {}^{N}/_{mm^2}}$$

- ✓ En el doble fondo:

$$z = 0\ m$$

$$\boldsymbol{\sigma_{sw-h}(doble\ fondo) = \sigma_{hg-sw}\,(doble\ fondo) = -60{,}27\ {}^{N}/_{mm^2}}$$

- ✓ En el entrepuente:

$$z = 0\ m$$

$$\boldsymbol{\sigma_{sw-h}(entrepuente) = \sigma_{hg-sw}\,(entrepuente) = 100{,}45\ {}^{N}/_{mm^2}}$$

- ✓ En la cubierta principal:

$$z = 0\ m$$

$$\boldsymbol{\sigma_{sw-h}(cubierta\ principal) = \sigma_{hg-sw}\,(cubierta\ principal) = 261{,}17\ {}^{N}/_{mm^2}}$$

Calculamos ahora la tensión longitudinal dinámica ($\sigma_{hg\text{-}dyn}$):

$$\sigma_{hg\text{-}dyn} = \sigma_{wv\text{-}LC} + \sigma_{wh\text{-}LC}$$

Ilustración 12: tensión longitudinal dinámica, DNV

4.1.2 Longitudinal stresses induced by dynamic hull girder bending

The longitudinal stresses, in N/mm², induced by acting vertical and horizontal wave bending moment for a dynamic load case and at the transverse section being considered, are obtained from the following formula:

$$\sigma_{wv\text{-}LC} = \frac{M_{wv\text{-}LC}}{I_{y\text{-}n50}}(z - z_{n\text{-}n50})10^{-3}$$

$$\sigma_{wh\text{-}LC} = -\frac{M_{wh\text{-}LC}}{I_{z\text{-}n50}}y \cdot 10^{-3}$$

Ilustración 13: tensión longitudinal dinámica debido a la flexión del buque-viga, DNV

Calculamos la componente vertical dinámica y para ello necesitamos momento flector vertical de ola:

3.5 Hull girder loads for dynamic load cases

3.5.1 General

The dynamic hull girder loads shall be applied for the dynamic load cases defined in Sec.2, are given in [3.5.2] to [3.5.5].

3.5.2 Vertical wave bending moment

The vertical wave bending moment, $M_{wv\text{-}LC}$, in kNm, shall be used for each dynamic load case in Sec.2, is defined in Table 4.

Table 4 Vertical wave bending moment for dynamic load cases

Load combination factor	$M_{wv\text{-}LC}$
$C_{WV} \geq 0$	$f_\beta C_{WV} M_{wv\text{-}h}$
$C_{WV} < 0$	$f_\beta C_{WV} \lvert M_{wv\text{-}s} \rvert$

where:

C_{WV} = load combination factor for vertical wave bending moment, shall be taken as specified in Sec.2

$M_{wv\text{-}h}$, $M_{wv\text{-}s}$ = hogging and sagging vertical wave bending moment taking into account the considered design load scenario, as defined in [3.1.1].

Ilustración 14: momento flector vertical debido a la ola, DNV

- f_β

$$f_\beta = 1$$

- C_{WV}

Table 4 Load combination factors for HSM, HSA and FSM load cases - strength assessment

Load component		*LCF*	*HSM-1*	*HSM-2*	*HSA-1*	*HSA-2*	*FSM-1*	*FSM-2*
Hull girder loads	M_{WV}	C_{WV}	−1	1	−0.7	0.7	$-0.4f_T - 0.6$	$0.4f_T + 0.6$
	Q_{WV}	C_{QW}	$-1.0f_{tp}$	$1.0f_{tp}$	$-0.6f_{tp}$	$0.6f_{tp}$	$-1.0f_{tp}$	$1.0f_{tp}$
	M_{WH}	C_{WH}	0	0	0	0	0	0
	M_{WT}	C_{WT}	0	0	0	0	0	0
Longitudinal accelerations	a_{surge}	C_{XS}	$0.6 - 0.2f_T$	$0.2f_T - 0.6$	0.2	−0.2	$0.2 - 0.4f_T$	$0.4f_T - 0.2$
	$a_{pitch\text{-}x}$	C_{XP}	$-0.15\text{-}L_1/300$	$0.15+L_1/300$	−1.0	1.0	0.15	−0.15
	$g \sin\varphi$	C_{XG}	0.6	−0.6	$0.4f_T + 0.1$	$-0.4f_T - 0.1$	−0.2	0.2
Transverse accelerations	a_{sway}	C_{YS}	0	0	0	0	0	0
	$a_{roll\text{-}y}$	C_{YR}	0	0	0	0	0	0
	$g \sin\theta$	C_{YG}	0	0	0	0	0	0
Vertical accelerations	a_{heave}	C_{ZH}	$0.5f_T - 0.15$	$0.15 - 0.5f_T$	0.4	−0.4	0	0
	$a_{roll\text{-}z}$	C_{ZR}	0	0	0	0	0	0
	$a_{pitch\text{-}z}$	C_{ZP}	−0.7	0.7	−1.0	1.0	0.15	−0.15

Ilustración 15: factores para las cargas, DNV

$$C_{WV} = -1$$

Con el momento flector vertical calculado anteriormente:

$$M_{wv-LC} = -11{,}216{,}76\ kNm$$

Con los demás parámetros ya calculados:

$$\sigma_{wv-LC}\ (fondo) = 81{,}29\ {}^{N}/_{mm^2}$$

$$\sigma_{wv-LC}\ (doble\ fondo) = 37{,}52\ {}^{N}/_{mm^2}$$

$$\sigma_{wv-LC}\ (entrepuente) = -62{,}53\ {}^{N}/_{mm^2}$$

$$\sigma_{wv-LC}\ (cubierta\ principal) = -162{,}57\ {}^{N}/_{mm^2}$$

Y, por último, calculamos la componente horizontal dinámica y para ello necesitamos el momento flector horizontal de ola:

3.5.4 Horizontal wave bending moment

The horizontal wave bending moment, in kNm, shall be used for each dynamic load case defined in Sec.2, shall be taken as:

$$M_{wh\text{-}LC} = f_\beta C_{WH} M_{wh}$$

where:

C_{WH} = load combination factor for horizontal wave bending moment, shall be taken as specified in Sec.2
M_{wh} = horizontal wave bending moment taking into account the appropriate design load scenario, as defined in [3.3.1].

Ilustración 16: momento flector horizontal debido a la ola, DNV

- C_{WH}

$$C_{WH} = 0$$

Por lo tanto:

$$M_{wh-LC} = 0\ kNm$$

Por lo que la componente horizontal dinámica será 0 para cualquier punto a calcular:

$$\sigma_{wh-LC}\ (fondo) = 0\ {}^{N}/_{mm^2}$$

$$\sigma_{wh-LC}\ (doble\ fondo) = 0\ {}^{N}/_{mm^2}$$

$$\sigma_{wh-LC}\ (entrepuente) = 0\ {}^{N}/_{mm^2}$$

$$\sigma_{wh-LC}\ (cubierta\ principal) = 0\ {}^{N}/_{mm^2}$$

De esta manera, la componente dinámica de la tensión queda, para cada punto del buque:

$$\boldsymbol{\sigma_{hg-dyn}\ (fondo) = 81,29\ {}^{N}/_{mm^2}}$$

$$\boldsymbol{\sigma_{hg-dyn}\ (doble\ fondo) = 37,52\ {}^{N}/_{mm^2}}$$

$$\boldsymbol{\sigma_{hg-dyn}\ (entrepuente) = -62,53\ {}^{N}/_{mm^2}}$$

$$\boldsymbol{\sigma_{hg-dyn}\ (cubierta\ principal) = -162,57\ {}^{N}/_{mm^2}}$$

Por lo que la tensión longitudinal total en cada punto a calcular es:

$$\boldsymbol{\sigma_{hg}\ (fondo) = -49,298\ {}^{N}/_{mm^2}}$$

$$\boldsymbol{\sigma_{hg}\ (doble\ fondo) = -22,753\ {}^{N}/_{mm^2}}$$

$$\sigma_{hg}\ (entrepuente) = 37,921\ {}^{N}/_{mm^2}$$

$$\sigma_{hg}\ (cubierta\ principal) = 98,595\ {}^{N}/_{mm^2}$$

6. ESCANTILLONADO LOCAL DE LA CUADERNA MAESTRA

6.1. Escantillonado de los elementos del fondo

A continuación, vamos a calcular el espesor de la chapa del fondo del buque, así como los refuerzos secundarios (longitudinales) y los primarios (varengas).

6.1.1. Espesor mínimo de la chapa del fondo

Siguiendo el DNV:

1.1 Minimum thickness requirements

1.1.1 The net thickness of plating, in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 1
b = coefficient as defined in Table 1.

For aluminum alloys, material factor $k$may be taken as equal to 1.

Table 1 Minimum net thickness for plating

Element	*Location*		*a*	*b*
Shell	Keel		5.0	0.05
	Bottom, bilge and sea chest boundaries		4.5	0.035
	Side shell and superstructure side	From upper end of bilge plating to T_{SC} + 4.6 m	4.0	0.035
		From T_{SC} + 4.6 m to T_{SC} + 6.9 m 6)		0.025
		From T_{SC} + 6.9 m to T_{SC} + 9.2 m 6)		0.015
		Elsewhere 6) 7)		0.01
Deck	Weather deck 1),2),3),4), 5) and strength deck 2),3)		4.5	0.02
	Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk			0.015
	Other decks 3),4),5)			0.01
Inner bottom	Cargo spaces loaded through cargo hatches except container holds		5.5	0.025
	Other spaces		4.5	0.02
Bulkheads	Bulkheads for cargo tanks, water ballast tanks and hold intended for cargo in bulk		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads 8)			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

Ilustración 17: espesores mínimos, DNV

Ya que la chapa que estamos calculando pertenece al fondo del buque:

$$a = 4{,}5$$

$$b = 0{,}035$$

$$L_2 = 55{,}29\ m$$

Por lo tanto, el espesor mínimo del fondo será:

$$\boldsymbol{t_{min_{fondo}} = 6,5\ mm}$$

6.1.2. Espesor de la chapa sometida a presiones

Siguiendo el DNV:

1 Plating subjected to lateral pressure

1.1 General

1.1.1 Plating

The net thickness, in mm, shall not be taken less than the greatest value for all applicable design load sets, as defined in Sec.2 [2.1.3], given by:

$$t = 0{,}0158\alpha_p b\sqrt{\frac{|P|}{C_a R_{eH}}}$$

where:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}} \quad \text{not to be taken greater than } C_{a\text{-}max}$$

β_a = coefficient as defined in Table 1

α_a = coefficient as defined in Table 1

$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Table 1 Plating, definition of β_a, α_a and $C_{a\text{-}max}$

Acceptance criteria	*Structural member*		β_a	α_a	$C_{a\text{-}max}$
AC-I	Longitudinal members	Longitudinal stiffened plating	0.90	0.50	0.80
		Transverse stiffened plating	0.90	1.00	0.80
	Other members		0.80	0.00	0.80
AC-II	Longitudinal members	Longitudinal stiffened plating	1.05	0.50	0.95
		Transverse stiffened plating	1.05	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal bulkhead members including possible bench structures between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo	Longitudinal stiffened plating	1.25	0.5	1.15
		Transverse stiffened plating	1.15	1.0	1.15
	Other longitudinal members	Longitudinal stiffened plating	1.10	0.50	1.00
		Transverse stiffened plating	1.10	1.00	1.00
	Transverse boundaries of ballast water tanks Transverse boundaries between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo		1.15	0.00	1.15
	Other members		1.00	0.00	1.00
	Longitudinal watertight boundaries 1)	Longitudinal stiffened plating	1.25	0.50	1.15
		Transverse stiffened plating	1.15	1.00	1.15
	Other watertight boundaries 1)		1.15	0.00	1.15
1) Only applicable for flooding pressure					

Ilustración 18: espesor de la chapa sometida a presiones, DNV

Calculamos α_p, siguiendo el DNV:

For symbols not defined in this section, see Ch.1 Sec.4.

α_p = correction factor for the panel aspect ratio to be taken as follows but not to be taken greater than 1.0:

$$\alpha_p = 1.2 - \frac{b}{2.1\,a}$$

a = length of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

b = breadth of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

P = design pressure for the considered design load set, see Sec.2 [2], calculated at the load calculation point defined in Ch.3 Sec.7 [2.2], in kN/m^2

σ_{hg} = hull girder longitudinal stress, in N/mm^2, as defined in Sec.2 [1], calculated at the load calculation point as defined in Ch.3 Sec.7 [2.2].

Ilustración 19: DNV

Siendo:

$$b = 700\ mm$$

$$a = 2400\ mm$$

Por lo que α_p:

$$\boldsymbol{\alpha_p = 1,06}$$

Procedemos ahora a calcular las presiones a las que está sometida esa chapa del fondo.

				Design load scenario						
				1	*2*	*3*	*4*	*5*	*6*	*7*
				Normal operations at harbour and sheltered water	*Normal operation at sea*	*Flow through ballast water exchange*	*Overfilling of ballast tanks and tank testing*	*Flooding*	*Special operation stillwater 3)*	*Special operations at sea 3)*
				Static (S)	*Static + dynamic (S + D)*	*Static + dynamic (S + D)*	*Accidental (A) and testing (T)*	*Accidental (A)*	*Static (S)*	*Static + dynamic (S+D)*
Load component	Hull girder loads		VBM	M_{sw}	M_{sw} + $M_{wv\text{-}LC}$	M_{sw} + $M_{wv\text{-}LC}$	M_{sw}	M_{sw}	M_{sw_i}	M_{sw_i} + $M_{wv\text{-}LC}$
			HBM	-	$M_{wh\text{-}LC}$	$M_{wh\text{-}LC}$	-	-	-	$M_{wh\text{-}LC}$
			VSF	Q_{sw}	Q_{sw} + $Q_{wv\text{-}LC}$	Q_{sw} + $Q_{wv\text{-}LC}$	-	-	Q_{sw_i}	Q_{sw_i} + $Q_{wv\text{-}LC}$
			TM 2)	M_{st}	M_{st} + $M_{wt\text{-}LC}$	M_{st} + $M_{wt\text{-}LC}$	M_{st}	M_{st}	M_{st_i}	M_{st_i} + $M_{wt\text{-}LC}$
	Local loads	P_{ex}	Exposed decks	-	P_D	-	-	-	P_s	P_S + P_W
			External shell	P_S	P_S + P_W	P_S + P_W	P_S	-	P_s	P_S + P_W
			Superstructure sides	-	max(P_W; P_{SI})	-	-	-	P_s	P_S + P_W
			Superstructure end bulkheads and deckhouse walls	-	P_A	-	-	-	P_s	P_S + P_W
		P_{in}	Boundaries of water ballast tanks 1)	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}	$P_{ls\text{-}2}$ + P_{ld}	max($P_{ls\text{-}4}$, $P_{ls\text{-}ST}$)	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
			Boundaries of tanks other than water ballast tanks			-	$P_{ls\text{-}ST}$	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
			Watertight boundaries	-	-	-	-	P_{fs}	-	-
			Boundaries of bulk cargo holds	P_{bs}	P_{bs} + P_{bd}	-	-	-	-	-
			Internal structures in tanks	P_{int}		-	-	-	-	-
		P_{dl}	Exposed decks and non-exposed decks and platforms	$P_{dl\text{-}s}$	$P_{dl\text{-}s}$ + $P_{dl\text{-}d}$	-	-	-	$P_{dl\text{-}s}$	$P_{dl\text{-}s}$ + $P_{dl\text{-}d}$

Ilustración 20: escenarios de diseño y cargas, DNV

Como vemos en la ilustración 20, la chapa está sometida a las siguientes presiones externas, en una condición normal de operaciones en el mar:

- Presión hidrostática (P_s), al estar sumergida a una determinada profundidad (T_{SC})
- Presión por olas (P_w)

Y, además, al ser el fondo y llevar encima un tanque, también está sometida a presiones internas debido al tanque:

- Presión hidrostática del fluido del tanque (P_{ls-1})
- Presión dinámica debido a las aceleraciones que experimenta el fluido dentro del tanque (P_{ld})

Presión hidrostática (P_s)

Calculamos el parámetro correspondiente a la presión hidrostática:

1.2 Hydrostatic pressure

1.2.1 The hydrostatic pressure, P_S at any load point, in kN/m^2, is obtained from Table 1. See also Figure 1.

Table 1 Hydrostatic pressure, PS

Location	Hydrostatic pressure, P_S, in kN/m^2
$z \le T_{LC}$	$\rho g\ (T_{LC}-z)$
$z > T_{LC}$	0

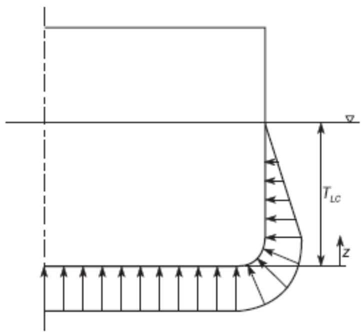


Figure 1 Transverse distribution of hydrostatic pressure Ps

Ilustración 21: presión hidrostática, DNV

Sustituyendo los valores:

$$\rho = 1{,}025\ {}^{t}/_{m^3}$$

$$g = 9{,}81\ {}^{m}/_{s^2}$$

$$T_{Lc} = T_{SC} = 5\ m$$

Y como estamos en el fondo:

$$z = 0\ m$$

La presión hidrostática será:

$$\boldsymbol{P_s = 50,28\ {}^{kN}/_{m^2}}$$

Presión por olas (P_w)

Calculamos el parámetro de la presión debido al oleaje:

1.3 External dynamic pressures for strength assessment

1.3.1 General

The hydrodynamic pressures for each dynamic load case defined in Sec.2 [2] are defined in [1.3.2] to [1.3.8].

1.3.2 Hydrodynamic pressures for HSM load cases

The hydrodynamic pressures, P_W, for HSM-1 and HSM-2 load cases, at any load point, in kN/m^2, shall be obtained from Table 2. See also Figure 2 and Figure 3.

Table 2 Hydrodynamic pressures for HSM load cases

	Wave pressure [kN/m^2]		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
HSM-1	$P_W = \max\{-P_{HS}; \rho g(z - T_{LC})\}$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
HSM-2	$P_W = \max\{P_{HS}; \rho g(z - T_{LC})\}$		

where:

$$P_{HS} = C_{f_T} f_{ps} f_{n\ell} f_h k_a k_p f_{yz} C_w \sqrt{\frac{L_0 + \lambda - 125}{L}}$$

C_{fT} = $f_T + 0.5 - (0.7 f_T - 0.2) C_B$

$f_{n\ell}$ = coefficient considering non-linear effects, to be taken as:
for extreme sea loads design load scenario:
$f_{nl} = 0.7$ at $f_{xL} = 0$
$f_{nl} = 0.9$ at $f_{xL} = 0.3$
$f_{nl} = 0.9$ at $f_{xL} = 0.7$
$f_{nl} = 0.6$ at $f_{xL} = 1$
for ballast water exchange design load scenario:
$f_{nl} = 0.85$ at $f_{xL} = 0$
$f_{nl} = 0.95$ at $f_{xL} = 0.3$
$f_{nl} = 0.95$ at $f_{xL} = 0.7$
$f_{nl} = 0.80$ at $f_{xL} = 1$.
Intermediate values are obtained by linear interpolation

f_{yz} = girth distribution coefficient, to be taken as:

$$f_{yz} = C_x \cdot \frac{z}{T_{LC}} + \left(2 - C_x\right) f_{yB} + 1$$

C_x = coefficient to be taken as:

$$C_x = 1{,}5 - \frac{|x - 0.5L|}{L}$$

f_h = coefficient to be taken as:

$$f_h = 3{,}0\left(1{,}21 - 0{,}66 f_T\right)$$

k_a = amplitude coefficient in the longitudinal direction of the ship, to be taken as:

$$k_a = \left(0{,}5 + f_T\right)\left[\left(3 - 2\sqrt{f_{yB}}\right) - \frac{20}{9} f_{xL}\left(7 - 6\sqrt{f_{yB}}\right)\right] + \frac{2}{3}\left(1 - f_T\right) \quad \text{for } f_{xL} < 0{,}15$$

$$k_a = 1{,}0 \quad \text{for } 0{,}15 \le f_{xL} < 0{,}7$$

$$k_a = 1 + \left(f_{xL} - 0{,}7\right)\left\{\left(\frac{40}{3} f_T - 5\right) + 2\left(1 - f_{yB}\right)\left[\frac{18}{C_B} f_T \left(f_{xL} - 0{,}7\right) - 0{,}25\left(2 - f_T\right)\right]\right\} \quad \text{for } f_{xL} \ge 0{,}7$$

λ = wave length of the dynamic load case, in m, to be taken as: $\lambda = 0.6(1 + f_T)L$

k_p = phase coefficient to be obtained from Table 3. Intermediate values shall be interpolated.

Ilustración 22: presión hidrodinámica, DNV

Table 3 Definition of phase coefficient K_p

f_{xL}	0	$0.3 - 0.1\,f_T$	$0.35 - 0.1\,f_T$	$0.8 - 0.2\,f_T$	$0.9 - 0.2\,f_T$	1.0
k_p	$-0.25\,f_T(1 + f_{yB})$	-1	1	1	-1	-1

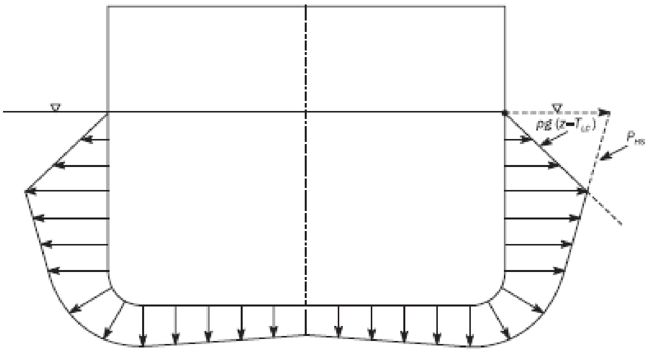


Figure 2 Transverse distribution amidships of dynamic pressure for HSM-1, HSA-1 and FSM-1 load cases

Ilustración 23: K_p y distribución transversal de presión dinámica según HSM-1, DNV

Escogiendo el HSM-1, nuestra P_w, será:

HSM-1	$P_W = \max\{-P_{HS};\rho g(z - T_{LC})\}$

Calculamos $-P_{HS}$:

- <u>C_{fT}</u>
  - $f_T = 1$

$$C_{fT} = 1{,}2$$

- <u>f_{ps}</u>

$$f_{ps} = 1$$

- <u>f_{nl}</u>
  - $f_{xL} = 0{,}5$

$$f_{nl} = 0{,}9$$

- <u>f_h</u>

$$f_h = 1{,}65$$

- <u>k_a</u>

$$k_a = 1$$

- <u>k_p</u>

$$k_p = 1$$

- <u>f_{yz}</u>
  - C_x (x=0,5L) = 1,5
  - f_{yB} (y=0) = 0

f_{yB} = ratio between Y-coordinate of the load point and B_x, to be taken as:

$f_{yB} = \frac{|2y|}{B_x}$ but not greater than 1.0

f_{yB} = 1 when $B_x = 0$

Ilustración 24: f_{yB}, DNV

$$f_{yz} = 1$$

- C_W

C_w = wave coefficient, shall be taken as:

$C_w = 0{,}0856L$	for	$L < 90$
$C_w = 10{,}75 - \left(\frac{300 - L}{100}\right)^{1{,}5}$	for	$90 \leq L \leq 300$
$C_w = 10.75$	for	$300 < L \leq 350$
$C_w = 10.75 - \left(\frac{L - 350}{150}\right)^{1{,}5}$	for	$350 < L \leq 500$

- L = 55,29

$$C_W = 4{,}733$$

- L_0

$$L_0 = 110 \text{ m}$$

- λ

$$\lambda = 66{,}348 \text{ m}$$

- L: eslora de reglamento definida anteriormente e igual a 55,29 m

$$\boldsymbol{P_{HS} = 8,128\ ^{kN}/_{m^2}}$$

Por otro lado, calculamos la otra componente para hacer el máximo entre P_{HS} y ella:

$$\boldsymbol{\rho g(z - T_{LC}) = -50,28\ ^{kN}/_{m^2}}$$

Por lo tanto, el máximo entre ellas es:

$$\boldsymbol{P_W = 8,128\ ^{kN}/_{m^2}}$$

Presión externa total

Por lo que la presión externa será:

$$P_{externa\ fondo} = P_S + P_W$$

$$\boldsymbol{P_{externa\ fondo} = 58,404\ ^{kN}/_{m^2}}$$

A continuación, antes de proceder a calcular las presiones internas debido al fluido dentro del tanque, calculamos las aceleraciones a las que va a estar sometida tanto la chapa como el fluido dentro y que determinará posteriormente la presión dinámica en el tanque.

Aceleración vertical (a_z)

3.2.3 Vertical acceleration

The vertical acceleration at any position for each dynamic load case, in m/s^2, shall be taken as:

$$a_Z = f_\beta\left[C_{ZH}a_{heave} + C_{ZR}a_{roll}y - C_{ZP}a_{pitch}(x - 0{,}45L)\right]$$

Ilustración 25: aceleración vertical a_z, DNV

Calculamos a_z:

- f_β

$$f_\beta = 1$$

- C_{ZH}

2.2 Load combination factors

2.2.1 The load combinations factors (LCFs) for the global loads and inertia load components for strength assessment are defined in:

— Table 4: LCFs for HSM, HSA and FSM load cases.
— Table 5: LCFs for BSR and BSP load cases.
— Table 6: LCFs for OST and OSA load cases.

Table 4 Load combination factors for HSM, HSA and FSM load cases - strength assessment

Load component		LCF	HSM-1	HSM-2	HSA-1	HSA-2	FSM-1	FSM-2
Hull girder loads	M_{WV}	C_{WV}	−1	1	−0.7	0.7	$-0.4f_T - 0.6$	$0.4f_T + 0.6$
	Q_{WV}	C_{QW}	$-1.0f_{lp}$	$1.0f_{lp}$	$-0.6f_{lp}$	$0.6f_{lp}$	$-1.0f_{lp}$	$1.0f_{lp}$
	M_{WH}	C_{WH}	0	0	0	0	0	0
	M_{WT}	C_{WT}	0	0	0	0	0	0
Longitudinal accelerations	a_{surge}	C_{XS}	$0.6 - 0.2f_T$	$0.2f_T - 0.6$	0.2	−0.2	$0.2 - 0.4f_T$	$0.4f_T - 0.2$
	$a_{pitch\text{-}x}$	C_{XP}	$-0.15\text{-}L_1/300$	$0.15+L_1/300$	−1.0	1.0	0.15	−0.15
	$g \sin\varphi$	C_{XG}	0.6	−0.6	$0.4f_T + 0.1$	$-0.4f_T - 0.1$	−0.2	0.2
Transverse accelerations	a_{sway}	C_{YS}	0	0	0	0	0	0
	$a_{roll\text{-}y}$	C_{YR}	0	0	0	0	0	0
	$g \sin\theta$	C_{YG}	0	0	0	0	0	0
Vertical accelerations	a_{heave}	C_{ZH}	$0.5f_T - 0.15$	$0.15 - 0.5f_T$	0.4	−0.4	0	0
	$a_{roll\text{-}z}$	C_{ZR}	0	0	0	0	0	0
	$a_{pitch\text{-}z}$	C_{ZP}	−0.7	0.7	−1.0	1.0	0.15	−0.15

Ilustración 26: factores de combinación de cargas, DNV

Como estamos en el caso HSM-1:

$$C_{ZH} = 0{,}35$$

- <u>a_{heave}</u>

2.2.3 Heave acceleration

The vertical acceleration due to heave, in m/s², shall be taken as:

$$a_{heave} = 0{,}8(1 + 0{,}03v)\left(0{,}72 + \frac{2L}{700}\right)\left(1{,}15 - \frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad L < 100\text{ m}$$

$$a_{heave} = \left(0{,}4 + \frac{L}{250}\right)\left(1 + 0{,}03v\left(3 - \frac{L}{50}\right)\right)\left(1{,}15 - \frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad 100 \le L < 150\text{ m}$$

$$a_{heave} = \left(1.15 - \frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad L \ge 150\text{ m}$$

where:

v = unless otherwise specified in Pt.5, to be taken as:
0 kt for $L < 100$ m
5 kt for $L \ge 150$ m
linear interpolation for L between 100 m and 150 m.

f_p = coefficient shall be taken as:

$f_p = f_{ps}$ for strength assessment

$f_p = f_R\left[\left(0{,}27 + 0{,}02f_T\right) - 17L \cdot 10^{-5}\right]$ for fatigue assessment.

Ilustración 27: a_{heave}, DNV

- $v = 0$
- $f_p = f_{ps} = 1$
- $a_0 = 0{,}962$

a_0 = acceleration parameter, shall be taken as:

$$a_0 = \left(1{,}58 - 0{,}47C_B\right)\left(\frac{2{,}4}{\sqrt{L}} + \frac{34}{L} - \frac{600}{L^2}\right)$$

Ilustración 28: parámetro de la aceleración, DNV

$$a_{heave} = 5{,}775\ {}^{m}/_{s^2}$$

- <u>C_{ZR}</u>

$$C_{ZR} = 0$$

Al ser C_{ZR} nulo, el cálculo de a_{roll} e 'y' no es necesario por el momento.

- <u>C_{ZP}</u>

$$C_{ZP} = -0{,}7$$

- <u>a_{pitch}</u>

2.2.5 Pitch acceleration

The pitch acceleration, in rad/s^2, shall be taken as:

$$a_{pitch} = 0{,}8(1 + 0{,}05v)f_p\left(0{,}72 + \frac{2L}{700}\right)\left(1{,}75 - \frac{22}{\sqrt{gL}}\right)\varphi\frac{\pi}{180}\left(\frac{2\pi}{T_\varphi}\right)^2 \qquad L < 100 \text{ m}$$

Ilustración 29: a_{pitch}, DNV

- φ = 33,86 º

The pitch angle, in deg, shall be taken as given in formula below and need not to be taken greater than 20 degree in general, and not to taken greater than 20 f_r degrees for ships with service area restrictions:

$$\varphi = 920 f_p L^{-0{,}84}\left\{1{,}0 + \left(\frac{2{,}57}{\sqrt{gL}}\right)^{1{,}2}\right\}$$

where:

f_p = coefficient shall be taken as:

$f_p = f_{ps}$ for strength assessment

$f_p = f_R\left[\left(0{,}27 - 0{,}02f_T\right) - \left(13 - 5f_T\right)\cdot L \cdot 10^{-5}\right]$ for fatigue assessment.

Ilustración 30: ángulo φ, DNV

- T_φ = 6,52 s

The pitch period, in s, shall be taken as:

$$T_\varphi = \sqrt{\frac{2\pi\lambda_\varphi}{g}}$$

where:

$\lambda_\varphi = 0.6\left(1 + f_T\right)L$

Ilustración 31: Tφ, DNV

$$a_{pitch} = 0{,}31\ {}^{rad}/_{s^2}$$

Para x = 0.5L, calculamos a_z:

$$\mathbf{a_z = 2{,}62\ {}^{m}/_{s^2}}$$

<u>Aceleración transversal (a_y)</u>

3.2.2 Transverse acceleration

The transverse acceleration at any position for each dynamic load case, in m/s^2, shall be taken as:

$$a_Y = f_\beta\left[C_{YG}g\sin\theta + C_{YS}a_{sway} - C_{YR}a_{roll}(z - R)\right]$$

Ilustración 32: aceleración transversal a_y, DNV

- f_β

$$f_\beta = 1$$

- C_{YG}

$$C_{YG} = 0$$

- C_{YS}

$$C_{YS} = 0$$

- C_{YR}

$$C_{YR} = 0$$

Al ser nulo los términos C_{YG}, C_{YS} y C_{YR} el cálculo de a_{sway}, ‘θ’ y a_{roll} no es necesario por el momento, quedando a_y:

$$\boldsymbol{a_y = 0\ {}^{m}/_{s^2}}$$

Aceleración longitudinal (a_x)

3.2.1 Longitudinal acceleration

The longitudinal acceleration at any position for each dynamic load case, in m/s², shall be taken as:

$$a_X = f_\beta\left[\left(-C_{XG}g\sin\varphi\right) + C_{XS}a_{surge} + C_{XP}a_{pitch}(z-R)\right]$$

Ilustración 33: aceleración longitudinal a_x, DNV

- f_β

$$f_\beta = 1$$

- C_{XG}

$$C_{XG} = 0{,}6$$

- C_{XS}

$$C_{XS} = 0{,}4$$

- a_{surge}

2.2.1 Surge acceleration

The longitudinal acceleration due to surge, in m/s², shall be taken as:

$$a_{surge} = 0{,}2\left(1{,}6 + \frac{1{,}5}{\sqrt{gL}}\right)f_p a_0 g$$

where:

f_p = coefficient shall be taken as:
$f_p = f_{ps}$ for strength assessment
$f_p = f_R\left[0.27 - \left(15 + 4f_T\right)L \cdot 10^{-5}\right]$ for fatigue assessment.

Ilustración 34: a_{surge}, DNV

$$a_{surge} = 3{,}14\ {}^{m}/_{s^2}$$

- C_{XP}

$$C_{XP} = -0{,}334$$

- a_{pitch}

$$a_{pitch} = 0{,}31\ {}^{rad}/_{s^2}$$

- z

$$z = 0$$

- R

R = vertical coordinate, in m, of the ship rotation centre, shall be taken as:

$$R = \min\left(\frac{D}{4} + \frac{T_{LC}}{2}, \frac{D}{2}\right)$$

Ilustración 35: R, DNV

$$R = 3{,}9$$

Por lo que la aceleración a_x es:

$$\boldsymbol{a_x = -2,09\ {}^{m}/_{s^2}}$$

Con las aceleraciones ya calculadas, calculamos las presiones dentro del tanque que serán la estática del fluido y la dinámica del mismo como hemos dicho anteriormente.

The internal pressure due to liquid acting on any load point of a tank and ballast hold boundary, in kN/m^2, for the static plus dynamic (S + D) design load scenarios shall be derived for each dynamic load case and shall be taken as:

$$P_{in} = P_{\ell s} + P_{\ell d} \text{ but not less than 0.}$$

where:

$P_{\ell s}$ = static pressure due to liquid in tanks and ballast holds, in kN/m^2, as defined in [1.2.1] to [1.2.6]
$P_{\ell d}$ = dynamic inertial pressure due to liquid in tanks and ballast holds, in kN/m^2, as defined in [1.3].

Ilustración 36: presiones en el interior del tanque, DNV

<u>Presión hidrostática del fluido del tanque (P_{ls})</u>

1.2.1 Normal operations at sea

The static pressure, in kN/m^2, in tanks and ballast holds for normal operations at sea, shall be taken as:

$P_{\ell s\text{-}1} = f_{cd}\,\rho_L\, g\left(z_{top} - z\right) + P_{PV}$ for tanks arranged with pressure relief valves

$P_{\ell s\text{-}1} = \rho_L\, g\left(z_{top} - z\right)$ for other cases.

Ilustración 37: presión hidrostática del tanque, DNV

- z_{top}

$$z_{top} = 1{,}4$$

- ρ_l

$$\rho_l = 1{,}025\ {}^{t}/_{m^3}$$

En el punto a considerar que es el fondo del buque por lo que z = 0:

$$\boldsymbol{P_{ls} = 14,08\ {}^{kN}/_{m^2}}$$

<u>Presión dinámica del fluido del tanque (P_{ld})</u>

1.3 Dynamic liquid pressure

1.3.1 The dynamic pressure due to liquid in tanks and ballast holds, in kN/m² shall be taken as:

$$P_{\ell d} = f_{cd}\,\rho_L\left[a_Z(z_0 - z) + f_{ull-\ell}\,a_x(x_0 - x) + f_{ull-t}\,a_y(y_o - y)\right]$$

where:

$f_{ull-\ell}$ = longitudinal acceleration correction factor for the ullage space above the liquid in tanks and ballast holds, taken as:
for strength assessment:
$f_{ull-\ell}$ = 0.62 for cargo tanks filled with any liquids inclusive water ballast
$f_{ull-\ell}$ = 1.0 for other cases
for fatigue assessment:

$$f_{ull-\ell} = 0.5 + \frac{|z_0 - z|}{\ell_{fs}}\frac{180}{\varphi\pi}$$ for cargo tanks and ballast holds

$f_{ull-\ell}$ = 1.0 for other cases
$f_{ull-\ell}$ shall not be less than 0.0 nor greater than 1.0

ℓ_{fs} = cargo tank length at the top of the tank or length of the ballast hold hatch coaming, in m

f_{ull-t} = transverse acceleration correction factor to account for the ullage space above the liquid in tanks and ballast holds, taken as:
for strength assessment:
f_{ull-t} = 0.67 for cargo tanks filled with any liquids inclusive water ballast
f_{ull-t} = 1.0 for other cases
for fatigue assessment:

$$f_{ull-t} = 0.5 + \frac{|z_0 - z|}{b_{top}}\frac{180}{\theta\pi}$$ for cargo tanks and ballast holds

f_{ull-t} = 1.0 for other cases

b_{top} = cargo tank breadth at the top of the tank or breadth of the ballast hold hatch coaming, in m determined at mid length of the tank or ballast hold hatch coaming

x_0 = X coordinate, in m, of the reference point
y_0 = Y coordinate, in m, of the reference point
z_0 = Z coordinate, in m, of the reference point.

Ilustración 38: presión dinámica del líquido

- <u>f_{cd}</u>

$$f_{cd} = 1$$

- <u>ρ_l</u>

$$\rho_l = 1{,}025\ {}^{t}/_{m^3}$$

- <u>x_0, y_0, z_0</u>

x_0 = X coordinate, in m, of the reference point
y_0 = Y coordinate, in m, of the reference point
z_0 = Z coordinate, in m, of the reference point.

The reference point shall be taken as the point with the highest value of V_j, calculated for all points that define the upper boundary of the tank or ballast hold as follows:

$$V_j = a_X(x_j - x_G) + a_Y(y_j - y_G) + (a_Z + g)(z_j - z_G)$$

where:

x_j = X coordinate, in m, of the point j on the upper boundary of the tank or ballast hold
y_j = Y coordinate, in m, of the point j on the upper boundary of the tank or ballast hold
z_j = Z coordinate, in m, of the point j on the upper boundary of the tank or ballast hold.

The following simplified method of determination of the reference point assuming a rectangular shape with area equal A_{top} of the top of the tank or the ballast hold hatch coaming is acceptable, see Figure 1:

$$x_j = x_{top} \pm 0{,}5\,\ell_{fs}$$

$$y_j = y_{top} \pm 0.5 b_{top}$$

where

x_{top} = X coordinate, in m, of the centre of the rectangular area A_{top} at the top of the tank or the ballast hold hatch coaming

y_{top} = Y coordinate, in m, of the centre of the rectangular area A_{top} at the top of the tank or the ballast hold hatch coaming

A_{top} = $\ell_{fs} \cdot b_{top}$: the area of an rectangular shape at the top of the tank or the ballast hold hatch coaming, in m².

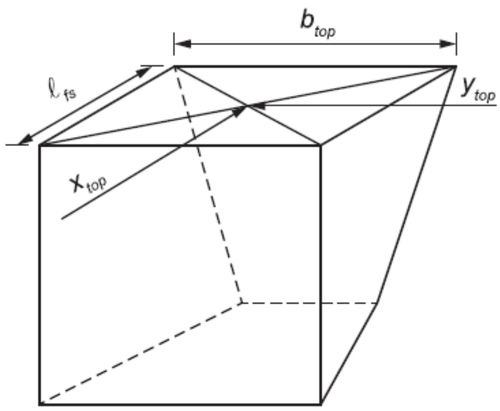


Figure 1 Area of a rectangular shape at the top of a tank

Ilustración 39: coordenadas del punto, DNV

- A_{top}

$$A_{top} = 93{,}15\ m^2$$

- x_{top}

$$x_{top} = 32{,}85\ m$$

- y_{top}

$$y_{top} = 0\ m$$

- x_j

$$x_j = 39{,}2\ m$$

- y_j

$$y_j = 3{,}66\ m$$

- z_j

$$z_j = 1{,}4\ m$$

Que serán nuestros puntos de referencia.

- <u>*x, y, z*</u>
  Son los puntos en los que estamos calculando los diferentes términos hasta ahora
- <u>*f_{ull-l}*</u>

$$f_{ull-l} = 0{,}62$$

- <u>*f_{ull-t}*</u>

$$f_{ull-t} = 0{,}67$$

Por lo tanto, una vez determinados todos los parámetros, la presión dinámica en el fondo es:

$$\boldsymbol{P_{ld} = -11{,}6\ ^{kN}/_{m^2}}$$

Por lo que la presión total interna dentro del tanque es:

$$\boldsymbol{P_{interna\ fondo} = 2{,}47\ ^{kN}/_{m^2}}$$

La presión que deberá soportar la chapa será la condición más desfavorable, es decir, la presión externa, por un lado, y el tanque vacío por el otro, por lo que:

$$\boldsymbol{P = 58,404\ {}^{kN}/_{m^2}}$$

Continuando con los cálculos, procedemos a calcular para hallar el espesor de los dos términos que nos faltan.

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}} \quad \text{not to be taken greater than } C_{a\text{-}max}$$

β_a = coefficient as defined in Table 1

α_a = coefficient as defined in Table 1

$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Ilustración 40: Ca, DNV

- β_a

$$\beta_a = 0{,}95$$

- α_a

$$\alpha_a = 0$$

Por lo tanto:

$$\boldsymbol{C_a = 0,95}$$

Y el coeficiente del material:

$$\boldsymbol{R_{eH} = 235\ {}^{N}/_{mm^2}}$$

Por lo que el espesor de la chapa es:

$$\boldsymbol{t = 6\ mm}$$

6.1.3. Espesor final de la chapa del fondo

El espesor de la chapa del fondo, en base a los cálculos realizados anteriormente será de:

$$\boldsymbol{t_{fondo} = 6,5\ mm}$$

6.1.4. Cálculo de los refuerzos secundarios. Longitudinales

A continuación, vamos a calcular los refuerzos longitudinales del fondo.

El módulo requerido será:

1.1.2 Section modulus

The minimum net section modulus, in cm^3, shall not be taken less than the greatest value calculated for all applicable design load sets as defined in Sec.2 [2.1.3], given by:

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

where:

f_{bdg} = bending moment factor as defined in Table 5. For stiffeners with end fixity deviating from the ones included in Table 5, with complex load pattern, or being part of a grillage, the requirement given in [1.2] applies

f_m = bending moment ratio between end support and midspan as defined in Table 5

f_u = factor for unsymmetrical profiles, to be taken as:

= 1.00 for flat bars and symmetrical profiles (T-profiles)

= 1.03 for bulb profiles

= 1.15 for unsymmetrical profiles (L-profiles)

C_s = permissible bending stress coefficient as defined in Table 3 for the acceptance criteria given in Table 4

$C_{s\text{-}max}$ = coefficient, as defined in Table 4

α_s = coefficient, as defined in Table 4

β_s = coefficient, as defined in Table 4.

Table 3 Stiffeners, definition of C_s

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

Table 4 Stiffeners, definition of β_s, α_s and $C_{s\text{-}max}$

Acceptance criteria	*Structural member*		β_s	α_s	$C_{s\text{-}max}$
	Other members		0.85	0.00	0.85
AC-II	Longitudinal members		1.10	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal members	In general	1.20	1.00	1.00
		On watertight boundaries 1)	1.20	1.00	1.15
	Other members	In general	1.00	0.00	1.00
		On watertight boundaries 1)	1.15	0.00	1.15
1) Only applicable for flooding pressure					

Ilustración 41: módulo de la sección, DNV

Table 5 Stiffeners, definition of f_{bdg} and f_m

Coefficient	Acceptance criteria	For continuous stiffeners with fixed ends		For continuous stiffeners with one fixed end and one simply supported end	For non-continuous stiffeners with simply supported ends
		Horizontal stiffeners and upper end of vertical stiffeners	Lower end of vertical stiffeners	Horizontal and vertical stiffeners	Horizontal and vertical stiffeners
f_{bdg}	AC-I, AC-II, AC-III	12.00	10.00	8.00	8.00
f_m	AC-I	2.00	2.33	1.77	-
	AC-II, AC-III	1.60	1.86	1.42	

Ilustración 42: módulo de la sección DNV

- f_u

$$f_u = 1{,}03$$

- P

$$P = 58{,}404\ {}^{kN}/_{m^2}$$

- s

$$s = 700\ mm$$

- l_{bdg}

$$l_{bdg} = 2{,}4\ m$$

- f_{bdg}

$$f_{bdg} = 12$$

- C_s
  - β_S

$$\beta_S = 1{,}1$$

  - α_S

$$\alpha_S = 1$$

  - σ_{hg}

$$\sigma_{hg} = -49{,}298\ {}^{N}/_{mm^2}$$

$$C_s = 0{,}89$$

Por lo que el módulo necesario que debe dar el perfil es:

$$Z_{longitudinal\ fondo} = 96{,}62\ cm^3$$

Introduciéndonos en el catálogo del Anexo I de llantas bulbo, escogemos:

$$\mathbf{160\ x\ 7\ con\ W = 113\ cm^3}$$

Comprobamos, a continuación, que el perfil de llanta bulbo escogido cumple con el espesor mínimo determinado por el reglamento:

1.1 General

1.1.1 Web plating

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

$$t_w = \frac{C_m f_{shr} |P| s \ell_{shr}}{d_{shr} C_t \tau_{eH}}$$

where:

f_{shr} = shear force distribution factor as defined in Table 1. For stiffeners with end fixity deviating from the ones included in Table 1, with complex load pattern, or being part of a grillage, the requirements given in [1.2] apply.

C_t = permissible shear stress coefficient for the acceptance criteria being considered, as defined in Table 2

C_m = coefficient for combined axial stress, bending stress and shear stress in stiffener

= 1.0 for ships of length less than 90 m and for flat bars and bulb profiles

= $0{,}71\left(1-\left(\frac{0{,}75}{C_{xt}}\cdot\frac{Z}{Z_a}\right)^{e_0}\right)^{-\frac{1}{e_0}}$, not less than 1 in other cases

C_{xt} = $0.52C_{st} + 0.56$

C_{st} = 0.5 for $C_s \leq 0{,}5$

= C_s for $0{,}5 < C_s < 0{,}95$

= 0.95 for $C_s \geq 0{,}95$

C_s = permissible bending stress coefficient as defined in [1.1.2]

Z = required net section modulus according to [1.1.2] in cm^3, shall not be taken greater than Z_a

Z_a = actual net elastic section modulus in cm^3, as defined in Ch.3 Sec.7 [1.4.4]

e_0 = $e_0 = 9{,}23\left(\frac{h_w}{t_{wa}}\sqrt{R_{eH}}\right)^{-0{,}25}$

t_{wa} = actual net web thickness of stiffener, in mm

h_w = depth of stiffener web, in mm, as shown in Ch.8 Sec.2.

Table 1 Definition of f_{shr}

Coefficient	*For continuous stiffeners with fixed end*			*For non-continuous stiffeners with simply supported ends*
	Horizontal stiffeners	*Upper end of vertical stiffeners*	*Lower end of vertical stiffeners*	*All stiffeners*
f_{shr}	0.5	0.4	0.7	0.5

Table 2 Stiffeners, definition of C_t

Acceptance criteria	*Structural member*	C_t
AC-I	All stiffeners	0.75
AC-II	All stiffeners	0.90
AC-III	All stiffeners	0.95

Ilustración 43: espesor refuerzo, DNV

- <u>Cm</u>

$$C_m = 1$$

- <u>f_{shr}</u>

$$f_{shr} = 0{,}5$$

- <u>P</u>

Presión en el fondo calculada anteriormente

- l_{shr}

$$l_{shr} = l - \frac{s}{2000}$$

Siendo 'l' la separación entre refuerzos primarios, igual a 2,4 m.

$$l_{shr} = 2{,}05$$

- d_{shr}

1.4.3 Effective shear depth of stiffeners

The effective shear depth of stiffeners, in mm, shall be taken as:

$$d_{shr} = h_{stf} + t_p \qquad \text{for } 75° \le \varphi_w \le 90°$$

$$d_{shr} = (h_{stf} + t_p)\sin\varphi_w \qquad \text{for } \varphi_w < 75°$$

where:

h_{stf} = height of stiffener, in mm, as defined in Sec.2 Figure 1
t_p = net thickness of the attached plating, in mm, as defined in Sec.2 Figure 1
φ_w = angle, in deg, as defined in Figure 17.

Ilustración 44: profundidad de corte efectiva para los refuerzos

- h_{stf} y t_p

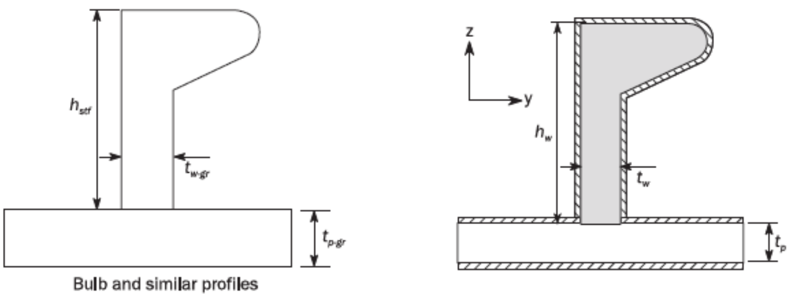


Figure 2 Net sectional properties of local supporting members (continued)

Ilustración 45: perfil bulbo, DNV

$$h_{stf} = b\ (tabla\ llanta\ bulbo) = 160\ mm$$

$$t_p = 7\ mm$$

$$d_{shr} = 167\ mm$$

- C_t

$$C_t = 0{,}9$$

- τ_{eH}

τ_{eH}	specified shear yield stress, $\tau_{eH} = \frac{R_{eH}}{\sqrt{3}}$	N/mm²

$$\tau_{eH} = 135{,}68\ {}^{N}/_{mm^2}$$

Por lo que el espesor del refuerzo debe ser:

$$t_w = 2{,}05\ mm$$

Por lo que el perfil escogido cumple los requisitos de espesor.

6.1.5. Cálculo de los refuerzos primarios. Varengas

Calculamos el módulo necesario que deben dar las varengas, colocadas cada 2400 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000 \frac{|P| s \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1

C_s = permissible stress coefficient to be taken as:

C_s = 0.70 for AC-I

C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 46: módulo requerido en refuerzos primarios, DNV

- P
  Presión calculada en el fondo determinada anteriormente
- s
  $$s = 2400\ mm$$
- l_{bdg}
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%
  $$l_{bdg} = 0{,}95\ x\ s$$
  $$l_{bdg} = 2{,}28\ m$$
- f_{bdg}

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

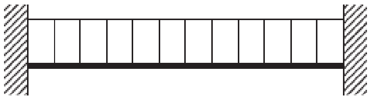
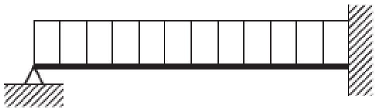
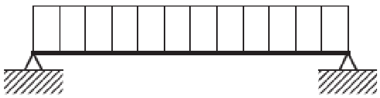
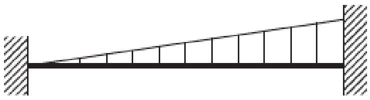
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
Position				*1*	*2*	*3*
Load model	*1* *Support*	*2* *Field*	*3* *Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 47: DNV

Caracterizaremos la varenga como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- <u>C_s</u>

  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar la varenga es:

$$Z_{varenga\ fondo} = 303{,}99\ cm^3$$

Introduciéndonos en el Anexo I de perfiles de llanta bulbo, escogemos:

$$\mathbf{220\ x\ 11{,}5\ con\ W = 323\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3
b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$
2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk
3) $bL_2 \leq 2.0$
4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 48: espesor t refuerzos primarios

Para el fondo del buque en la zona del doble fondo que son tanques:

$$a = 5$$

$$b = 0{,}03$$

Con los demás parámetros definidos:

$$t_{mínimo\ varenga\ fondo} = 6{,}66\ mm$$

Por lo tanto, cumple el espesor mínimo.

6.1.6. Cálculo de los refuerzos primarios. Vagras

Calculamos el módulo necesario que deben dar las vagras, colocadas con una separación entre ellas de 2800 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000\frac{|P|\, s\, \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1

C_s = permissible stress coefficient to be taken as:

C_s = 0.70 for AC-I

C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 49: módulo requerido en refuerzos primarios, DNV

- P

  Presión calculada en el fondo determinada anteriormente
- s

$$s = 2800\ mm$$

- l_{bdg}

  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 2{,}66\ m$$

- f_{bdg}

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

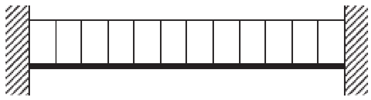
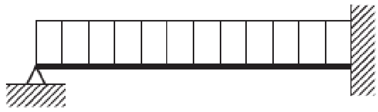
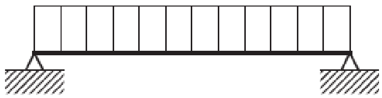
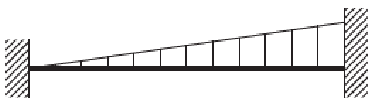
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
Position				*1*	*2*	*3*
Load model	*1 Support*	*2 Field*	*3 Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 50: DNV

Caracterizaremos la vagra como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- $\underline{C_s}$
  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar la vagra es:

$$Z_{vagra\ fondo} = 482{,}72\ cm^3$$

Introduciéndonos en el Anexo I de perfiles bulbo, escogemos:

$$\mathbf{260\ x\ 12\ con\ W = 493\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3
b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$
2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk
3) $bL_2 \leq 2.0$
4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 51: espesor t refuerzos primarios

Para el fondo del buque en la zona del doble fondo que son tanques:

$$a = 5$$

$$b = 0{,}03$$

Con los demás parámetros definidos:

$$t_{mínimo\ vagra\ fondo} = 6{,}66\ mm$$

Por lo tanto, cumple el espesor mínimo.

6.2. Escantillonado de los elementos del doble fondo

6.2.1. Espesor mínimo de la chapa de doble fondo

Siguiendo el DNV:

1.1 Minimum thickness requirements

1.1.1 The net thickness of plating, in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 1
b = coefficient as defined in Table 1.

For aluminum alloys, material factor $k$may be taken as equal to 1.

Table 1 Minimum net thickness for plating

Element	*Location*		*a*	*b*
Shell	Keel		5.0	0.05
	Bottom, bilge and sea chest boundaries		4.5	0.035
	Side shell and superstructure side	From upper end of bilge plating to T_{SC} + 4.6 m	4.0	0.035
		From T_{SC} + 4.6 m to T_{SC} + 6.9 m [6)]		0.025
		From T_{SC} + 6.9 m to T_{SC} + 9.2 m [6)]		0.015
		Elsewhere[6) 7)]		0.01
Deck	Weather deck[1),2),3),4), 5)] and strength deck[2),3)]		4.5	0.02
	Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk			0.015
	Other decks[3),4),5)]			0.01
Inner bottom	Cargo spaces loaded through cargo hatches except container holds		5.5	0.025
	Other spaces		4.5	0.02
Bulkheads	Bulkheads for cargo tanks, water ballast tanks and hold intended for cargo in bulk		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

Ilustración 52: espesores mínimos, DNV

Ya que la chapa que estamos calculando pertenece al doble fondo del buque:

$$a = 5{,}5$$

$$b = 0{,}025$$

$$L_2 = 55{,}29\,m$$

Por lo tanto, el espesor mínimo del fondo será:

$$\boldsymbol{t_{min_{doble\,fondo}} = 7\,mm}$$

6.2.2. Espesor de la chapa sometida a presiones

Siguiendo el DNV:

1 Plating subjected to lateral pressure

1.1 General

1.1.1 Plating

The net thickness, in mm, shall not be taken less than the greatest value for all applicable design load sets, as defined in Sec.2 [2.1.3], given by:

$$t = 0{,}0158\alpha_p b\sqrt{\frac{|P|}{C_a R_{eH}}}$$

where:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}}$$ not to be taken greater than $C_{a\text{-}max}$

β_a = coefficient as defined in Table 1

α_a = coefficient as defined in Table 1

$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Table 1 Plating, definition of β_a, α_a and $C_{a\text{-}max}$

Acceptance criteria	*Structural member*		β_a	α_a	$C_{a\text{-}max}$
AC-I	Longitudinal members	Longitudinal stiffened plating	0.90	0.50	0.80
		Transverse stiffened plating	0.90	1.00	0.80
	Other members		0.80	0.00	0.80
AC-II	Longitudinal members	Longitudinal stiffened plating	1.05	0.50	0.95
		Transverse stiffened plating	1.05	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal bulkhead members including possible bench structures between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo	Longitudinal stiffened plating	1.25	0.5	1.15
		Transverse stiffened plating	1.15	1.0	1.15
	Other longitudinal members	Longitudinal stiffened plating	1.10	0.50	1.00
		Transverse stiffened plating	1.10	1.00	1.00
	Transverse boundaries of ballast water tanks Transverse boundaries between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo		1.15	0.00	1.15
	Other members		1.00	0.00	1.00
	Longitudinal watertight boundaries 1)	Longitudinal stiffened plating	1.25	0.50	1.15
		Transverse stiffened plating	1.15	1.00	1.15
	Other watertight boundaries 1)		1.15	0.00	1.15
1) Only applicable for flooding pressure					

Ilustración 53: espesor de la chapa sometida a presiones, DNV

Calculamos α_p, siguiendo el DNV:

For symbols not defined in this section, see Ch.1 Sec.4.

α_p = correction factor for the panel aspect ratio to be taken as follows but not to be taken greater than 1.0:

$$\alpha_p = 1.2 - \frac{b}{2.1\,a}$$

a = length of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

b = breadth of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

P = design pressure for the considered design load set, see Sec.2 [2], calculated at the load calculation point defined in Ch.3 Sec.7 [2.2], in kN/m^2

σ_{hg} = hull girder longitudinal stress, in N/mm^2, as defined in Sec.2 [1], calculated at the load calculation point as defined in Ch.3 Sec.7 [2.2].

Ilustración 54 DNV

Siendo:

$$b = 700\ mm$$

$$a = 2400\ mm$$

Por lo que α_p:

$$\boldsymbol{\alpha_p = 1,06}$$

Procedemos ahora a calcular las presiones a las que está sometida esa chapa del doble fondo.

				Design load scenario						
				1	2	3	4	5	6	7
				Normal operations at harbour and sheltered water	Normal operation at sea	Flow through ballast water exchange	Overfilling of ballast tanks and tank testing	Flooding	Special operation stillwater 3)	Special operations at sea 3)
				Static (S)	Static + dynamic (S + D)	Static + dynamic (S + D)	Accidental (A) and testing (T)	Accidental (A)	Static (S)	Static + dynamic (S+D)
Load component	Hull girder loads		VBM	M_{sw}	M_{sw} + $M_{wv\text{-}LC}$	M_{sw} + $M_{wv\text{-}LC}$	M_{sw}	M_{sw}	M_{sw_i}	M_{sw_i} + $M_{wv\text{-}LC}$
			HBM	-	$M_{wh\text{-}LC}$	$M_{wh\text{-}LC}$	-	-	-	$M_{wh\text{-}LC}$
			VSF	Q_{sw}	Q_{sw} + $Q_{wv\text{-}LC}$	Q_{sw} + $Q_{wv\text{-}LC}$	-	-	Q_{sw_i}	Q_{sw_i} + $Q_{wv\text{-}LC}$
			TM 2)	M_{st}	M_{st} + $M_{wt\text{-}LC}$	M_{st} + $M_{wt\text{-}LC}$	M_{st}	M_{st}	M_{st_i}	M_{st_i} + $M_{wt\text{-}LC}$
	Local loads	P_{ex}	Exposed decks	-	P_D	-	-	-	P_s	P_S + P_W
			External shell	P_S	P_S + P_W	P_S + P_W	P_S	-	P_s	P_S + P_W
			Superstructure sides	-	max(P_W; P_{SI})	-	-	-	P_s	P_S + P_W
			Superstructure end bulkheads and deckhouse walls	-	P_A	-	-	-	P_s	P_S + P_W
		P_{in}	Boundaries of water ballast tanks 1)	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}	$P_{ls\text{-}2}$ + P_{ld}	max($P_{ls\text{-}4}$, $P_{ls\text{-}ST}$)	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
			Boundaries of tanks other than water ballast tanks			-	$P_{ls\text{-}ST}$	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
			Watertight boundaries	-	-	-	-	P_{fs}	-	-
			Boundaries of bulk cargo holds	P_{bs}	P_{bs} + P_{bd}	-	-	-	-	-
			Internal structures in tanks	P_{int}		-	-	-	-	-
		P_{dl}	Exposed decks and non-exposed decks and platforms	$P_{dl\text{-}s}$	$P_{dl\text{-}s}$ + $P_{dl\text{-}d}$	-	-	-	$P_{dl\text{-}s}$	$P_{dl\text{-}s}$ + $P_{dl\text{-}d}$

Ilustración 55: escenarios de diseño y cargas, DNV

Como vemos en la ilustración 52, la chapa está sometida a las siguientes presiones. Por un lado, la presión del tanque de fueloil que lleva debajo:

- Presión hidrostática del fluido del tanque (P_{ls-1}) que será 0.
- Presión dinámica debido a las aceleraciones que experimenta el fluido dentro del tanque (P_{ld})

Y, además, al ser el doble fondo y tener por encima la cubierta de doble fondo donde está la cámara de máquinas, estará sometida a las presiones debido a ésta y sus equipos:

- Presión sobre cubierta de cámara de máquinas estática (P_{dl-s})
- Presión sobre cubierta de cámara de máquinas dinámica (P_{dl-d})

Calculamos cada una de las presiones arriba expuestas:

Presión dinámica del fluido del tanque (P_{ld})

1.3 Dynamic liquid pressure

1.3.1 The dynamic pressure due to liquid in tanks and ballast holds, in kN/m² shall be taken as:

$$P_{\ell d} = f_{cd}\,\rho_L\left[a_Z(z_0 - z) + f_{ull-\ell}\,a_x(x_0 - x) + f_{ull-t}\,a_y(y_0 - y)\right]$$

where:

$f_{ull\text{-}\ell}$ = longitudinal acceleration correction factor for the ullage space above the liquid in tanks and ballast holds, taken as:
for strength assessment:
$f_{ull\text{-}\ell}$ = 0.62 for cargo tanks filled with any liquids inclusive water ballast
$f_{ull\text{-}\ell}$ = 1.0 for other cases
for fatigue assessment:

$$f_{ull-\ell} = 0.5 + \frac{|z_0 - z|}{\ell_{fs}}\frac{180}{\varphi\pi} \qquad \text{for cargo tanks and ballast holds}$$

$f_{ull\text{-}\ell}$ = 1.0 for other cases
$f_{ull\text{-}\ell}$ shall not be less than 0.0 nor greater than 1.0

ℓ_{fs} = cargo tank length at the top of the tank or length of the ballast hold hatch coaming, in m

$f_{ull\text{-}t}$ = transverse acceleration correction factor to account for the ullage space above the liquid in tanks and ballast holds, taken as:
for strength assessment:
$f_{ull\text{-}t}$ = 0.67 for cargo tanks filled with any liquids inclusive water ballast
$f_{ull\text{-}t}$ = 1.0 for other cases
for fatigue assessment:

$$f_{ull-t} = 0.5 + \frac{|z_0 - z|}{b_{top}}\frac{180}{\theta\pi} \qquad \text{for cargo tanks and ballast holds}$$

$f_{ull\text{-}t}$ = 1.0 for other cases

b_{top} = cargo tank breadth at the top of the tank or breadth of the ballast hold hatch coaming, in m determined at mid length of the tank or ballast hold hatch coaming

x_0 = X coordinate, in m, of the reference point

y_0 = Y coordinate, in m, of the reference point

z_0 = Z coordinate, in m, of the reference point.

Ilustración 56: presión dinámica del líquido

- f_{cd}

$$f_{cd} = 1$$

- ρ_l

$$\rho_l = 1{,}025\ {}^{t}/_{m^3}$$

- a_z

$$a_z = 2{,}62\ {}^{m}/_{s^2}$$

- a_x

$$a_x = -2{,}24\ {}^{m}/_{s^2}$$

- a_y

$$a_y = 0\ {}^{m}/_{s^2}$$

- x_0, y_0, z_0

x_0 = X coordinate, in m, of the reference point
y_0 = Y coordinate, in m, of the reference point
z_0 = Z coordinate, in m, of the reference point.

The reference point shall be taken as the point with the highest value of V_j, calculated for all points that define the upper boundary of the tank or ballast hold as follows:

$$V_j = a_X(x_j - x_G) + a_Y(y_j - y_G) + (a_Z + g)(z_j - z_G)$$

where:

x_j = X coordinate, in m, of the point j on the upper boundary of the tank or ballast hold
y_j = Y coordinate, in m, of the point j on the upper boundary of the tank or ballast hold
z_j = Z coordinate, in m, of the point j on the upper boundary of the tank or ballast hold.

The following simplified method of determination of the reference point assuming a rectangular shape with area equal A_{top} of the top of the tank or the ballast hold hatch coaming is acceptable, see Figure 1:

$$x_j = x_{top} \pm 0{,}5\ \ell_{fs}$$

$$y_j = y_{top} \pm 0.5 b_{top}$$

where

x_{top} = X coordinate, in m, of the centre of the rectangular area A_{top} at the top of the tank or the ballast hold hatch coaming
y_{top} = Y coordinate, in m, of the centre of the rectangular area A_{top} at the top of the tank or the ballast hold hatch coaming
A_{top} = $\ell_{fs} \cdot b_{top}$: the area of an rectangular shape at the top of the tank or the ballast hold hatch coaming, in m^2.

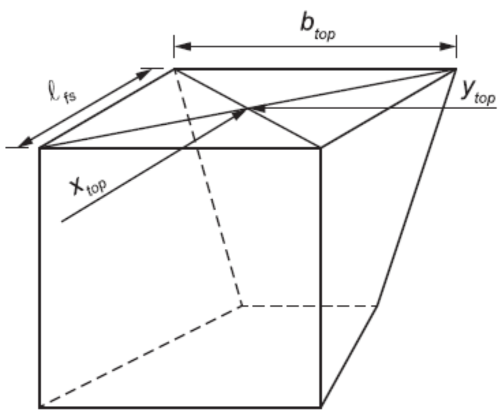


Figure 1 Area of a rectangular shape at the top of a tank

Ilustración 57: coordenadas del punto, DNV

- A_{top}

$$A_{top} = 93{,}15\ m^2$$

- x_{top}

$$x_{top} = 32{,}85\ m$$

- y_{top}

$$y_{top} = 0\ m$$

- x_j

$$x_j = 39{,}2\ m$$

- y_j

$$y_j = 3,66\,m$$

- z_j

$$z_j = 1,4\,m$$

Que serán nuestros puntos de referencia.

- *x, y, z*
  Son los puntos en los que estamos calculando los diferentes términos hasta ahora
- *f_{ull-l}*

$$f_{ull-l} = 0,62$$

- *f_{ull-t}*

$$f_{ull-t} = 0,67$$

Por lo tanto, una vez determinados todos los parámetros, la presión dinámica en el doble fondo es:

$$\boldsymbol{P_{ld} = -16,44\ {}^{kN}/_{m^2}}$$

Presión sobre cubierta de cámara de máquinas estática (P_{dl-s})

2 Non-exposed decks and platforms

2.1 Application

2.1.1 General

The loads on non-exposed decks including inner bottom are given in Sec.5 [2.3], except accommodation decks, wheelhouse decks and platforms in machinery space. For these decks loads defined in [2.2] and [2.3] are applicable.

2.2 Pressure due to distributed load

2.2.1 The static and dynamic pressures due to distributed load shall be considered. The distributed loads shall be calculated according to Sec.5 [2.3.1].

The static distributed load P_{dl-s}, including selfweight, shall be defined by the designer without being less than:

— 2.5 kN/m^2 (0.25 t/m^2 distributed mass) for accommodation decks, tween decks and platforms in general
— 3.5 kN/m^2 (0.35 t/m^2 distributed mass) for wheelhouse deck
— 8 kN/m^2 (0.8 t/m^2 distributed mass) for platforms in machinery space.

Ilustración 58: cargas en cubierta, DNV

Siguiendo la imagen mostrada arriba, para la cubierta de cámara de máquinas, la presión será de:

$$\boldsymbol{P_{dl-s} = 8\ {}^{kN}/_{m^2}}$$

Presión sobre cubierta dinámica (P_{dl-d})

La presión dinámica a la que estará sometida la cubierta será la presión que ejerzan los equipos de cámara de máquinas y personas que estén sobre ella sometidos a la aceleración sobre el eje Z:

$$P_{dl-d} = P_{dl-s}\ x\ {}^{a_z}/_{g}$$

Por lo tanto, calculamos la aceleración en el eje Z del buque en ese punto:

Aceleración vertical (a_z)

3.2.3 Vertical acceleration

The vertical acceleration at any position for each dynamic load case, in m/s², shall be taken as:

$$a_Z = f_\beta\left[C_{ZH}a_{heave} + C_{ZR}a_{roll}y - C_{ZP}a_{pitch}(x - 0{,}45L)\right]$$

Ilustración 59: aceleración vertical a_z, DNV

Calculamos a_Z:

- f_β

$$f_\beta = 1$$

- C_{ZH}

2.2 Load combination factors

2.2.1 The load combinations factors (LCFs) for the global loads and inertia load components for strength assessment are defined in:

— Table 4: LCFs for HSM, HSA and FSM load cases.
— Table 5: LCFs for BSR and BSP load cases.
— Table 6: LCFs for OST and OSA load cases.

Table 4 Load combination factors for HSM, HSA and FSM load cases - strength assessment

Load component		*LCF*	*HSM-1*	*HSM-2*	*HSA-1*	*HSA-2*	*FSM-1*	*FSM-2*
Hull girder loads	M_{WV}	C_{WV}	−1	1	−0.7	0.7	$-0.4f_T - 0.6$	$0.4f_T + 0.6$
	Q_{WV}	C_{QW}	$-1.0f_{lp}$	$1.0f_{lp}$	$-0.6f_{lp}$	$0.6f_{lp}$	$-1.0f_{lp}$	$1.0f_{lp}$
	M_{WH}	C_{WH}	0	0	0	0	0	0
	M_{WT}	C_{WT}	0	0	0	0	0	0
Longitudinal accelerations	a_{surge}	C_{XS}	$0.6 - 0.2f_T$	$0.2f_T - 0.6$	0.2	−0.2	$0.2 - 0.4f_T$	$0.4f_T - 0.2$
	$a_{pitch\text{-}x}$	C_{XP}	$-0.15\text{-}L_1/300$	$0.15\text{+}L_1/300$	−1.0	1.0	0.15	−0.15
	$g\sin\varphi$	C_{XG}	0.6	−0.6	$0.4f_T + 0.1$	$-0.4f_T - 0.1$	−0.2	0.2
Transverse accelerations	a_{sway}	C_{YS}	0	0	0	0	0	0
	$a_{roll\text{-}y}$	C_{YR}	0	0	0	0	0	0
	$g\sin\theta$	C_{YG}	0	0	0	0	0	0
Vertical accelerations	a_{heave}	C_{ZH}	$0.5f_T - 0.15$	$0.15 - 0.5f_T$	0.4	−0.4	0	0
	$a_{roll\text{-}z}$	C_{ZR}	0	0	0	0	0	0
	$a_{pitch\text{-}z}$	C_{ZP}	−0.7	0.7	−1.0	1.0	0.15	−0.15

Ilustración 60: factores de combinación de cargas, DNV

Como estamos en el caso HSM-1:

$$C_{ZH} = 0{,}35$$

- a_{heave}

2.2.3 Heave acceleration

The vertical acceleration due to heave, in m/s², shall be taken as:

$$a_{heave} = 0{,}8(1 + 0{,}03v)\left(0{,}72 + \frac{2L}{700}\right)\left(1{,}15 - \frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad L < 100\text{ m}$$

$$a_{heave} = \left(0{,}4 + \frac{L}{250}\right)\left(1 + 0{,}03v\left(3 - \frac{L}{50}\right)\right)\left(1{,}15 - \frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad 100 \le L < 150\text{ m}$$

$$a_{heave} = \left(1{,}15 - \frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad L \ge 150\text{ m}$$

where:

v = unless otherwise specified in Pt.5, to be taken as:
0 kt for $L < 100$ m
5 kt for $L \ge 150$ m
linear interpolation for L between 100 m and 150 m.

f_p = coefficient shall be taken as:

$f_p = f_{ps}$ for strength assessment

$f_p = f_R\left[\left(0{,}27 + 0{,}02f_T\right) - 17L \cdot 10^{-5}\right]$ for fatigue assessment.

Ilustración 61: a_{heave}, DNV

- $v = 0$
- $f_p = f_{ps} = 1$
- $a_0 = 0{,}962$

a_0 = acceleration parameter, shall be taken as:

$$a_0 = \left(1{,}58 - 0{,}47C_B\right)\left(\frac{2{,}4}{\sqrt{L}} + \frac{34}{L} - \frac{600}{L^2}\right)$$

Ilustración 62: parámetro de la aceleración, DNV

$$a_{heave} = 5{,}775\ {}^{m}/_{s^2}$$

- <u>C_{ZR}</u>

$$C_{ZR} = 0$$

Al ser C_{ZR} nulo, el cálculo de a_{roll} e ‘y’ no es necesario por el momento.

- <u>C_{ZP}</u>

$$C_{ZP} = -0{,}7$$

- <u>a_{pitch}</u>

2.2.5 Pitch acceleration

The pitch acceleration, in rad/s², shall be taken as:

$$a_{pitch} = 0{,}8(1 + 0{,}05v)f_p\left(0{,}72 + \frac{2L}{700}\right)\left(1{,}75 - \frac{22}{\sqrt{gL}}\right)\varphi\frac{\pi}{180}\left(\frac{2\pi}{T_\varphi}\right)^2 \qquad L < 100\text{ m}$$

Ilustración 63: a_{pitch}, DNV

- $\varphi = 33{,}86$ º

The pitch angle, in deg, shall be taken as given in formula below and need not to be taken greater than 20 degree in general, and not to taken greater than 20 f_r degrees for ships with service area restrictions:

$$\varphi = 920 f_p L^{-0.84}\left\{1.0 + \left(\frac{2.57}{\sqrt{gL}}\right)^{1.2}\right\}$$

where:

f_p = coefficient shall be taken as:
$f_p = f_{ps}$ for strength assessment
$f_p = f_R\left[\left(0.27 - 0.02 f_T\right) - \left(13 - 5 f_T\right) \cdot L \cdot 10^{-5}\right]$ for fatigue assessment.

Ilustración 64: ángulo φ, DNV

- T_φ = 6,52 s

The pitch period, in s, shall be taken as:

$$T_\varphi = \sqrt{\frac{2\pi\lambda_\varphi}{g}}$$

where:

$\lambda_\varphi = 0.6\left(1 + f_T\right)L$

Ilustración 65: Tφ, DNV

$$a_{pitch} = 0{,}31\ {rad}/{s^2}$$

Para x = 0.5L, calculamos a_Z:

$$\boldsymbol{a_z = 2{,}62\ {m}/{s^2}}$$

Por lo que la presión dinámica será:

$$\boldsymbol{P_{dl-d} = 2{,}14\ {kN}/{m^2}}$$

__Presión total sobre la cubierta de doble fondo__

Por lo tanto, la presión que deberá soportar será la más desfavorable entre la que hay por el lado de cámara de máquinas y la que hay por el doble fondo:

$$\boldsymbol{P_{cub.entrepuente} = 16{,}44\ {kN}/{m^2}}$$

Continuamos con los cálculos de los demás parámetros necesarios para hallar el espesor de la chapa de la cubierta entrepuente:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{\left|\sigma_{hg}\right|}{R_{eH}}$$ not to be taken greater than $C_{a\text{-}max}$

β_a = coefficient as defined in Table 1
α_a = coefficient as defined in Table 1
$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Ilustración 66: C_a, DNV

- __β_a__

$$\beta_a = 0{,}95$$

- __α_a__

$$\alpha_a = 0$$

Por lo tanto:

$$\boldsymbol{C_a = 0{,}95}$$

Y el coeficiente del material:

$$R_{eH} = 235 \ {}^{N}/_{mm^2}$$

Por lo que el espesor de la chapa es:

$$t = 3,18 \ mm$$

6.2.3. Espesor final de la chapa de la cubierta de doble fondo

El espesor de la chapa de la cubierta de doble fondo, en base a los cálculos realizados anteriormente será de:

$$t_{cub.\ doble\ fondo} = 7 \ mm$$

6.2.4. Cálculo de los refuerzos secundarios. Longitudinales

A continuación, vamos a calcular los refuerzos longitudinales del doble fondo.

El módulo requerido será:

1.1.2 Section modulus

The minimum net section modulus, in cm^3, shall not be taken less than the greatest value calculated for all applicable design load sets as defined in Sec.2 [2.1.3], given by:

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

where:

f_{bdg} = bending moment factor as defined in Table 5. For stiffeners with end fixity deviating from the ones included in Table 5, with complex load pattern, or being part of a grillage, the requirement given in [1.2] applies

f_m = bending moment ratio between end support and midspan as defined in Table 5

f_u = factor for unsymmetrical profiles, to be taken as:
= 1.00 for flat bars and symmetrical profiles (T-profiles)
= 1.03 for bulb profiles
= 1.15 for unsymmetrical profiles (L-profiles)

C_s = permissible bending stress coefficient as defined in Table 3 for the acceptance criteria given in Table 4

$C_{s\text{-}max}$ = coefficient, as defined in Table 4

α_s = coefficient, as defined in Table 4

β_s = coefficient, as defined in Table 4.

Table 3 Stiffeners, definition of C_s

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

Table 4 Stiffeners, definition of β_s, α_s and $C_{s\text{-}max}$

Acceptance criteria	*Structural member*		β_s	α_s	$C_{s\text{-}max}$
	Other members		0.85	0.00	0.85
AC-II	Longitudinal members		1.10	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal members	In general	1.20	1.00	1.00
		On watertight boundaries 1)	1.20	1.00	1.15
	Other members	In general	1.00	0.00	1.00
		On watertight boundaries 1)	1.15	0.00	1.15
1) Only applicable for flooding pressure					

Ilustración 67: módulo de la sección, DNV

Table 5 Stiffeners, definition of f_{bdg} and f_m

Coefficient	*Acceptance criteria*	*For continuous stiffeners with fixed ends*		*For continuous stiffeners with one fixed end and one simply supported end*	*For non-continuous stiffeners with simply supported ends*
		Horizontal stiffeners and upper end of vertical stiffeners	*Lower end of vertical stiffeners*	*Horizontal and vertical stiffeners*	*Horizontal and vertical stiffeners*
f_{bdg}	AC-I, AC-II, AC-III	12.00	10.00	8.00	8.00
f_m	AC-I	2.00	2.33	1.77	-
	AC-II, AC-III	1.60	1.86	1.42	

Ilustración 68: módulo de la sección DNV

- f_u

$$f_u = 1{,}03$$

- P

$$P = 16{,}44\ {}^{kN}/_{m^2}$$

- s

$$s = 700\ mm$$

- l_{bdg}

$$l_{bdg} = 2{,}4\ m$$

- f_{bdg}

$$f_{bdg} = 12$$

- C_s
  - β_S
  - α_S
  - σ_{hg}

$$\beta_S = 1{,}1$$

$$\alpha_S = 1$$

$$\sigma_{hg} = -22{,}75\ {}^{N}/_{mm^2}$$

$$C_s = 1$$

Por lo que el módulo necesario que debe dar el perfil es:

$$Z_{longitudinal\ doble\ fondo} = 24{,}13\ cm^3$$

Introduciéndonos en el catálogo del Anexo I de llantas bulbo, escogemos:

$$\mathbf{80\ x\ 6\ con\ W = 29\ cm^3}$$

Comprobamos, a continuación, que el perfil de llanta bulbo escogido cumple con el espesor mínimo determinado por el reglamento:

1.1 General

1.1.1 Web plating

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

$$t_w = \frac{C_m f_{shr} |P| s\, \ell_{shr}}{d_{shr} C_t \tau_{eH}}$$

where:

f_{shr} = shear force distribution factor as defined in Table 1. For stiffeners with end fixity deviating from the ones included in Table 1, with complex load pattern, or being part of a grillage, the requirements given in [1.2] apply.

C_t = permissible shear stress coefficient for the acceptance criteria being considered, as defined in Table 2

C_m = coefficient for combined axial stress, bending stress and shear stress in stiffener

= 1.0 for ships of length less than 90 m and for flat bars and bulb profiles

= $0{,}71\left(1-\left(\frac{0{,}75}{C_{xt}}\cdot\frac{Z}{Z_a}\right)^{e_0}\right)^{-\frac{1}{e_0}}$, not less than 1 in other cases

C_{xt} = $0.52C_{st} + 0.56$

C_{st} = 0.5 for $C_s \le 0{,}5$

= C_s for $0{,}5 < C_s < 0{,}95$

= 0.95 for $C_s \ge 0{,}95$

C_s = permissible bending stress coefficient as defined in [1.1.2]

Z = required net section modulus according to [1.1.2] in cm^3, shall not be taken greater than Z_a

Z_a = actual net elastic section modulus in cm^3, as defined in Ch.3 Sec.7 [1.4.4]

e_0 = $e_0 = 9{,}23\left(\frac{h_w}{t_{wa}}\sqrt{R_{eH}}\right)^{-0{,}25}$

t_{wa} = actual net web thickness of stiffener, in mm
h_w = depth of stiffener web, in mm, as shown in Ch.8 Sec.2.

Table 1 Definition of f_{shr}

Coefficient	For continuous stiffeners with fixed end			For non-continuous stiffeners with simply supported ends
	Horizontal stiffeners	Upper end of vertical stiffeners	Lower end of vertical stiffeners	All stiffeners
f_{shr}	0.5	0.4	0.7	0.5

Table 2 Stiffeners, definition of C_t

Acceptance criteria	Structural member	C_t
AC-I	All stiffeners	0.75
AC-II	All stiffeners	0.90
AC-III	All stiffeners	0.95

Ilustración 69: espesor refuerzo, DNV

- Cm

$$C_m = 1$$

- f_{shr}

$$f_{shr} = 0{,}5$$

- P

Presión en el fondo calculada anteriormente

- l_{shr}

$$l_{shr} = l - \frac{s}{2000}$$

Siendo 'l' la separación entre refuerzos primarios, igual a 2,4 m.

$$l_{shr} = 2{,}05$$

- d_{shr}

1.4.3 Effective shear depth of stiffeners

The effective shear depth of stiffeners, in mm, shall be taken as:

$d_{shr} = h_{stf} + t_p$ for $75° \leq \varphi_w \leq 90°$

$d_{shr} = (h_{stf} + t_p) \sin \varphi_w$ for $\varphi_w < 75°$

where:

h_{stf} = height of stiffener, in mm, as defined in Sec.2 Figure 1
t_p = net thickness of the attached plating, in mm, as defined in Sec.2 Figure 1
φ_w = angle, in deg, as defined in Figure 17.

Ilustración 70: profundidad de corte efectiva para los refuerzos

- h_{stf} y t_p

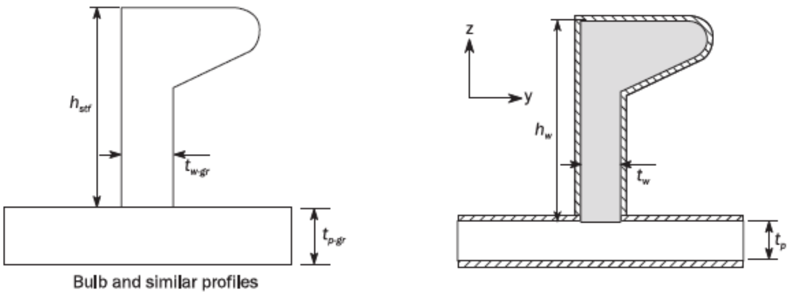


Figure 2 Net sectional properties of local supporting members (continued)

Ilustración 71: perfil bulbo, DNV

$$h_{stf} = b\ (tabla\ llanta\ bulbo) = 80\ mm$$
$$t_p = 7\ mm$$
$$d_{shr} = 87\ mm$$

- C_t

$$C_t = 0{,}9$$

- T_{eH}

τ_{eH}	specified shear yield stress, $\tau_{eH} = \frac{R_{eH}}{\sqrt{3}}$	N/mm^2

$$\tau_{eH} = 135{,}68\ {}^{N}/_{mm^2}$$

Por lo que el espesor del refuerzo debe ser:

$$t_w = 2{,}44\ mm$$

Por lo que el perfil escogido cumple los requisitos de espesor.

6.2.5. Cálculo de los refuerzos primarios. Varengas

Calculamos el módulo necesario que deben dar las varengas, colocadas cada 2400 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000\frac{|P|\, s\, \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1

C_s = permissible stress coefficient to be taken as:

C_s = 0.70 for AC-I

C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 72: módulo requerido en refuerzos primarios, DNV

- P
  Presión calculada en el fondo determinada anteriormente
- s

$$s = 2400\ mm$$

- l_{bdg}
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 2{,}28\ m$$

- f_{bdg}

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

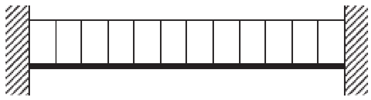
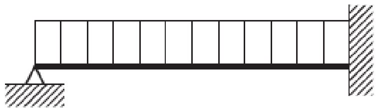
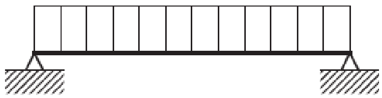
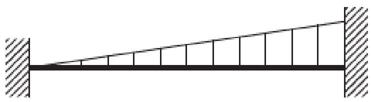
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
Position				*1*	*2*	*3*
Load model	*1 Support*	*2 Field*	*3 Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 73: DNV

Caracterizaremos la varenga como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- <u>C_s</u>
  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar la varenga es:

$$Z_{varenga\ doble\ fondo} = 85{,}56\ cm^3$$

Introduciéndonos en el Anexo I de llanta bulbo, escogemos:

$$\mathbf{140\ x\ 8\ con\ W = 87\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3
b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$

2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk

3) $bL_2 \leq 2.0$

4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 74: espesor t refuerzos primarios

Para el fondo del buque en la zona del doble fondo que son tanques:

$$a = 5$$

$$b = 0{,}03$$

Con los demás parámetros definidos:

$$t_{mínimo\ varenga\ doble\ fondo} = 6{,}66\ mm$$

Por lo tanto, cumple el espesor mínimo.

6.2.6. Cálculo de los refuerzos primarios. Vagras

Calculamos el módulo necesario que deben dar las vagras, colocadas con una separación entre ellas de 2800 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000 \frac{|P| s \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1

C_s = permissible stress coefficient to be taken as:

C_s = 0.70 for AC-I

C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 75: módulo requerido en refuerzos primarios, DNV

- P
  Presión calculada en el fondo determinada anteriormente
- s

$$s = 2800\ mm$$

- l_{bdg}
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 2{,}66\ m$$

- f_{bdg}

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

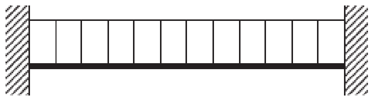
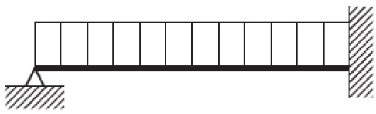
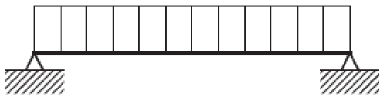
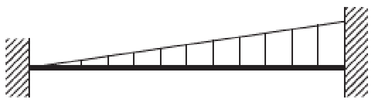
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
Position				*1*	*2*	*3*
Load model	*1* *Support*	*2* *Field*	*3* *Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 76: DNV

Caracterizaremos la vagra como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- $\underline{C_s}$
  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar la vagra es:

$$Z_{vagra\ doble\ fondo} = 135{,}87\ cm^3$$

Introduciéndonos en el Anexo I de llanta bulbo, escogemos:

$$\mathbf{180\ x\ 8\ con\ W = 161\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3
b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$
2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk
3) $bL_2 \leq 2.0$
4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 77: espesor t refuerzos primarios

Para el fondo del buque en la zona del doble fondo que son tanques:

$$a = 5$$

$$b = 0{,}03$$

Con los demás parámetros definidos:

$$t_{mínimo\ vagra\ doble\ fondo} = 6{,}66\ mm$$

Por lo tanto, cumple el espesor mínimo.

6.3. Escantillonado de los elementos de costado por debajo del cinturón de hielo

Calculamos las características de los elementos estructurales del costado del buque dimensionando, primeramente, el espesor de la chapa del forro, calculada a 1/3 del puntal de cada chapa de acero, como punto característico, para posterior seguir con el cálculo de las bulárcamas y palmejares.

6.3.1. Espesor mínimo de la chapa de costado bajo el cinturón de hielo

Siguiendo el DNV:

1.1 Minimum thickness requirements

1.1.1 The net thickness of plating, in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 1
b = coefficient as defined in Table 1.

For aluminum alloys, material factor $k$may be taken as equal to 1.

Table 1 Minimum net thickness for plating

Element	*Location*		*a*	*b*
Shell	Keel		5.0	0.05
	Bottom, bilge and sea chest boundaries		4.5	0.035
	Side shell and superstructure side	From upper end of bilge plating to T_{SC} + 4.6 m	4.0	0.035
		From T_{SC} + 4.6 m to T_{SC} + 6.9 m [6)]		0.025
		From T_{SC} + 6.9 m to T_{SC} + 9.2 m [6)]		0.015
		Elsewhere[6) 7)]		0.01
Deck	Weather deck[1),2),3),4), 5)] and strength deck[2),3)]		4.5	0.02
	Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk			0.015
	Other decks[3),4),5)]			0.01
Inner bottom	Cargo spaces loaded through cargo hatches except container holds		5.5	0.025
	Other spaces		4.5	0.02
Bulkheads	Bulkheads for cargo tanks, water ballast tanks and hold intended for cargo in bulk		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

Ilustración 78: espesores mínimos, DNV

Ya que la chapa que estamos calculando pertenece al costado del buque:

$$a = 4$$

$$b = 0{,}035$$

$$L_2 = 55{,}29\ m$$

Por lo tanto, el espesor mínimo del fondo será:

$$\boldsymbol{t_{min_{costado}} = 6\ mm}$$

6.3.2. Espesor de la chapa sometida a presiones bajo el cinturón de hielo

Siguiendo el DNV:

1 Plating subjected to lateral pressure

1.1 General

1.1.1 Plating

The net thickness, in mm, shall not be taken less than the greatest value for all applicable design load sets, as defined in Sec.2 [2.1.3], given by:

$$t = 0{,}0158\alpha_p b \sqrt{\frac{|P|}{C_a R_{eH}}}$$

where:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}}$$ not to be taken greater than $C_{a\text{-}max}$

β_a = coefficient as defined in Table 1

α_a = coefficient as defined in Table 1

$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Table 1 Plating, definition of β_a, α_a and $C_{a\text{-}max}$

Acceptance criteria	*Structural member*		β_a	α_a	$C_{a\text{-}max}$
AC-I	Longitudinal members	Longitudinal stiffened plating	0.90	0.50	0.80
		Transverse stiffened plating	0.90	1.00	0.80
	Other members		0.80	0.00	0.80
AC-II	Longitudinal members	Longitudinal stiffened plating	1.05	0.50	0.95
		Transverse stiffened plating	1.05	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal bulkhead members including possible bench structures between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo	Longitudinal stiffened plating	1.25	0.5	1.15
		Transverse stiffened plating	1.15	1.0	1.15
	Other longitudinal members	Longitudinal stiffened plating	1.10	0.50	1.00
		Transverse stiffened plating	1.10	1.00	1.00
	Transverse boundaries of ballast water tanks Transverse boundaries between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo		1.15	0.00	1.15
	Other members		1.00	0.00	1.00
	Longitudinal watertight boundaries [1)]	Longitudinal stiffened plating	1.25	0.50	1.15
		Transverse stiffened plating	1.15	1.00	1.15
	Other watertight boundaries [1)]		1.15	0.00	1.15
1) Only applicable for flooding pressure					

Ilustración 79: espesor de la chapa sometida a presiones, DNV

Calculamos α_p, siguiendo el DNV:

For symbols not defined in this section, see Ch.1 Sec.4.

α_p = correction factor for the panel aspect ratio to be taken as follows but not to be taken greater than 1.0:

$$\alpha_p = 1.2 - \frac{b}{2.1\,a}$$

a = length of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

b = breadth of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

P = design pressure for the considered design load set, see Sec.2 [2], calculated at the load calculation point defined in Ch.3 Sec.7 [2.2], in kN/m^2

σ_{hg} = hull girder longitudinal stress, in N/mm^2, as defined in Sec.2 [1], calculated at the load calculation point as defined in Ch.3 Sec.7 [2.2].

Ilustración 80 DNV

Siendo:

$$b = 600\ mm$$

$$a = 3200\ mm$$

Por lo que α_p:

$$\boldsymbol{\alpha_p = 1{,}11}$$

Procedemos ahora a calcular las presiones a las que está sometida esa chapa del costado.

				Design load scenario						
				1	2	3	4	5	6	7
				Normal operations at harbour and sheltered water	Normal operation at sea	Flow through ballast water exchange	Overfilling of ballast tanks and tank testing	Flooding	Special operation stillwater 3)	Special operations at sea 3)
				Static (S)	Static + dynamic (S + D)	Static + dynamic (S + D)	Accidental (A) and testing (T)	Accidental (A)	Static (S)	Static + dynamic (S+D)
Load component	Hull girder loads		VBM	M_{sw}	M_{sw} + $M_{wv\text{-}LC}$	M_{sw} + $M_{wv\text{-}LC}$	M_{sw}	M_{sw}	M_{sw_i}	M_{sw_i} + $M_{wv\text{-}LC}$
			HBM	-	$M_{wh\text{-}LC}$	$M_{wh\text{-}LC}$	-	-	-	$M_{wh\text{-}LC}$
			VSF	Q_{sw}	Q_{sw} + $Q_{wv\text{-}LC}$	Q_{sw} + $Q_{wv\text{-}LC}$	-	-	Q_{sw_i}	Q_{sw_i} + $Q_{wv\text{-}LC}$
			TM 2)	M_{st}	M_{st} + $M_{wt\text{-}LC}$	M_{st} + $M_{wt\text{-}LC}$	M_{st}	M_{st}	M_{st_i}	M_{st_i} + $M_{wt\text{-}LC}$
	Local loads	P_{ex}	Exposed decks	-	P_D	-	-	-	P_s	P_S + P_W
			External shell	P_S	P_S + P_W	P_S + P_W	P_S	-	P_s	P_S + P_W
			Superstructure sides	-	max(P_W; P_{SI})	-	-	-	P_s	P_S + P_W
			Superstructure end bulkheads and deckhouse walls	-	P_A	-	-	-	P_s	P_S + P_W
		P_{in}	Boundaries of water ballast tanks 1)	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}	$P_{ls\text{-}2}$ + P_{ld}	max($P_{ls\text{-}4}$; $P_{ls\text{-}ST}$)	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
			Boundaries of tanks other than water ballast tanks			-	$P_{ls\text{-}ST}$	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
			Watertight boundaries	-	-	-	-	P_{fs}	-	-
			Boundaries of bulk cargo holds	P_{bs}	P_{bs} + P_{bd}	-	-	-	-	-
			Internal structures in tanks	P_{int}		-	-	-	-	-
		P_{dt}	Exposed decks and non-exposed decks and platforms	$P_{dt\text{-}s}$	$P_{dt\text{-}s}$ + $P_{dt\text{-}d}$	-	-	-	$P_{dt\text{-}s}$	$P_{dt\text{-}s}$ + $P_{dt\text{-}d}$

Ilustración 81: escenarios de diseño y cargas, DNV

Calculamos la presión a la que estará sometida la chapa de costado a 1/3 del puntal de la chapa como punto de referencia, es decir, si el cinturón de hielo comienza a 3,5 m de la línea base, y el fondo acaba a 1,4 m sobre la línea base, la diferencia entre ellos es de 2,1 m que es lo que medirá la chapa de alto.

Calculamos a 1/3 de esos 2,1 m, es decir a 0,7 m mas 1,4 m, es decir a 2,1 m sobre la línea base como punto característico.

En ese punto la presión será la ejercida por el mar en el costado de dos maneras:

- Presión hidrostática (P_s), al estar sumergida a una determinada profundidad
- Presión por olas (P_w)

Presión hidrostática (P_s)

Calculamos el parámetro correspondiente a la presión hidrostática:

1.2 Hydrostatic pressure

1.2.1 The hydrostatic pressure, P_S at any load point, in kN/m^2, is obtained from Table 1. See also Figure 1.

Table 1 Hydrostatic pressure, PS

Location	Hydrostatic pressure, P_S, in kN/m^2
$z \leq T_{LC}$	$\rho g\ (T_{LC}-z)$
$z > T_{LC}$	0

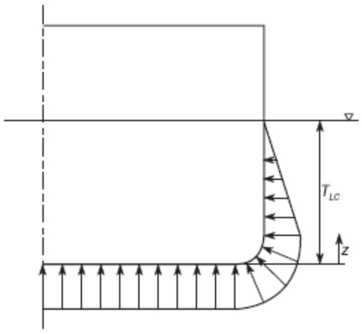


Figure 1 Transverse distribution of hydrostatic pressure Ps

Ilustración 82: presión hidrostática, DNV

Sustituyendo los valores:

$$\rho = 1{,}025\ {}^{t}/_{m^3}$$

$$g = 9{,}81\ {}^{m}/_{s^2}$$

$$T_{Lc} = T_{SC} = 5\ m$$

Y como estamos en el costado a 1/3 del puntal:

$$z = 2{,}6\ m$$

La presión hidrostática será:

$$\boldsymbol{P_s = 29{,}16\ {}^{kN}/_{m^2}}$$

Presión por olas (P_w)

Calculamos el parámetro de la presión debido al oleaje en el costado:

1.3 External dynamic pressures for strength assessment

1.3.1 General

The hydrodynamic pressures for each dynamic load case defined in Sec.2 [2] are defined in [1.3.2] to [1.3.8].

1.3.2 Hydrodynamic pressures for HSM load cases

The hydrodynamic pressures, P_W, for HSM-1 and HSM-2 load cases, at any load point, in kN/m^2, shall be obtained from Table 2. See also Figure 2 and Figure 3.

Table 2 Hydrodynamic pressures for HSM load cases

	Wave pressure [kN/m^2]		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
HSM-1	$P_W = \max\{-P_{HS}; \rho g(z - T_{LC})\}$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
HSM-2	$P_W = \max\{P_{HS}; \rho g(z - T_{LC})\}$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$

where:

$$P_{HS} = C_{f_T} f_{ps} f_{n\ell} f_h k_a k_p f_{yz} C_w \sqrt{\frac{L_0 + \lambda - 125}{L}}$$

C_{fT} = $f_T + 0.5 - (0.7 f_T - 0.2) C_B$

$f_{n\ell}$ = coefficient considering non-linear effects, to be taken as:
for extreme sea loads design load scenario:
$f_{nl} = 0.7$ at $f_{xL} = 0$
$f_{nl} = 0.9$ at $f_{xL} = 0.3$
$f_{nl} = 0.9$ at $f_{xL} = 0.7$
$f_{nl} = 0.6$ at $f_{xL} = 1$
for ballast water exchange design load scenario:
$f_{nl} = 0.85$ at $f_{xL} = 0$
$f_{nl} = 0.95$ at $f_{xL} = 0.3$
$f_{nl} = 0.95$ at $f_{xL} = 0.7$
$f_{nl} = 0.80$ at $f_{xL} = 1$.
Intermediate values are obtained by linear interpolation

f_{yz} = girth distribution coefficient, to be taken as:

$$f_{yz} = C_x \cdot \frac{z}{T_{LC}} + \left(2 - C_x\right) f_{yB} + 1$$

C_x = coefficient to be taken as:

$$C_x = 1{,}5 - \frac{|x - 0.5L|}{L}$$

f_h = coefficient to be taken as:

$$f_h = 3{,}0\left(1{,}21 - 0{,}66 f_T\right)$$

k_a = amplitude coefficient in the longitudinal direction of the ship, to be taken as:

$$k_a = \left(0{,}5 + f_T\right)\left[\left(3 - 2\sqrt{f_{yB}}\right) - \frac{20}{9} f_{xL}\left(7 - 6\sqrt{f_{yB}}\right)\right] + \frac{2}{3}\left(1 - f_T\right) \quad \text{for } f_{xL} < 0{,}15$$

$$k_a = 1{,}0 \quad \text{for } 0{,}15 \le f_{xL} < 0{,}7$$

$$k_a = 1 + \left(f_{xL} - 0{,}7\right)\left\{\left(\frac{40}{3} f_T - 5\right) + 2\left(1 - f_{yB}\right)\left[\frac{18}{C_B} f_T\left(f_{xL} - 0{,}7\right) - 0{,}25\left(2 - f_T\right)\right]\right\} \quad \text{for } f_{xL} \ge 0{,}7$$

λ = wave length of the dynamic load case, in m, to be taken as: $\lambda = 0.6(1 + f_T)L$

k_p = phase coefficient to be obtained from Table 3. Intermediate values shall be interpolated.

Ilustración 83: presión hidrodinámica, DNV

Table 3 Definition of phase coefficient K_p

f_{xL}	0	$0.3 - 0.1\ f_T$	$0.35 - 0.1\ f_T$	$0.8 - 0.2\ f_T$	$0.9 - 0.2\ f_T$	1.0
k_p	$-0.25\ f_T(1 + f_{yB})$	-1	1	1	-1	-1

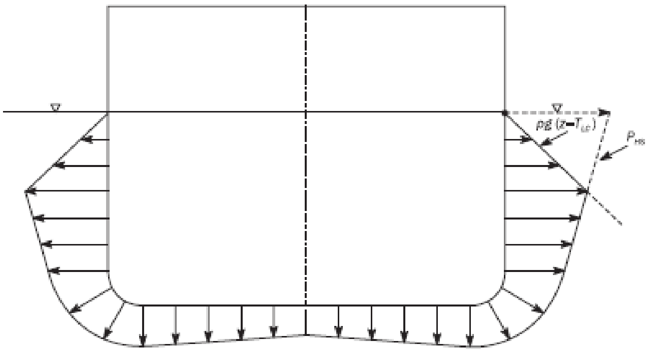


Figure 2 Transverse distribution amidships of dynamic pressure for HSM-1, HSA-1 and FSM-1 load cases

Ilustración 84: K_p y distribución transversal de presión dinámica según HSM-1, DNV

Escogiendo el HSM-1, nuestra P_w, será:

HSM-1	$P_W = \max\{-P_{HS}; \rho g(z - T_{LC})\}$

Calculamos $-P_{HS}$:

- $\underline{C_{fT}}$
  - $f_T = 1$

$$C_{fT} = 1{,}2$$

- $\underline{f_{ps}}$

$$f_{ps} = 1$$

- $\underline{f_{nl}}$
  - $f_{xL} = 0{,}5$

$$f_{nl} = 0{,}9$$

- $\underline{f_h}$

$$f_h = 1{,}65$$

- $\underline{k_a}$

$$k_a = 1$$

- $\underline{k_p}$

$$k_p = 1$$

- $\underline{f_{yz}}$
  - $C_x\ (x=0{,}5L) = 1{,}5$
  - $f_{yB}\ (y=5{,}75) = 1$

f_{yB} = ratio between Y-coordinate of the load point and B_x, to be taken as:

$f_{yB} = \frac{|2y|}{B_x}$ but not greater than 1.0

$f_{yB} = 1$ when $B_x = 0$

Ilustración 85: f_{yB}, DNV

$$f_{yz} = 2{,}13$$

- C_W

C_w = wave coefficient, shall be taken as:

$C_w = 0{,}0856L$	for	$L < 90$
$C_w = 10{,}75 - \left(\frac{300-L}{100}\right)^{1{,}5}$	for	$90 \leq L \leq 300$
$C_w = 10.75$	for	$300 < L \leq 350$
$C_w = 10.75 - \left(\frac{L-350}{150}\right)^{1{,}5}$	for	$350 < L \leq 500$

  - L = 55,29

$$C_W = 4{,}733$$

- L_0

$$L_0 = 110 \text{ m}$$

- λ

$$\lambda = 66{,}348 \text{ m}$$

- L: eslora de reglamento definida anteriormente e igual a 55,29 m

$$\boldsymbol{P_{HS} = 17{,}31\ {}^{kN}/_{m^2}}$$

Por otro lado, calculamos la otra componente para hacer el máximo entre P_{HS} y ella:

$$\boldsymbol{\rho g(z - T_{LC}) = -29{,}16\ {}^{kN}/_{m^2}}$$

Por lo tanto, el máximo entre ellas es:

$$\boldsymbol{P_W = 17{,}31\ {}^{kN}/_{m^2}}$$

Presión externa total

Por lo que la presión externa será:

$$P_{externa\ fondo} = P_S + P_W$$

$$\boldsymbol{P_{externa\ costado} = 46{,}47\ {}^{kN}/_{m^2}}$$

Continuamos con los cálculos de los demás parámetros necesarios para hallar el espesor de la chapa del costado:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}} \quad \text{not to be taken greater than } C_{a\text{-}max}$$

β_a = coefficient as defined in Table 1
α_a = coefficient as defined in Table 1
$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Ilustración 86: C_a, DNV

- β_a

$$\beta_a = 0{,}95$$

- α_a

$$\alpha_a = 0$$

Por lo tanto:

$$\boldsymbol{C_a = 0{,}95}$$

Y el coeficiente del material:

$$R_{eH} = 235\ {}^{N}/_{mm^2}$$

Por lo que el espesor de la chapa es:

$$t = 5\ mm$$

6.3.3. Espesor final de la chapa del costado bajo el cinturón de hielo

El espesor de la chapa del fondo, en base a los cálculos realizados anteriormente será de:

$$t_{costado} = 6\ mm$$

6.3.4. Cálculo de los refuerzos secundarios. Cuadernas

A continuación, vamos a calcular las cuadernas del costado entre el doble fondo y la cubierta de entrepuente.

El módulo requerido será:

1.1.2 Section modulus

The minimum net section modulus, in cm^3, shall not be taken less than the greatest value calculated for all applicable design load sets as defined in Sec.2 [2.1.3], given by:

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

where:

f_{bdg}	=	bending moment factor as defined in Table 5. For stiffeners with end fixity deviating from the ones included in Table 5, with complex load pattern, or being part of a grillage, the requirement given in [1.2] applies
f_m	=	bending moment ratio between end support and midspan as defined in Table 5
f_u	=	factor for unsymmetrical profiles, to be taken as:
	=	1.00 for flat bars and symmetrical profiles (T-profiles)
	=	1.03 for bulb profiles
	=	1.15 for unsymmetrical profiles (L-profiles)
C_s	=	permissible bending stress coefficient as defined in Table 3 for the acceptance criteria given in Table 4
$C_{s\text{-}max}$	=	coefficient, as defined in Table 4
α_s	=	coefficient, as defined in Table 4
β_s	=	coefficient, as defined in Table 4.

Table 3 Stiffeners, definition of C_s

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

Table 4 Stiffeners, definition of β_s, α_s and $C_{s\text{-}max}$

Acceptance criteria	*Structural member*		β_s	α_s	$C_{s\text{-}max}$
	Other members		0.85	0.00	0.85
AC-II	Longitudinal members		1.10	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal members	In general	1.20	1.00	1.00
		On watertight boundaries 1)	1.20	1.00	1.15
	Other members	In general	1.00	0.00	1.00
		On watertight boundaries 1)	1.15	0.00	1.15
1) Only applicable for flooding pressure					

Ilustración 87: módulo de la sección, DNV

Table 5 Stiffeners, definition of f_{bdg} and f_m

Coefficient	*Acceptance criteria*	*For continuous stiffeners with fixed ends*		*For continuous stiffeners with one fixed end and one simply supported end*	*For non-continuous stiffeners with simply supported ends*
		Horizontal stiffeners and upper end of vertical stiffeners	*Lower end of vertical stiffeners*	*Horizontal and vertical stiffeners*	*Horizontal and vertical stiffeners*
f_{bdg}	AC-I, AC-II, AC-III	12.00	10.00	8.00	8.00
f_m	AC-I	2.00	2.33	1.77	-
	AC-II, AC-III	1.60	1.86	1.42	

Ilustración 88: módulo de la sección DNV

- f_u

$$f_u = 1{,}03$$

- P

$$P = 46{,}47\ {}^{kN}/_{m^2}$$

- s

$$s = 600\ mm$$

- l_{bdg}

$$l_{bdg} = 2{,}4\ m$$

- f_{bdg}

$$f_{bdg} = 12$$

- C_s
  - β_S

$$\beta_S = 0{,}95$$

  - α_S

$$\alpha_S = 0$$

  - σ_{hg}

$$\sigma_{hg} = -22{,}75\ {}^{N}/_{mm^2}$$

$$C_s = 0{,}95$$

Por lo que el módulo necesario que debe dar el perfil es:

$$Z_{longitudinal\ costado\ bajo\ cinturon\ hielo} = 61{,}75\ cm^3$$

Introduciéndonos en el catálogo del Anexo I de llantas bulbo, escogemos:

$$\mathbf{120\ x\ 8\ con\ W = 63\ cm^3}$$

Comprobamos, a continuación, que el perfil de llanta bulbo escogido cumple con el espesor mínimo determinado por el reglamento:

1.1 General

1.1.1 Web plating

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

$$t_w = \frac{C_m f_{shr} |P| s\, \ell_{shr}}{d_{shr} C_t \tau_{eH}}$$

where:

f_{shr} = shear force distribution factor as defined in Table 1. For stiffeners with end fixity deviating from the ones included in Table 1, with complex load pattern, or being part of a grillage, the requirements given in [1.2] apply.

C_t = permissible shear stress coefficient for the acceptance criteria being considered, as defined in Table 2

C_m = coefficient for combined axial stress, bending stress and shear stress in stiffener

= 1.0 for ships of length less than 90 m and for flat bars and bulb profiles

= $0{,}71\left(1-\left(\frac{0{,}75}{C_{xt}}\cdot\frac{Z}{Z_a}\right)^{e_0}\right)^{-\frac{1}{e_0}}$, not less than 1 in other cases

C_{xt} = $0.52C_{st} + 0.56$

C_{st} = 0.5 for $C_s \le 0{,}5$

= C_s for $0{,}5 < C_s < 0{,}95$

= 0.95 for $C_s \ge 0{,}95$

C_s = permissible bending stress coefficient as defined in [1.1.2]

Z = required net section modulus according to [1.1.2] in cm^3, shall not be taken greater than Z_a

Z_a = actual net elastic section modulus in cm^3, as defined in Ch.3 Sec.7 [1.4.4]

e_0 = $e_0 = 9{,}23\left(\frac{h_w}{t_{wa}}\sqrt{R_{eH}}\right)^{-0{,}25}$

t_{wa} = actual net web thickness of stiffener, in mm
h_w = depth of stiffener web, in mm, as shown in Ch.8 Sec.2.

Table 1 Definition of f_{shr}

Coefficient	For continuous stiffeners with fixed end			For non-continuous stiffeners with simply supported ends
	Horizontal stiffeners	Upper end of vertical stiffeners	Lower end of vertical stiffeners	All stiffeners
f_{shr}	0.5	0.4	0.7	0.5

Table 2 Stiffeners, definition of C_t

Acceptance criteria	Structural member	C_t
AC-I	All stiffeners	0.75
AC-II	All stiffeners	0.90
AC-III	All stiffeners	0.95

Ilustración 89: espesor refuerzo, DNV

- Cm

$$C_m = 1$$

- f_{shr}

$$f_{shr} = 0{,}5$$

- P

Presión en el fondo calculada anteriormente

- l_{shr}

$$l_{shr} = l - \frac{s}{2000}$$

Siendo 'l' la separación entre refuerzos primarios, igual a 2,4 m.

$$l_{shr} = 2{,}05$$

- d_{shr}

1.4.3 Effective shear depth of stiffeners

The effective shear depth of stiffeners, in mm, shall be taken as:

$$d_{shr} = h_{stf} + t_p \qquad \text{for } 75° \le \varphi_w \le 90°$$
$$d_{shr} = (h_{stf} + t_p)\sin\varphi_w \qquad \text{for } \varphi_w < 75°$$

where:

h_{stf} = height of stiffener, in mm, as defined in Sec.2 Figure 1
t_p = net thickness of the attached plating, in mm, as defined in Sec.2 Figure 1
φ_w = angle, in deg, as defined in Figure 17.

Ilustración 90: profundidad de corte efectiva para los refuerzos

- h_{stf} y t_p

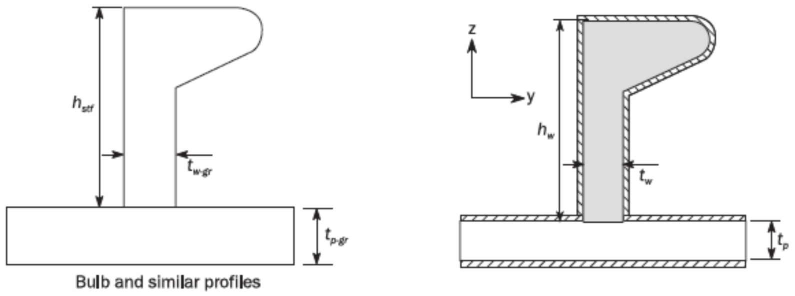


Figure 2 Net sectional properties of local supporting members (continued)

Ilustración 91: perfil bulbo, DNV

$$h_{stf} = b\ (tabla\ llanta\ bulbo) = 120\ mm$$
$$t_p = 6\ mm$$
$$d_{shr} = 126\ mm$$

- C_t

$$C_t = 0{,}9$$

- τ_{eH}

τ_{eH}	specified shear yield stress, $\tau_{eH} = \frac{R_{eH}}{\sqrt{3}}$	N/mm²

$$\tau_{eH} = 135{,}68\ {}^{N}/_{mm^2}$$

Por lo que el espesor del refuezo debe ser:

$$t_w = 2{,}16\ mm$$

Por lo que el perfil escogido cumple los requisitos de espesor.

6.3.5. Cálculo de los refuerzos primarios. Bulárcamas

Calculamos el módulo necesario que deben dar las bulárcamas, colocadas cada 2400 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000 \frac{|P| s \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1
C_s = permissible stress coefficient to be taken as:
C_s = 0.70 for AC-I
C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 92: módulo requerido en refuerzos primarios, DNV

- <u>P</u>
  Presión calculada en el costado determinada anteriormente
- <u>s</u>

$$s = 2400\ mm$$

- <u>l_{bdg}</u>
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 2{,}28\ m$$

- <u>f_{bdg}</u>

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

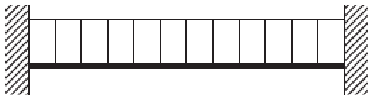
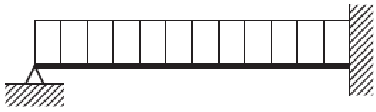
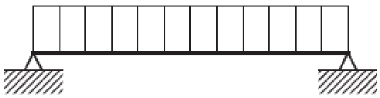
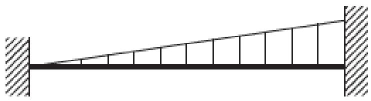
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
Position				*1*	*2*	*3*
Load model	*1* *Support*	*2* *Field*	*3* *Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 93: DNV

Caracterizaremos la bulárcama como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- $\underline{C_s}$
  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar la bulárcama es:

$$Z_{bulárcama\ costado} = 222{,}06\ cm^3$$

Introduciéndonos en el Anexo I de llanta bulbo, escogemos:

$$\mathbf{200\ x\ 9\ con\ W = 278\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3
b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$
2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk
3) $bL_2 \leq 2.0$
4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 94: espesor t refuerzos primarios

Para el costado del buque, casco hasta la cubierta de francobordo:

$$a = 4{,}5$$

$$b = 0{,}015$$

Con los demás parámetros definidos:

$$t_{mínimo\ bulárcama} = 5{,}33\ mm$$

Por lo tanto, cumple el espesor mínimo.

6.3.6. Cálculo de los refuerzos primarios. Palmejares

Calculamos el módulo necesario que deben dar los palmejares, situados entre cubiertas, con una separación de 3,2 m (altura entre cubiertas), según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000\frac{|P|\, s\, \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1

C_s = permissible stress coefficient to be taken as:

C_s = 0.70 for AC-I

C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 95: módulo requerido en refuerzos primarios, DNV

- <u>P</u>
  Presión calculada en el costado determinada anteriormente
- <u>s</u>

$$s = 3200\ mm$$

- <u>l_{bdg}</u>
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 3{,}04\ m$$

- <u>f_{bdg}</u>

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

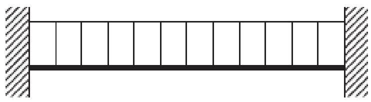
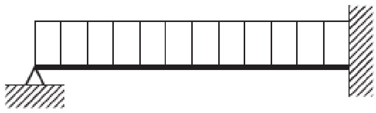
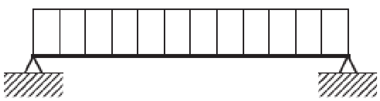
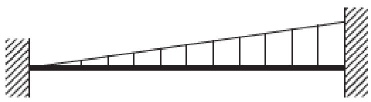
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
	Position			*1*	*2*	*3*
Load model	*1 Support*	*2 Field*	*3 Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 96: DNV

Caracterizaremos el palmejar como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- <u>C_s</u>
  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar el palmejar es:

$$Z_{palmejar} = 573{,}35\ cm^3$$

Introduciéndonos en el Anexo I de llanta bulbo, escogemos:

$$\mathbf{280\ x\ 12\ con\ W = 566\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3
b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening [4]	5.0	0.025 [1]
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 [2]
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 [3]
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$
2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk
3) $bL_2 \leq 2.0$
4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 97: espesor t refuerzos primarios

Para el costado del buque:

$$a = 4{,}5$$
$$b = 0{,}015$$

Con los demás parámetros definidos:

$$t_{mínimo\ palmejar} = 5{,}33\ mm$$

Por lo tanto, cumple el espesor mínimo.

6.4. Escantillonado de los elementos de costado por encima del cinturón de hielo

Calculamos las características de los elementos estructurales del costado del buque dimensionando, primeramente, el espesor de la chapa del forro, calculada a 1/3 del puntal de cada chapa de acero, como punto característico, para posterior seguir con el cálculo de las cuadernas, bulárcamas y palmejares.

6.4.1. Espesor mínimo de la chapa de costado sobre el cinturón de hielo

Siguiendo el DNV:

1.1 Minimum thickness requirements

1.1.1 The net thickness of plating, in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 1
b = coefficient as defined in Table 1.

For aluminum alloys, material factor $k$may be taken as equal to 1.

Table 1 Minimum net thickness for plating

Element	*Location*		*a*	*b*
Shell	Keel		5.0	0.05
	Bottom, bilge and sea chest boundaries		4.5	0.035
	Side shell and superstructure side	From upper end of bilge plating to T_{SC} + 4.6 m	4.0	0.035
		From T_{SC} + 4.6 m to T_{SC} + 6.9 m [6)]		0.025
		From T_{SC} + 6.9 m to T_{SC} + 9.2 m [6)]		0.015
		Elsewhere[6) 7)]		0.01
Deck	Weather deck[1),2),3),4), 5)] and strength deck[2),3)]		4.5	0.02
	Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk			0.015
	Other decks[3),4),5)]			0.01
Inner bottom	Cargo spaces loaded through cargo hatches except container holds		5.5	0.025
	Other spaces		4.5	0.02
Bulkheads	Bulkheads for cargo tanks, water ballast tanks and hold intended for cargo in bulk		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

Ilustración 98: espesores mínimos, DNV

Ya que la chapa que estamos calculando pertenece al costado del buque:

$$a = 4$$

$$b = 0{,}035$$

$$L_2 = 55{,}29\ m$$

Por lo tanto, el espesor mínimo del fondo será:

$$\boldsymbol{t_{min_{costado}} = 6\ mm}$$

6.4.2. Espesor de la chapa sometida a presiones sobre el cinturón de hielo

Siguiendo el DNV:

1 Plating subjected to lateral pressure

1.1 General

1.1.1 Plating

The net thickness, in mm, shall not be taken less than the greatest value for all applicable design load sets, as defined in Sec.2 [2.1.3], given by:

$$t = 0{,}0158\alpha_p b\sqrt{\frac{|P|}{C_a R_{eH}}}$$

where:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}}$$ not to be taken greater than $C_{a\text{-}max}$

β_a = coefficient as defined in Table 1

α_a = coefficient as defined in Table 1

$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Table 1 Plating, definition of β_a, α_a and $C_{a\text{-}max}$

Acceptance criteria	*Structural member*		β_a	α_a	$C_{a\text{-}max}$
AC-I	Longitudinal members	Longitudinal stiffened plating	0.90	0.50	0.80
		Transverse stiffened plating	0.90	1.00	0.80
	Other members		0.80	0.00	0.80
AC-II	Longitudinal members	Longitudinal stiffened plating	1.05	0.50	0.95
		Transverse stiffened plating	1.05	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal bulkhead members including possible bench structures between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo	Longitudinal stiffened plating	1.25	0.5	1.15
		Transverse stiffened plating	1.15	1.0	1.15
	Other longitudinal members	Longitudinal stiffened plating	1.10	0.50	1.00
		Transverse stiffened plating	1.10	1.00	1.00
	Transverse boundaries of ballast water tanks Transverse boundaries between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo		1.15	0.00	1.15
	Other members		1.00	0.00	1.00
	Longitudinal watertight boundaries 1)	Longitudinal stiffened plating	1.25	0.50	1.15
		Transverse stiffened plating	1.15	1.00	1.15
	Other watertight boundaries 1)		1.15	0.00	1.15
1) Only applicable for flooding pressure					

Ilustración 99: espesor de la chapa sometida a presiones, DNV

Calculamos α_p, siguiendo el DNV:

For symbols not defined in this section, see Ch.1 Sec.4.

α_p = correction factor for the panel aspect ratio to be taken as follows but not to be taken greater than 1.0:

$$\alpha_p = 1.2 - \frac{b}{2.1\,a}$$

a = length of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

b = breadth of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

P = design pressure for the considered design load set, see Sec.2 [2], calculated at the load calculation point defined in Ch.3 Sec.7 [2.2], in kN/m^2

σ_{hg} = hull girder longitudinal stress, in N/mm^2, as defined in Sec.2 [1], calculated at the load calculation point as defined in Ch.3 Sec.7 [2.2].

Ilustración 100 DNV

Siendo:

$$b = 600\ mm$$

$$a = 3200\ mm$$

Por lo que $\alpha_{p:}$

$$\boldsymbol{\alpha_p = 1,11}$$

Procedemos ahora a calcular las presiones a las que está sometida esa chapa del costado.

			Design load scenario						
			1	2	3	4	5	6	7
			Normal operations at harbour and sheltered water	Normal operation at sea	Flow through ballast water exchange	Overfilling of ballast tanks and tank testing	Flooding	Special operation stillwater 3)	Special operations at sea 3)
			Static (S)	Static + dynamic (S + D)	Static + dynamic (S + D)	Accidental (A) and testing (T)	Accidental (A)	Static (S)	Static + dynamic (S+D)
Load component	Hull girder loads	VBM	M_{sw}	M_{sw} + $M_{wv\text{-}LC}$	M_{sw} + $M_{wv\text{-}LC}$	M_{sw}	M_{sw}	M_{sw_i}	M_{sw_i} + $M_{wv\text{-}LC}$
		HBM	-	$M_{wh\text{-}LC}$	$M_{wh\text{-}LC}$	-	-	-	$M_{wh\text{-}LC}$
		VSF	Q_{sw}	Q_{sw} + $Q_{wv\text{-}LC}$	Q_{sw} + $Q_{wv\text{-}LC}$	-	-	Q_{sw_i}	Q_{sw_i} + $Q_{wv\text{-}LC}$
		TM 2)	M_{st}	M_{st} + $M_{wt\text{-}LC}$	M_{st} + $M_{wt\text{-}LC}$	M_{st}	M_{st}	M_{st_i}	M_{st_i} + $M_{wt\text{-}LC}$
	Local loads, P_{ex}	Exposed decks	-	P_D	-	-	-	P_s	P_S + P_W
		External shell	P_S	P_S + P_W	P_S + P_W	P_S	-	P_s	P_S + P_W
		Superstructure sides	-	max(P_W; P_{SI})	-	-	-	P_s	P_S + P_W
		Superstructure end bulkheads and deckhouse walls	-	P_A	-	-	-	P_s	P_S + P_W
	Local loads, P_{in}	Boundaries of water ballast tanks 1)	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}	$P_{ls\text{-}2}$ + P_{ld}	max($P_{ls\text{-}4}$, $P_{ls\text{-}ST}$)	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
		Boundaries of tanks other than water ballast tanks			-	$P_{ls\text{-}ST}$	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
		Watertight boundaries	-	-	-	-	P_{fs}	-	-
		Boundaries of bulk cargo holds	P_{bs}	P_{bs} + P_{bd}	-	-	-	-	-
		Internal structures in tanks	P_{int}		-	-	-	-	-
	Local loads, P_{dl}	Exposed decks and non-exposed decks and platforms	$P_{dl\text{-}s}$	$P_{dl\text{-}s}$ + $P_{dl\text{-}d}$	-	-	-	$P_{dl\text{-}s}$	$P_{dl\text{-}s}$ + $P_{dl\text{-}d}$

Ilustración 101: escenarios de diseño y cargas, DNV

Calculamos la presión a la que estará sometida la chapa de costado a 1/3 del puntal de la chapa como punto de referencia, es decir, si el cinturón de hielo termina a 5,3 m de la línea base (como observaremos posteriormente), y el puntal del buque hasta la cubierta principal es de 7,8 m, la diferencia entre ellos es de 2,5 m que es lo que medirá la chapa de alto.

Calculamos a 1/3 de esos 2,5 m, es decir a 0,83 m más 5,3 m, es decir a 6,13 m sobre la línea base como punto característico.

En ese punto la presión será la ejercida por el mar en el costado de dos maneras:

- Presión hidrostática (P_s), al estar sumergida a una determinada profundidad
- Presión por olas (P_w)

Presión hidrostática (P_s)

Calculamos el parámetro correspondiente a la presión hidrostática:

1.2 Hydrostatic pressure

1.2.1 The hydrostatic pressure, P_S at any load point, in kN/m^2, is obtained from Table 1. See also Figure 1.

Table 1 Hydrostatic pressure, PS

Location	Hydrostatic pressure, P_S, in kN/m^2
$z \le T_{LC}$	$\rho g\,(T_{LC}-z)$
$z > T_{LC}$	0

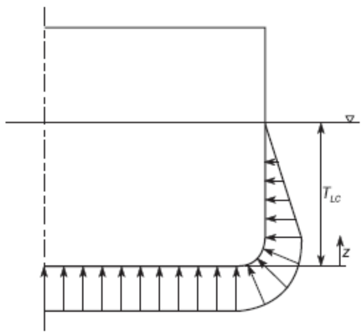


Figure 1 Transverse distribution of hydrostatic pressure Ps

Ilustración 102: presión hidrostática, DNV

Sustituyendo los valores:

$$\rho = 1{,}025\ {}^{t}/_{m^3}$$

$$g = 9{,}81\ {}^{m}/_{s^2}$$

$$T_{Lc} = T_{SC} = 5\,m$$

Y como estamos en el costado a 1/3 del puntal:

$$z = 6{,}13\,m$$

La presión hidrostática será:

$$\boldsymbol{P_s = 0\ {}^{kN}/_{m^2}}$$

La presión estática es igual a 0 ya que el punto en cuestión a esa altura no está bajo la línea de flotación al calado de escantillonado del buque.

Presión por olas (P_w)

Calculamos el parámetro de la presión debido al oleaje en el costado:

1.3 External dynamic pressures for strength assessment

1.3.1 General

The hydrodynamic pressures for each dynamic load case defined in Sec.2 [2] are defined in [1.3.2] to [1.3.8].

1.3.2 Hydrodynamic pressures for HSM load cases

The hydrodynamic pressures, P_W, for HSM-1 and HSM-2 load cases, at any load point, in kN/m^2, shall be obtained from Table 2. See also Figure 2 and Figure 3.

Table 2 Hydrodynamic pressures for HSM load cases

	Wave pressure [kN/m^2]		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
HSM-1	$P_W = \max\{-P_{HS}; \rho g(z - T_{LC})\}$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
HSM-2	$P_W = \max\{P_{HS}; \rho g(z - T_{LC})\}$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$

where:

$$P_{HS} = C_{f_T} f_{ps} f_{n\ell} f_h k_a k_p f_{yz} C_w \sqrt{\frac{L_0 + \lambda - 125}{L}}$$

C_{fT} = $f_T + 0.5 - (0.7f_T - 0.2)C_B$

$f_{n\ell}$ = coefficient considering non-linear effects, to be taken as:
for extreme sea loads design load scenario:
$f_{nl} = 0.7$ at $f_{xL} = 0$
$f_{nl} = 0.9$ at $f_{xL} = 0.3$
$f_{nl} = 0.9$ at $f_{xL} = 0.7$
$f_{nl} = 0.6$ at $f_{xL} = 1$
for ballast water exchange design load scenario:
$f_{nl} = 0.85$ at $f_{xL} = 0$
$f_{nl} = 0.95$ at $f_{xL} = 0.3$
$f_{nl} = 0.95$ at $f_{xL} = 0.7$
$f_{nl} = 0.80$ at $f_{xL} = 1$.
Intermediate values are obtained by linear interpolation

f_{yz} = girth distribution coefficient, to be taken as:

$$f_{yz} = C_x \cdot \frac{z}{T_{LC}} + \left(2 - C_x\right) f_{yB} + 1$$

C_x = coefficient to be taken as:

$$C_x = 1{,}5 - \frac{|x - 0.5L|}{L}$$

f_h = coefficient to be taken as:

$$f_h = 3{,}0\left(1{,}21 - 0{,}66 f_T\right)$$

k_a = amplitude coefficient in the longitudinal direction of the ship, to be taken as:

$$k_a = \left(0{,}5 + f_T\right)\left[\left(3 - 2\sqrt{f_{yB}}\right) - \frac{20}{9} f_{xL}\left(7 - 6\sqrt{f_{yB}}\right)\right] + \frac{2}{3}\left(1 - f_T\right) \quad \text{for } f_{xL} < 0{,}15$$

$$k_a = 1{,}0 \quad \text{for } 0{,}15 \le f_{xL} < 0{,}7$$

$$k_a = 1 + \left(f_{xL} - 0{,}7\right)\left\{\left(\frac{40}{3} f_T - 5\right) + 2\left(1 - f_{yB}\right)\left[\frac{18}{C_B} f_T\left(f_{xL} - 0{,}7\right) - 0{,}25\left(2 - f_T\right)\right]\right\} \quad \text{for } f_{xL} \ge 0{,}7$$

λ = wave length of the dynamic load case, in m, to be taken as: $\lambda = 0.6(1 + f_T)L$

k_p = phase coefficient to be obtained from Table 3. Intermediate values shall be interpolated.

Ilustración 103: presión hidrodinámica, DNV

Table 3 Definition of phase coefficient K_p

f_{xL}	0	$0.3 - 0.1\ f_T$	$0.35 - 0.1\ f_T$	$0.8 - 0.2\ f_T$	$0.9 - 0.2\ f_T$	1.0
k_p	$-0.25\ f_T(1 + f_{yB})$	-1	1	1	-1	-1

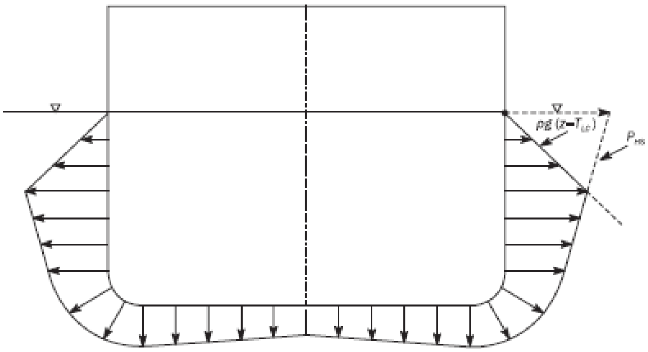


Figure 2 Transverse distribution amidships of dynamic pressure for HSM-1, HSA-1 and FSM-1 load cases

Ilustración 104: K_p y distribución transversal de presión dinámica según HSM-1, DNV

Escogiendo el HSM-1, nuestra P_w, será:

HSM-1	$P_W = \max\{-P_{HS}; \rho g(z - T_{LC})\}$

Calculamos $-P_{HS}$:

- C_{fT}
  - $f_T = 1$

$$C_{fT} = 1{,}2$$

- f_{ps}

$$f_{ps} = 1$$

- f_{nl}
  - $f_{xL} = 0{,}5$

$$f_{nl} = 0{,}9$$

- f_h

$$f_h = 1{,}65$$

- k_a

$$k_a = 1$$

- k_p

$$k_p = 1$$

- f_{yz}
  - $C_x\ (x=0{,}5L) = 1{,}5$
  - $f_{yB}\ (y=5{,}75) = 1$

f_{yB} = ratio between Y-coordinate of the load point and B_x, to be taken as:

$f_{yB} = \frac{|2y|}{B_x}$ but not greater than 1.0

$f_{yB} = 1$ when $B_x = 0$

Ilustración 105: f_{yB}, DNV

$$f_{yz} = 3{,}34$$

- C_W

C_w = wave coefficient, shall be taken as:

$C_w = 0{,}0856L$	for	$L < 90$
$C_w = 10{,}75 - \left(\frac{300-L}{100}\right)^{1{,}5}$	for	$90 \le L \le 300$
$C_w = 10.75$	for	$300 < L \le 350$
$C_w = 10.75 - \left(\frac{L-350}{150}\right)^{1{,}5}$	for	$350 < L \le 500$

  - L = 55,29

$$C_W = 4{,}733$$

- L_0

$$L_0 = 110 \text{ m}$$

- λ

$$\lambda = 66{,}348 \text{ m}$$

- L: eslora de reglamento definida anteriormente e igual a 55,29 m

$$\boldsymbol{P_{HS} = 27{,}14 \ {}^{kN}/_{m^2}}$$

Por otro lado, calculamos la otra componente para hacer el máximo entre P_{HS} y ella:

$$\boldsymbol{\rho g(z - T_{LC}) = 11{,}36 \ {}^{kN}/_{m^2}}$$

Por lo tanto, el máximo entre ellas es:

$$\boldsymbol{P_W = 27{,}14 \ {}^{kN}/_{m^2}}$$

Presión externa total

Por lo que la presión externa será:

$$P_{externa\ fondo} = P_S + P_W$$

$$\boldsymbol{P_{externa\ costado} = 27{,}14 \ {}^{kN}/_{m^2}}$$

Continuamos con los cálculos de los demás parámetros necesarios para hallar el espesor de la chapa del costado:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}}$$ not to be taken greater than $C_{a\text{-}max}$

β_a = coefficient as defined in Table 1
α_a = coefficient as defined in Table 1
$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Ilustración 106: C_a, DNV

- β_a

$$\beta_a = 0{,}95$$

- α_a

$$\alpha_a = 0$$

Por lo tanto:

$$\boldsymbol{C_a = 0{,}95}$$

Y el coeficiente del material:

$$R_{eH} = 235 \ ^{N}/_{mm^2}$$

Por lo que el espesor de la chapa es:

$$t = 3,67 \ mm$$

6.4.3. Espesor final de la chapa del costado sobre el cinturón de hielo

El espesor de la chapa del fondo, en base a los cálculos realizados anteriormente será de:

$$t_{costado} = 6 \ mm$$

6.4.4. Cálculo de los refuerzos secundarios. Cuadernas

A continuación, vamos a calcular las cuadernas del costado entre la cubierta de entrepuente y la cubierta principal del buque.

El módulo requerido será:

1.1.2 Section modulus

The minimum net section modulus, in cm^3, shall not be taken less than the greatest value calculated for all applicable design load sets as defined in Sec.2 [2.1.3], given by:

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

where:

f_{bdg} = bending moment factor as defined in Table 5. For stiffeners with end fixity deviating from the ones included in Table 5, with complex load pattern, or being part of a grillage, the requirement given in [1.2] applies

f_m = bending moment ratio between end support and midspan as defined in Table 5

f_u = factor for unsymmetrical profiles, to be taken as:

= 1.00 for flat bars and symmetrical profiles (T-profiles)

= 1.03 for bulb profiles

= 1.15 for unsymmetrical profiles (L-profiles)

C_s = permissible bending stress coefficient as defined in Table 3 for the acceptance criteria given in Table 4

$C_{s\text{-}max}$ = coefficient, as defined in Table 4

α_s = coefficient, as defined in Table 4

β_s = coefficient, as defined in Table 4.

Table 3 Stiffeners, definition of C_s

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

Table 4 Stiffeners, definition of β_s, α_s and $C_{s\text{-}max}$

Acceptance criteria	*Structural member*		β_s	α_s	$C_{s\text{-}max}$
	Other members		0.85	0.00	0.85
AC-II	Longitudinal members		1.10	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal members	In general	1.20	1.00	1.00
		On watertight boundaries 1)	1.20	1.00	1.15
	Other members	In general	1.00	0.00	1.00
		On watertight boundaries 1)	1.15	0.00	1.15
1) Only applicable for flooding pressure					

Ilustración 107: módulo de la sección, DNV

Table 5 Stiffeners, definition of f_{bdg} and f_m

Coefficient	*Acceptance criteria*	*For continuous stiffeners with fixed ends*		*For continuous stiffeners with one fixed end and one simply supported end*	*For non-continuous stiffeners with simply supported ends*
		Horizontal stiffeners and upper end of vertical stiffeners	*Lower end of vertical stiffeners*	*Horizontal and vertical stiffeners*	*Horizontal and vertical stiffeners*
f_{bdg}	AC-I, AC-II, AC-III	12.00	10.00	8.00	8.00
f_m	AC-I	2.00	2.33	1.77	-
	AC-II, AC-III	1.60	1.86	1.42	

Ilustración 108: módulo de la sección DNV

- f_u

$$f_u = 1{,}03$$

- P

$$P = 27{,}14\ {}^{kN}/_{m^2}$$

- s

$$s = 600\ mm$$

- l_{bdg}

$$l_{bdg} = 2{,}4\ m$$

- f_{bdg}

$$f_{bdg} = 12$$

- C_s
  - β_S

$$\beta_S = 0{,}95$$

  - α_S

$$\alpha_S = 0$$

  - σ_{hg}

$$\sigma_{hg} = 37{,}92\ {}^{N}/_{mm^2}$$

$$C_s = 0{,}95$$

Por lo que el módulo necesario que debe dar el perfil es:

$$Z_{longitudinal\ costado\ sobre\ cinturón\ hielo} = 42{,}07\ cm^3$$

Introduciéndonos en el catálogo del Anexo I de llantas bulbo, escogemos:

$$\mathbf{100\ x\ 8\ con\ W = 45\ cm^3}$$

Comprobamos, a continuación, que el perfil de llanta bulbo escogido cumple con el espesor mínimo determinado por el reglamento:

1.1 General

1.1.1 Web plating

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

$$t_w = \frac{C_m f_{shr} |P| s\, \ell_{shr}}{d_{shr} C_t \tau_{eH}}$$

where:

f_{shr} = shear force distribution factor as defined in Table 1. For stiffeners with end fixity deviating from the ones included in Table 1, with complex load pattern, or being part of a grillage, the requirements given in [1.2] apply.

C_t = permissible shear stress coefficient for the acceptance criteria being considered, as defined in Table 2

C_m = coefficient for combined axial stress, bending stress and shear stress in stiffener

= 1.0 for ships of length less than 90 m and for flat bars and bulb profiles

= $0{,}71\left(1-\left(\frac{0{,}75}{C_{xt}}\cdot\frac{Z}{Z_a}\right)^{e_0}\right)^{-\frac{1}{e_0}}$, not less than 1 in other cases

C_{xt} = $0.52C_{st} + 0.56$

C_{st} = 0.5 for $C_s \leq 0{,}5$

= C_s for $0{,}5 < C_s < 0{,}95$

= 0.95 for $C_s \geq 0{,}95$

C_s = permissible bending stress coefficient as defined in [1.1.2]

Z = required net section modulus according to [1.1.2] in cm^3, shall not be taken greater than Z_a

Z_a = actual net elastic section modulus in cm^3, as defined in Ch.3 Sec.7 [1.4.4]

e_0 = $e_0 = 9{,}23\left(\frac{h_w}{t_{wa}}\sqrt{R_{eH}}\right)^{-0{,}25}$

t_{wa} = actual net web thickness of stiffener, in mm
h_w = depth of stiffener web, in mm, as shown in Ch.8 Sec.2.

Table 1 Definition of f_{shr}

Coefficient	For continuous stiffeners with fixed end			For non-continuous stiffeners with simply supported ends
	Horizontal stiffeners	Upper end of vertical stiffeners	Lower end of vertical stiffeners	All stiffeners
f_{shr}	0.5	0.4	0.7	0.5

Table 2 Stiffeners, definition of C_t

Acceptance criteria	Structural member	C_t
AC-I	All stiffeners	0.75
AC-II	All stiffeners	0.90
AC-III	All stiffeners	0.95

Ilustración 109: espesor refuerzo, DNV

- Cm

$$C_m = 1$$

- f_{shr}

$$f_{shr} = 0{,}5$$

- P

Presión en el fondo calculada anteriormente

- l_{shr}

$$l_{shr} = l - \frac{s}{2000}$$

Siendo 'l' la separación entre refuerzos primarios, igual a 2,4 m.

$$l_{shr} = 2{,}05$$

- d_{shr}

1.4.3 Effective shear depth of stiffeners

The effective shear depth of stiffeners, in mm, shall be taken as:

$d_{shr} = h_{stf} + t_p$ for $75° \le \varphi_w \le 90°$

$d_{shr} = (h_{stf} + t_p) \sin \varphi_w$ for $\varphi_w < 75°$

where:

h_{stf} = height of stiffener, in mm, as defined in Sec.2 Figure 1
t_p = net thickness of the attached plating, in mm, as defined in Sec.2 Figure 1
φ_w = angle, in deg, as defined in Figure 17.

Ilustración 110: profundidad de corte efectiva para los refuerzos

- h_{stf} y t_p

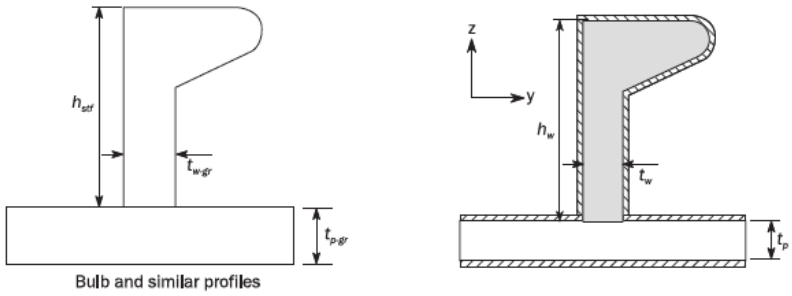


Figure 2 Net sectional properties of local supporting members (continued)

Ilustración 111: perfil bulbo, DNV

$$h_{stf} = b\ (tabla\ llanta\ bulbo) = 100\ mm$$
$$t_p = 6\ mm$$
$$d_{shr} = 106\ mm$$

- C_t

$$C_t = 0,9$$

- τ_{eH}

τ_{eH}	specified shear yield stress, $\tau_{eH} = \frac{R_{eH}}{\sqrt{3}}$	N/mm^2

$$\tau_{eH} = 135,68\ {}^{N}/_{mm^2}$$

Por lo que el espesor del refuerzo debe ser:

$$t_w = 1,5\ mm$$

Por lo que el perfil escogido cumple los requisitos de espesor.

6.4.5. Cálculo de los refuerzos primarios. Bulárcamas

Calculamos el módulo necesario que deben dar las bulárcamas, colocadas cada 2400 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000\frac{|P|\, s\, \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1

C_s = permissible stress coefficient to be taken as:

C_s = 0.70 for AC-I

C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 112: módulo requerido en refuerzos primarios, DNV

- P
  Presión calculada en el costado determinada anteriormente
- s

$$s = 2400\ mm$$

- l_{bdg}
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 2{,}28\ m$$

- f_{bdg}

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

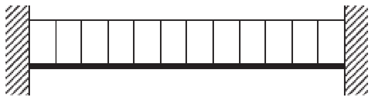
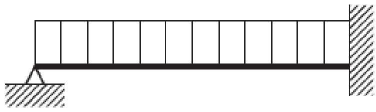
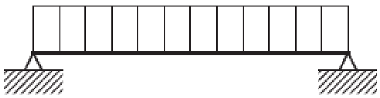
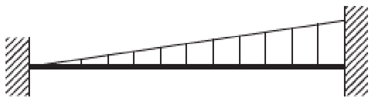
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
Position				*1*	*2*	*3*
Load model	*1* *Support*	*2* *Field*	*3* *Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 113: DNV

Caracterizaremos la bulárcama como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- <u>C_s</u>
  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar la bulárcama es:

$$Z_{bulárcama\ costado} = 141{,}25\ cm^3$$

Introduciéndonos en el Anexo I de llanta bulbo, escogemos:

$$\mathbf{180\ x\ 8\ con\ W = 278\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3

b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$
2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk
3) $bL_2 \leq 2.0$
4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 114: espesor t refuerzos primarios

Para el costado del buque, casco hasta la cubierta de francobordo:

$$a = 4{,}5$$

$$b = 0{,}015$$

Con los demás parámetros definidos:

$$t_{mínimo\ bulárcama} = 5{,}33\ mm$$

Por lo tanto, cumple el espesor mínimo.

6.4.6. Cálculo de los refuerzos primarios. Palmejares

Calculamos el módulo necesario que deben dar los palmejares, situados entre cubiertas, con una separación de 3,2 m (altura entre cubiertas), según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000\frac{|P|\, s\, \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1
C_s = permissible stress coefficient to be taken as:
C_s = 0.70 for AC-I
C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 115: módulo requerido en refuerzos primarios, DNV

- <u>P</u>
  Presión calculada en el costado determinada anteriormente
- <u>s</u>

$$s = 3200\ mm$$

- <u>l_{bdg}</u>
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 3{,}04\ m$$

- <u>f_{bdg}</u>

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

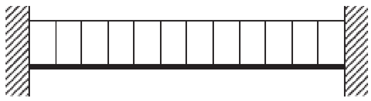
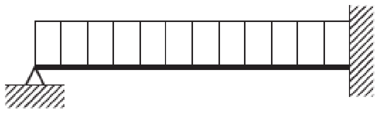
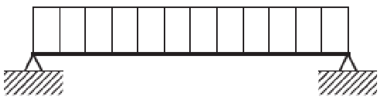
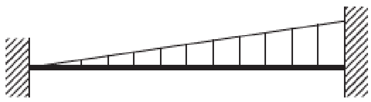
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
	Position			*1*	*2*	*3*
Load model	*1 Support*	*2 Field*	*3 Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 116: DNV

Caracterizaremos el palmejar como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- <u>C_s</u>
  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar el palmejar es:

$$Z_{palmejar} = 334{,}82\ cm^3$$

Introduciéndonos en el Anexo I de llanta bulbo, escogemos:

$$\mathbf{240\ x\ 10\ con\ W = 566\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3

b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$

2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk

3) $bL_2 \leq 2.0$

4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 117: espesor t refuerzos primarios

Para el costado del buque:

$$a = 4{,}5$$

$$b = 0{,}015$$

Con los demás parámetros definidos:

$$t_{mínimo\ palmejar} = 5{,}33\ mm$$

Por lo tanto, cumple el espesor mínimo.

6.5. Escantillonado del casco teniendo en cuenta la cota de hielo ICE 1-B

Una vez calculado el espesor de la chapa del costado, y fijándonos en la cota de clase de protección contra hielos ICE 1-B para la navegación en aguas árticas y antárticas, calculamos los requerimientos técnicos estructurales que requiere el buque según el reglamento Polar Code y el DNV.

6.5.1. ICE 1-B

La cota ICE 1-B hace referencia al refuerzo estructural que deben llevar los buques en su casco para la navegación en mares con bloques de hielo, específicamente, aunque es válido para la navegación en cualquier tipo de mar con hielo en su superficie, la clase 1-B especifica el refuerzo que deben llevar los buques para la navegación en el Báltico Norte.

Además, el DNV especifica que la cota de clase 1-B se refiere a los buques con capacidad de navegar en aguas infestadas de hielo en condiciones de hielo moderado con asistencia de rompehielos cuando sea necesario.

6.5.2. Material empleado

Según el reglamento DNV, el grado del acero empleado en la zona de protección contra hielos debe ser de grado B o AH:

Table 8 Minimum material grades for ships with ice strengthening

Structural member category	*Material grade*
Shell strakes in way of ice strengthening area for plates.	Grade B/AH

Ilustración 118: grados de material para buques con protección contra hielos

Por lo tanto, siguiendo el DNV, el acero escogido tendrá un límite elástico de 235 N/mm y según el reglamento:

2.2 Material factor, *k*

Unless otherwise specified, the material factor *k*, of normal and higher strength steel for hull girder strength and scantling purposes shall be taken as defined in Table 2.

For intermediate values of R_{eH}, *k* is obtained by linear interpolation.

Table 2 Material factor *k*

Specified minimum yield stress R_{eH}, in N/mm^2	*k*
235	1.00
315	0.78
355	0.72
390	0.66/0.68 1)
460	0.62

Ilustración 119: factor del material, K, DNV

Siguiendo la ilustración 93, el factor de material, 'K' será:

$$K = 1$$

6.5.3. Zona de protección contra hielos

A continuación, explicamos la zona de protección que debe tener el casco del buque para hacer frente a los posibles cascotes de hielo que se encuentre durante su navegación.

Dicha zona será un ***cinturón contra hielos*** como mostraremos en una imagen próximamente, y estará limitado por:

- LBWL (lowest ballast waterline)

Se corresponde con la línea de agua más baja en la condición de lastre del buque. En nuestro caso se corresponderá con el calado mínimo al que operará el buque en condiciones de tanques vacíos. Dicho calado lo obtenemos del Cuaderno 5 y es de 4,29 m.

- UIWL (upper ice wáter line)

Se corresponde con la línea de agua más alta en la que operará el buque en situación de hielo a su alrededor.
Se corresponderá con el calado de máxima carga a la salida de puerto ya que habrá alguna situación en la que el buque saldrá de puerto con los tanques llenos. Dicho calado lo obtenemos del Cuaderno 5 y es de 4,76 m.

Como hemos dicho anteriormente, la zona del casco de protección contra hielos, ***ice belt regions,*** no excederá los 5 m de profundidad en el costado en la zona de proa y en la zona media del buque, tal y como indica el DNV para la cota 1-B, y como apreciamos en la siguiente ilustración:

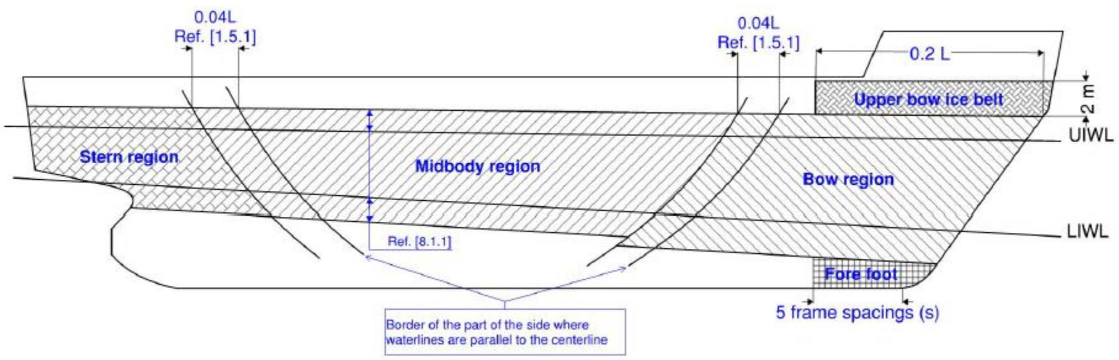


Ilustración 120: cinturón de protección contra hielos

Siguiendo el reglamento, determinamos la extensión exacta de la protección contra hielos que tendrá el buque:

Table 11 Vertical extension of ice belt

Ice class	*Region*	*Above UIWL [m]*	*Below LIWL [m]*
Ice(1A*F) and **Ice(1A*)**	Bow	0.60	1.20
	Midbody		
	Stern		1.0
Ice(1A)	Bow	0.50	0.90
	Midbody		0.75
	Stern		
Ice(1B) and **Ice(1C)**	Bow	0.40	0.70
	Midbody		0.60
	Stern		

Ilustración 121: extensión vertical del cinturón de hielo

Por lo tanto, siguiendo el DNV, para la región media y la cota 1-B:

- LBWL

$$LBWL = 4{,}29 - 0{,}6 = 3{,}69\ m$$

  Introduciendo un margen de seguridad:

$$\boldsymbol{LBWL = 3,5\ m}$$

- UIWL

$$UIWL = 4{,}76 + 0{,}4 = 5{,}16\ m$$

  Introduciendo un margen de seguridad:

$$\boldsymbol{UIWL = 5,3\ m}$$

6.5.4. Espesor de la chapa en el costado en la zona de protección contra hielos

Siguiendo el DNV, el espesor de la chapa en la zona de la región contra hielos, donde la estructura será transversal, se calcula como:

$$t = 21.1 \cdot s_1 \sqrt{\frac{f_1 \cdot P_{PL}}{R_{eH}}} + t_c$$

P_{PL} = 0.75 P
P = as given in [7.3]
s_1 = stiffener spacing measured along the plating between ordinary and/or intermediate stiffeners, in m
f_1 = $1.3 - \frac{4.2}{\left(\frac{h}{s_1} + 1.8\right)^2}$, maximum 1.0
f_2 = $0.6 + \frac{0.4}{\frac{h}{s_1}}$, when $\frac{h}{s_1} \leq 1$
= $1.4 - 0.4\,(h/s_1)$; when $1 \leq h/s_1 \leq 1.8$
h = As given in [7.2]
t_c = Increment for abrasion and corrosion in mm; normally 2 mm. If abrasion resistant coating which is type approved according to DNV-CP-0293 is used, t_c may be reduced by 1 mm.

Guidance note:
Abrasion resistant coating which is not type approved according to DNV-CP-0293 may be accepted based on adequate documentation of satisfactory service experience and laboratory tests.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

Ilustración 122: espesor de la chapa en región transversal, DNV

Donde:

- S_1, es la separación entre los elementos ya sean primarios o secundarios en el costado:

$$S_1 = 0{,}6\ m$$

- f_1

  Con S_1 igual a 0,6 y h igual a 0,25 para la cota 1-B:

7.2 Height of the ice load area

An ice strengthened ship is assumed to operate in open sea conditions corresponding to a level ice thickness not exceeding h_o. The design ice height (h) of the area actually under ice pressure at any particular point of time is, however, assumed to be only a fraction of the ice thickness. The values for h_o and h are given in Table 7.

Table 7 Values of h_o and h

Ice class	*h_o [m]*	*h [m]*
Ice(1A*F) and **Ice(1A*)**	1.0	0.35
Ice(1A)	0.8	0.30
Ice(1B)	0.6	0.25
Ice(1C)	0.4	0.22

Ilustración 123: valor de h, DNV

$$f_1 = 0{,}445\ m$$

- P_{PL}

Es el valor de la presión de hielo P, multiplicado por 0,75. Calculamos ahora la presión del hielo, P:

7.3 Ice pressure

The design ice pressure (based on a nominal ice pressure of 5600 kN/m^2), in kN/m^2, is determined by the formula:

$$P = 5600 \cdot c_d \cdot c_1 \cdot c_a$$

where:

c_d = factor which takes account of the influence of the size and engine output of the ship. This factor is taken as maximum c_d = 1. It is calculated by the formula:

$$c_d = \frac{a_1 \cdot k_1 + b_1}{1000}$$

$$k_1 = \frac{\sqrt{\Delta_f P_S}}{1000}$$

a_1 and b_1 are given in Table 8.

Table 8 Values of a_1 and b_1

	Region			
	Bow		*Midbody and stern*	
	$k_1 \leq 12$	*$k_1 > 12$*	*$k_1 \leq 12$*	*$k_1 > 12$*
a_1	30	6	8	2
b_1	230	518	214	286

Δ_f = displacement, in tonnes, as defined in [1.5.3]

P_S = machinery output, available when sailing in ice, in kW. If additional power sources are available for propulsion power (e.g. shaft motors) in addition to the power of the main engine(s), they shall also be included in the total engine output used as the basis for hull scantling calculations. The engine output used for the calculation of the hull scantlings shall be clearly stated on the shell expansion drawing. $P_S \geq P_{min}$, where P_{min} is defined in [7.1.4]

c_1 = factor that reflects the magnitude of the load expected in the hull area in question relative to the bow area.

The value of c_1 is given in Table 9.

Table 9 Values of c_1

Ice class	*Region*		
	Bow	*Midbody*	*Stern*
Ice(1A*F) and **Ice(1A*)**	1.0	1.0	0.75
Ice(1A)	1.0	0.85	0.65
Ice(1B)	1.0	0.70	0.45
Ice(1C)	1.0	0.50	0.25

For ice class **Ice(1A*F)** an additional lower bow ice belt, see [8.1.2], is defined with factor c_1 = 0.20.

c_a = factor which takes account of the probability that the full length of the area under consideration will be under pressure at the same time. It is calculated by the formula:

$$c_a = \sqrt{\frac{\ell_0}{\ell_a}}$$, maximum 1.0, minimum 0.35, ℓ_0 = 0.6 m

ℓ_a shall be taken as given in Table 10.

Table 10 Values of ℓ_a

Structure	*Type of framing*	ℓ_a
Shell	transverse	frame spacing
	longitudinal	1.7 × frame spacing
Frames	transverse	frame spacing
	longitudinal	span of frame
Ice stringer		span of stringer
Web frame		2 × web frame spacing

Ilustración 124: presión por hielo, DNV

c_d

- k_1
  Para el cálculo de k_1, calculamos primeramente Δ_f (correspondiente al desplazamiento mayor en condición de navegación en hielo, dado en el Cuaderno 5, desplazamiento a máxima carga) y P_s (correspondiente a la potencia entregada por la maquinaria de propulsión en la condición de navegación en hielos a velocidad crucero, en nuestro caso motores eléctricos conectados a los AziPODs, según el Cuaderno 6)

$$\Delta_f = 1840\ t$$
$$P_s = 1031\ kW$$

  Por lo tanto, k_1:

$$k_1 = 1{,}377$$

- a_1, b_1
  Por lo tanto, obtenido k_1 calculamos a_1 y b_1, para la sección media:

$$a_1 = 8$$
$$b_1 = 214$$

Por lo que ya estamos en disposición de calcular c_d:

$$C_d = 0{,}225$$

- c_1
  Para la cota 1-B y región central:

$$C_1 = 0{,}7$$

- c_a
  - l_o

$$l_0 = 0{,}6$$

- l_a
  Para el casco y una estructura transversal en los costados:

$$l_a = 0{,}6$$

Por lo que c_a:

$$C_a = 1$$

De esta manera, sustituimos los factores calculados anteriormente en la expresión de la presión, y obtenemos una presión de:

$$P = 882{,}07\ {}^{kN}/_{m^2}$$

Y un valor de P_{PL}:

$$P_{PL} = 661{,}55\ {}^{kN}/_{m^2}$$

- t_c

  Calculamos t_c, incremento por abrasión y corrosión:

$$t_c = 2\ mm$$

- R_{EH}

  Calculado anteriormente:

$$R_{eH} = 235\ {}^{N}/_{mm^2}$$

Obtenemos, finalmente, un espesor de la chapa del costado en el cinturón de hielo de:

$$t_{hielo} = 16{,}17\ mm$$

Por lo tanto, el espesor de la chapa del cinturón de hielo en la zona media del buque, donde se sitúa la cuaderna maestra, será de:

$$\boldsymbol{t_{hielo} = 16{,}5\ mm}$$

6.6. Escantillonado de los elementos de la cubierta de entrepuente

Calculamos las características de los elementos estructurales de la cubierta de entrepuente del buque, donde reposará la zona de laboratorios, hospital y lavandería.

Calculamos primeramente el espesor mínimo, para después calcular el espesor neto que debe tener la cubierta de entrepuente, y sus refuerzos tanto secundarios (longitudinales) como primarios (baos y esloras).

6.6.1. Espesor mínimo de la chapa de la cubierta de entrepuente

Siguiendo el DNV:

1.1 Minimum thickness requirements

1.1.1 The net thickness of plating, in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 1
b = coefficient as defined in Table 1.

For aluminum alloys, material factor $k$may be taken as equal to 1.

Table 1 Minimum net thickness for plating

Element	*Location*		*a*	*b*
Shell	Keel		5.0	0.05
	Bottom, bilge and sea chest boundaries		4.5	0.035
	Side shell and superstructure side	From upper end of bilge plating to T_{SC} + 4.6 m	4.0	0.035
		From T_{SC} + 4.6 m to T_{SC} + 6.9 m [6)]		0.025
		From T_{SC} + 6.9 m to T_{SC} + 9.2 m [6)]		0.015
		Elsewhere[6) 7)]		0.01
Deck	Weather deck[1),2),3),4), 5)] and strength deck[2),3)]		4.5	0.02
	Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk			0.015
	Other decks[3),4),5)]			0.01
Inner bottom	Cargo spaces loaded through cargo hatches except container holds		5.5	0.025
	Other spaces		4.5	0.02
Bulkheads	Bulkheads for cargo tanks, water ballast tanks and hold intended for cargo in bulk		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

Ilustración 125: espesores mínimos, DNV

Ya que la chapa que estamos calculando pertenece a la cubierta de entrepuente, que tiene debajo el espacio de máquinas, y por encima la cubierta principal e intemperie del buque:

$$a = 4{,}5$$

$$b = 0{,}01$$

$$L_2 = 55{,}29\ m$$

Por lo tanto, el espesor mínimo de la chapa de la cubierta de entrepuente será:

$$t_{min_{entrepuente}} = 5,5\ mm$$

6.6.2. Espesor de la chapa sometida a presiones

Siguiendo el DNV:

1 Plating subjected to lateral pressure

1.1 General

1.1.1 Plating

The net thickness, in mm, shall not be taken less than the greatest value for all applicable design load sets, as defined in Sec.2 [2.1.3], given by:

$$t = 0{,}0158\alpha_p b\sqrt{\frac{|P|}{C_a R_{eH}}}$$

where:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}}$$ not to be taken greater than $C_{a\text{-}max}$

β_a = coefficient as defined in Table 1

α_a = coefficient as defined in Table 1

$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Table 1 Plating, definition of β_a, α_a and $C_{a\text{-}max}$

Acceptance criteria	*Structural member*		β_a	α_a	$C_{a\text{-}max}$
AC-I	Longitudinal members	Longitudinal stiffened plating	0.90	0.50	0.80
		Transverse stiffened plating	0.90	1.00	0.80
	Other members		0.80	0.00	0.80
AC-II	Longitudinal members	Longitudinal stiffened plating	1.05	0.50	0.95
		Transverse stiffened plating	1.05	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal bulkhead members including possible bench structures between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo	Longitudinal stiffened plating	1.25	0.5	1.15
		Transverse stiffened plating	1.15	1.0	1.15
	Other longitudinal members	Longitudinal stiffened plating	1.10	0.50	1.00
		Transverse stiffened plating	1.10	1.00	1.00
	Transverse boundaries of ballast water tanks Transverse boundaries between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo		1.15	0.00	1.15
	Other members		1.00	0.00	1.00
	Longitudinal watertight boundaries 1)	Longitudinal stiffened plating	1.25	0.50	1.15
		Transverse stiffened plating	1.15	1.00	1.15
	Other watertight boundaries 1)		1.15	0.00	1.15
1) Only applicable for flooding pressure					

Ilustración 126: espesor de la chapa sometida a presiones, DNV

Calculamos α_p, siguiendo el DNV:

For symbols not defined in this section, see Ch.1 Sec.4.

α_p = correction factor for the panel aspect ratio to be taken as follows but not to be taken greater than 1.0:

$$\alpha_p = 1.2 - \frac{b}{2.1\,a}$$

a = length of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

b = breadth of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]

P = design pressure for the considered design load set, see Sec.2 [2], calculated at the load calculation point defined in Ch.3 Sec.7 [2.2], in kN/m^2

σ_{hg} = hull girder longitudinal stress, in N/mm^2, as defined in Sec.2 [1], calculated at the load calculation point as defined in Ch.3 Sec.7 [2.2].

Ilustración 127: DNV

Siendo:

$$b = 700\ mm$$

$$a = 2400\ mm$$

Por lo que α_p:

$$\boldsymbol{\alpha_p = 1,06}$$

Procedemos ahora a calcular las presiones a las que está sometida esa chapa de la cubierta entrepuente.

			Design load scenario						
			1	*2*	*3*	*4*	*5*	*6*	*7*
			Normal operations at harbour and sheltered water	*Normal operation at sea*	*Flow through ballast water exchange*	*Overfilling of ballast tanks and tank testing*	*Flooding*	*Special operation stillwater*[3)]	*Special operations at sea*[3)]
			Static (S)	*Static + dynamic (S + D)*	*Static + dynamic (S + D)*	*Accidental (A) and testing (T)*	*Accidental (A)*	*Static (S)*	*Static + dynamic (S+D)*
Load component	Hull girder loads	VBM	M_{sw}	M_{sw} + $M_{wv\text{-}LC}$	M_{sw} + $M_{wv\text{-}LC}$	M_{sw}	M_{sw}	M_{sw_i}	M_{sw_i} + $M_{wv\text{-}LC}$
		HBM	-	$M_{wh\text{-}LC}$	$M_{wh\text{-}LC}$	-	-	-	$M_{wh\text{-}LC}$
		VSF	Q_{sw}	Q_{sw} + $Q_{wv\text{-}LC}$	Q_{sw} + $Q_{wv\text{-}LC}$	-	-	Q_{sw_i}	Q_{sw_i} + $Q_{wv\text{-}LC}$
		TM [2)]	M_{st}	M_{st} + $M_{wt\text{-}LC}$	M_{st} + $M_{wt\text{-}LC}$	M_{st}	M_{st}	M_{st_i}	M_{st_i} + $M_{wt\text{-}LC}$
	Local loads, P_{ex}	Exposed decks	-	P_D	-	-	-	P_s	P_S + P_W
		External shell	P_S	P_S + P_W	P_S + P_W	P_S	-	P_s	P_S + P_W
		Superstructure sides	-	max(P_W; P_{SI})	-	-	-	P_s	P_S + P_W
		Superstructure end bulkheads and deckhouse walls	-	P_A	-	-	-	P_s	P_S + P_W
	Local loads, P_{in}	Boundaries of water ballast tanks[1)]	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}	$P_{ls\text{-}2}$ + P_{ld}	max($P_{ls\text{-}4}$, $P_{ls\text{-}ST}$)	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
		Boundaries of tanks other than water ballast tanks			-	$P_{ls\text{-}ST}$	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
		Watertight boundaries	-	-	-	-	P_{fs}	-	-
		Boundaries of bulk cargo holds	P_{bs}	P_{bs} + P_{bd}	-	-	-	-	-
		Internal structures in tanks	P_{int}		-	-	-	-	-
	Local loads, P_{dt}	Exposed decks and non-exposed decks and platforms	$P_{dt\text{-}s}$	$P_{dt\text{-}s}$ + $P_{dt\text{-}d}$	-	-	-	$P_{dt\text{-}s}$	$P_{dt\text{-}s}$ + $P_{dt\text{-}d}$

Ilustración 128: escenarios de diseño y cargas, DNV

2.3.1 Pressure due to distributed load

The static and dynamic pressures due to distributed load shall be considered, for example deck cargo or other equipment.

The total pressure, in kN/m^2, for the static (S) design load scenario shall be taken as:

$$P_{dl} = P_{dl-s}$$

The pressure, in kN/m^2, for the static plus dynamic (S + D) design load scenario shall be derived for each dynamic load case and shall be taken as:

$$P_{dl} = P_{dl-s} + P_{dl-d}$$

where:

$P_{dl\text{-}s}$ = static pressure, in kN/m^2, due to the distributed load, minimum 2.5 kN/m^2, including selfweight, unless a higher load is defined by the designer

$P_{dl\text{-}d}$ = dynamic pressure, in kN/m^2, due to the distributed load
= $P_{dl\text{-}s} \cdot a_z/g$

a_Z = vertical envelope acceleration, in m/s^2, as defined in Sec.3 [3.3.3]. Optionally, the acceleration for the considered dynamic load case, according to Sec.3 [3.2.3], may be applied.

Ilustración 129: presiones sobre cubiertas, DNV

Calculamos la presión a la que estará sometida la chapa que será la del peso de los equipos de laboratorio y personas que sostiene encima, estática y sometida a la aceleración en el eje z:

- Presión sobre cubierta estática ($P_{dl\text{-}s}$)
- Presión sobre cubierta dinámica ($P_{dl\text{-}d}$)

Presión sobre cubierta estática ($P_{dl\text{-}s}$)

2 Non-exposed decks and platforms

2.1 Application

2.1.1 General

The loads on non-exposed decks including inner bottom are given in Sec.5 [2.3], except accommodation decks, wheelhouse decks and platforms in machinery space. For these decks loads defined in [2.2] and [2.3] are applicable.

2.2 Pressure due to distributed load

2.2.1 The static and dynamic pressures due to distributed load shall be considered. The distributed loads shall be calculated according to Sec.5 [2.3.1].

The static distributed load $P_{dl\text{-}s}$, including selfweight, shall be defined by the designer without being less than:

— 2.5 kN/m^2 (0.25 t/m^2 distributed mass) for accommodation decks, tween decks and platforms in general
— 3.5 kN/m^2 (0.35 t/m^2 distributed mass) for wheelhouse deck
— 8 kN/m^2 (0.8 t/m^2 distributed mass) for platforms in machinery space.

Ilustración 130: cargas en cubierta, DNV

Para la cubierta de entrepuente que llevará encima los distintos laboratorios, hospital y lavandería:

$$\boldsymbol{P_{dl-s} = 2,5\ {}^{kN}/_{m^2}}$$

Presión sobre cubierta dinámica ($P_{dl\text{-}d}$)

La presión dinámica a la que estará sometida la cubierta será la presión que ejerzan los equipos y personas que estén sobre ella sometidos a la aceleración sobre el eje Z:

$$P_{dl-d} = P_{dl-s}\ x\ {}^{a_z}/_{g}$$

Por lo tanto, calculamos la aceleración en el eje Z del buque en ese punto:

Aceleración vertical (a_z)

3.2.3 Vertical acceleration

The vertical acceleration at any position for each dynamic load case, in m/s^2, shall be taken as:

$$a_Z = f_\beta \left[C_{ZH} a_{heave} + C_{ZR} a_{roll} y - C_{ZP} a_{pitch} (x - 0{,}45L) \right]$$

Ilustración 131: aceleración vertical a_z, DNV

Calculamos a_z:

- *f_β*

$$f_\beta = 1$$

- *C_{ZH}*

2.2 Load combination factors

2.2.1 The load combinations factors (LCFs) for the global loads and inertia load components for strength assessment are defined in:

— Table 4: LCFs for HSM, HSA and FSM load cases.
— Table 5: LCFs for BSR and BSP load cases.
— Table 6: LCFs for OST and OSA load cases.

Table 4 Load combination factors for HSM, HSA and FSM load cases - strength assessment

Load component		*LCF*	*HSM-1*	*HSM-2*	*HSA-1*	*HSA-2*	*FSM-1*	*FSM-2*
Hull girder loads	M_{WV}	C_{WV}	−1	1	−0.7	0.7	$-0.4f_T - 0.6$	$0.4f_T + 0.6$
	Q_{WV}	C_{QW}	$-1.0f_{lp}$	$1.0f_{lp}$	$-0.6f_{lp}$	$0.6f_{lp}$	$-1.0f_{lp}$	$1.0f_{lp}$
	M_{WH}	C_{WH}	0	0	0	0	0	0
	M_{WT}	C_{WT}	0	0	0	0	0	0
Longitudinal accelerations	a_{surge}	C_{XS}	$0.6 - 0.2f_T$	$0.2f_T - 0.6$	0.2	−0.2	$0.2 - 0.4f_T$	$0.4f_T - 0.2$
	$a_{pitch-x}$	C_{XP}	$-0.15-L_1/300$	$0.15+L_1/300$	−1.0	1.0	0.15	−0.15
	$g \sin\varphi$	C_{XG}	0.6	−0.6	$0.4f_T + 0.1$	$-0.4f_T - 0.1$	−0.2	0.2
Transverse accelerations	a_{sway}	C_{YS}	0	0	0	0	0	0
	a_{roll-y}	C_{YR}	0	0	0	0	0	0
	$g \sin\theta$	C_{YG}	0	0	0	0	0	0
Vertical accelerations	a_{heave}	C_{ZH}	$0.5f_T - 0.15$	$0.15 - 0.5f_T$	0.4	−0.4	0	0
	a_{roll-z}	C_{ZR}	0	0	0	0	0	0
	$a_{pitch-z}$	C_{ZP}	−0.7	0.7	−1.0	1.0	0.15	−0.15

Ilustración 132: factores de combinación de cargas, DNV

Como estamos en el caso HSM-1:

$$C_{ZH} = 0{,}35$$

- *a_{heave}*

2.2.3 Heave acceleration

The vertical acceleration due to heave, in m/s², shall be taken as:

$$a_{heave} = 0{,}8(1+0{,}03v)\left(0{,}72+\frac{2L}{700}\right)\left(1{,}15-\frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad L < 100 \text{ m}$$

$$a_{heave} = \left(0{,}4+\frac{L}{250}\right)\left(1+0{,}03v\left(3-\frac{L}{50}\right)\right)\left(1{,}15-\frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad 100 \le L < 150 \text{ m}$$

$$a_{heave} = \left(1.15-\frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad L \ge 150 \text{ m}$$

where:

v = unless otherwise specified in Pt.5, to be taken as:
0 kt for L < 100 m
5 kt for L ≥ 150 m
linear interpolation for L between 100 m and 150 m.

f_p = coefficient shall be taken as:

$f_p = f_{ps}$ for strength assessment

$f_p = f_R\left[\left(0{,}27+0{,}02f_T\right)-17L\cdot 10^{-5}\right]$ for fatigue assessment.

Ilustración 133: a_{heave}, DNV

- $v = 0$
- $f_p = f_{ps} = 1$
- $a_0 = 0{,}962$

a_0 = acceleration parameter, shall be taken as:

$$a_0 = \left(1{,}58-0{,}47C_B\right)\left(\frac{2{,}4}{\sqrt{L}}+\frac{34}{L}-\frac{600}{L^2}\right)$$

Ilustración 134: parámetro de la aceleración, DNV

$$a_{heave} = 5{,}775 \ {}^{m}/_{s^2}$$

➢ <u>C_{ZR}</u>

$$C_{ZR} = 0$$

Al ser C_{ZR} nulo, el cálculo de a_{roll} e 'y' no es necesario por el momento.

➢ <u>C_{ZP}</u>

$$C_{ZP} = -0{,}7$$

➢ <u>a_{pitch}</u>

2.2.5 Pitch acceleration

The pitch acceleration, in rad/s², shall be taken as:

$$a_{pitch} = 0{,}8(1+0{,}05v)f_p\left(0{,}72+\frac{2L}{700}\right)\left(1{,}75-\frac{22}{\sqrt{gL}}\right)\varphi\frac{\pi}{180}\left(\frac{2\pi}{T_\varphi}\right)^2 \qquad L < 100 \text{ m}$$

Ilustración 135: a_{pitch}, DNV

- $\varphi = 33{,}86$ º

The pitch angle, in deg, shall be taken as given in formula below and need not to be taken greater than 20 degree in general, and not to taken greater than 20 f_r degrees for ships with service area restrictions:

$$\varphi = 920 f_p L^{-0.84}\left\{1.0 + \left(\frac{2.57}{\sqrt{gL}}\right)^{1.2}\right\}$$

where:

f_p = coefficient shall be taken as:
$f_p = f_{ps}$ for strength assessment
$f_p = f_R\left[\left(0.27 - 0.02 f_T\right) - \left(13 - 5 f_T\right) \cdot L \cdot 10^{-5}\right]$ for fatigue assessment.

Ilustración 136: ángulo φ, DNV

- T_φ = 6,52 s

The pitch period, in s, shall be taken as:

$$T_\varphi = \sqrt{\frac{2\pi\lambda_\varphi}{g}}$$

where:

$\lambda_\varphi = 0.6\left(1 + f_T\right)L$

Ilustración 137: Tφ, DNV

$$a_{pitch} = 0{,}31\ {}^{rad}/_{s^2}$$

Para x = 0.5L, calculamos a_z:

$$\boldsymbol{a_z = 2,62\ {}^{m}/_{s^2}}$$

Por lo que la presión dinámica será:

$$\boldsymbol{P_{dl-d} = 0,668\ {}^{kN}/_{m^2}}$$

<u>Presión total sobre cubierta entrepuente</u>

Por lo tanto, la presión total sobre la cubierta entrepuente será:

$$\boldsymbol{P_{cub.entrepuente} = 3,17\ {}^{kN}/_{m^2}}$$

Continuamos con los cálculos de los demás parámetros necesarios para hallar el espesor de la chapa de la cubierta entrepuente:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{\left|\sigma_{hg}\right|}{R_{eH}}$$ not to be taken greater than C_{a-max}

β_a = coefficient as defined in Table 1
α_a = coefficient as defined in Table 1
C_{a-max} = maximum permissible bending stress coefficient as defined in Table 1.

Ilustración 138: C_a, DNV

- <u>β_a</u>

$$\beta_a = 0{,}95$$

- <u>α_a</u>

$$\alpha_a = 0$$

Por lo tanto:

$$\boldsymbol{C_a = 0,95}$$

Y el coeficiente del material:

$$R_{eH} = 235 \ {}^{N}/_{mm^2}$$

Por lo que el espesor de la chapa es:

$$t = 1,4 \ mm$$

6.6.3. Espesor final de la chapa de la cubierta de entrepuente

El espesor de la chapa de la cubierta entrepuente, en base a los cálculos realizados anteriormente será de:

$$t_{cub.entrepuente} = 5,5 \ mm$$

6.6.4. Cálculo de los refuerzos secundarios. Longitudinales

A continuación, vamos a calcular los refuerzos longitudinales de la cubierta de entrepuente.

El módulo requerido será:

1.1.2 Section modulus

The minimum net section modulus, in cm^3, shall not be taken less than the greatest value calculated for all applicable design load sets as defined in Sec.2 [2.1.3], given by:

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

where:

f_{bdg} = bending moment factor as defined in Table 5. For stiffeners with end fixity deviating from the ones included in Table 5, with complex load pattern, or being part of a grillage, the requirement given in [1.2] applies

f_m = bending moment ratio between end support and midspan as defined in Table 5

f_u = factor for unsymmetrical profiles, to be taken as:
= 1.00 for flat bars and symmetrical profiles (T-profiles)
= 1.03 for bulb profiles
= 1.15 for unsymmetrical profiles (L-profiles)

C_s = permissible bending stress coefficient as defined in Table 3 for the acceptance criteria given in Table 4

$C_{s\text{-}max}$ = coefficient, as defined in Table 4

α_s = coefficient, as defined in Table 4

β_s = coefficient, as defined in Table 4.

Table 3 Stiffeners, definition of C_s

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

Table 4 Stiffeners, definition of β_s, α_s and $C_{s\text{-}max}$

Acceptance criteria	Structural member		β_s	α_s	$C_{s\text{-}max}$
	Other members		0.85	0.00	0.85
AC-II	Longitudinal members		1.10	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal members	In general	1.20	1.00	1.00
		On watertight boundaries 1)	1.20	1.00	1.15
	Other members	In general	1.00	0.00	1.00
		On watertight boundaries 1)	1.15	0.00	1.15
1) Only applicable for flooding pressure					

Table 5 Stiffeners, definition of f_{bdg} and f_m

Coefficient	Acceptance criteria	For continuous stiffeners with fixed ends		For continuous stiffeners with one fixed end and one simply supported end	For non-continuous stiffeners with simply supported ends
		Horizontal stiffeners and upper end of vertical stiffeners	Lower end of vertical stiffeners	Horizontal and vertical stiffeners	Horizontal and vertical stiffeners
f_{bdg}	AC-I, AC-II, AC-III	12.00	10.00	8.00	8.00
f_m	AC-I	2.00	2.33	1.77	-
	AC-II, AC-III	1.60	1.86	1.42	

Ilustración 139: módulo de la sección DNV

- f_u

$$f_u = 1{,}03$$

- P

$$P = 3{,}17\ {}^{kN}/_{m^2}$$

- s

$$s = 700\ mm$$

- l_{bdg}

$$l_{bdg} = 2{,}4\ m$$

- f_{bdg}

$$f_{bdg} = 12$$

- C_s
  - β_S

$$\beta_S = 1{,}1$$

  - α_S

$$\alpha_S = 1$$

  - σ_{hg}

$$\sigma_{hg} = 37{,}92\ {}^{N}/_{mm^2}$$

$$C_S = 0{,}939$$

Por lo que el módulo necesario que debe dar el perfil es:

$$Z_{longitudinal\ entrepuente} = 4{,}97\ cm^3$$

Introduciéndonos en el catálogo del Anexo I de llantas bulbo, escogemos:

$$\mathbf{60\ x\ 4\ con\ W = 13\ cm^3}$$

Comprobamos, a continuación, que el perfil de llanta bulbo escogido cumple con el espesor mínimo determinado por el reglamento:

1.1 General

1.1.1 Web plating

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

$$t_w = \frac{C_m f_{shr} |P| s\, \ell_{shr}}{d_{shr} C_t \tau_{eH}}$$

where:

f_{shr} = shear force distribution factor as defined in Table 1. For stiffeners with end fixity deviating from the ones included in Table 1, with complex load pattern, or being part of a grillage, the requirements given in [1.2] apply.

C_t = permissible shear stress coefficient for the acceptance criteria being considered, as defined in Table 2

C_m = coefficient for combined axial stress, bending stress and shear stress in stiffener

= 1.0 for ships of length less than 90 m and for flat bars and bulb profiles

= $0{,}71\left(1-\left(\frac{0{,}75}{C_{xt}}\cdot\frac{Z}{Z_a}\right)^{e_0}\right)^{-\frac{1}{e_0}}$, not less than 1 in other cases

C_{xt} = $0.52C_{st} + 0.56$

C_{st} = 0.5 for $C_s \leq 0{,}5$

= C_s for $0{,}5 < C_s < 0{,}95$

= 0.95 for $C_s \geq 0{,}95$

C_s = permissible bending stress coefficient as defined in [1.1.2]

Z = required net section modulus according to [1.1.2] in cm^3, shall not be taken greater than Z_a

Z_a = actual net elastic section modulus in cm^3, as defined in Ch.3 Sec.7 [1.4.4]

e_0 = $e_0 = 9{,}23\left(\frac{h_w}{t_{wa}}\sqrt{R_{eH}}\right)^{-0{,}25}$

t_{wa} = actual net web thickness of stiffener, in mm

h_w = depth of stiffener web, in mm, as shown in Ch.8 Sec.2.

Table 1 Definition of f_{shr}

Coefficient	*For continuous stiffeners with fixed end*			*For non-continuous stiffeners with simply supported ends*
	Horizontal stiffeners	*Upper end of vertical stiffeners*	*Lower end of vertical stiffeners*	*All stiffeners*
f_{shr}	0.5	0.4	0.7	0.5

Table 2 Stiffeners, definition of C_t

Acceptance criteria	*Structural member*	C_t
AC-I	All stiffeners	0.75
AC-II	All stiffeners	0.90
AC-III	All stiffeners	0.95

Ilustración 140: espesor refuerzo, DNV

- <u>*Cm*</u>

$$C_m = 1$$

- <u>*f_{shr}*</u>

$$f_{shr} = 0{,}5$$

- <u>*P*</u>
  Presión en el fondo calculada anteriormente

- <u>*l_{shr}*</u>

$$l_{shr} = l - \frac{s}{2000}$$

Siendo 'l' la separación entre refuerzos primarios, igual a 2,4 m.

$$l_{shr} = 2{,}05$$

- <u>*d_{shr}*</u>

1.4.3 Effective shear depth of stiffeners

The effective shear depth of stiffeners, in mm, shall be taken as:

$$d_{shr} = h_{stf} + t_p \qquad \text{for } 75° \le \varphi_w \le 90°$$

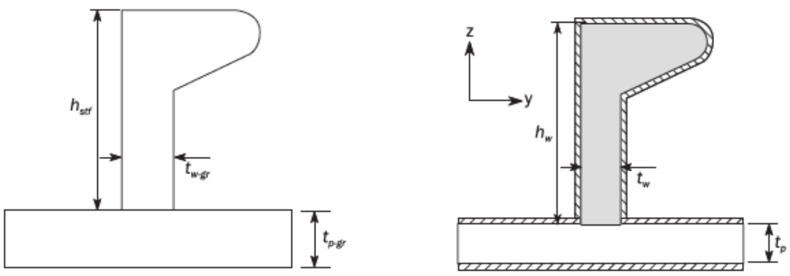
$$d_{shr} = (h_{stf} + t_p)\sin\varphi_w \qquad \text{for } \varphi_w < 75°$$

where:

h_{stf} = height of stiffener, in mm, as defined in Sec.2 Figure 1
t_p = net thickness of the attached plating, in mm, as defined in Sec.2 Figure 1
φ_w = angle, in deg, as defined in Figure 17.

Ilustración 141: profundidad de corte efectiva para los refuerzos

- <u>*h_{stf} y t_p*</u>



Bulb and similar profiles

Figure 2 Net sectional properties of local supporting members (continued)

Ilustración 142: perfil bulbo, DNV

$$h_{stf} = b\ (tabla\ llanta\ bulbo) = 60\ mm$$
$$t_p = 5{,}5\ mm$$
$$d_{shr} = 65{,}5\ mm$$

- <u>*C_t*</u>

$$C_t = 0{,}9$$

- <u>*T_{eH}*</u>

τ_{eH}	specified shear yield stress, $\tau_{eH} = \frac{R_{eH}}{\sqrt{3}}$	N/mm^2

$$\tau_{eH} = 135{,}68\ {}^{N}/_{mm^2}$$

Por lo que el espesor del refuerzo debe ser:

$$t_w = 0{,}28\ mm$$

Por lo que el perfil escogido cumple los requisitos de espesor.

6.6.5. Cálculo de los refuerzos primarios. Baos

Calculamos el módulo necesario que deben dar los baos, colocados cada 2400 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus
The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000 \frac{|P| s \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1
C_s = permissible stress coefficient to be taken as:
C_s = 0.70 for AC-I
C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 143: módulo requerido en refuerzos primarios, DNV

- <u>P</u>
  Presión calculada en la cubierta de entrepuente determinada anteriormente
- <u>s</u>

$$s = 2400\ mm$$

- <u>l_{bdg}</u>
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 2{,}28\ m$$

- <u>f_{bdg}</u>

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

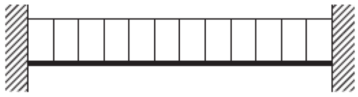
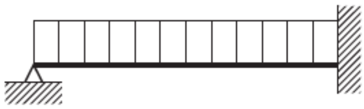
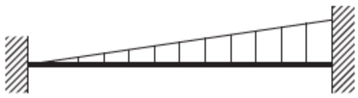
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
Position				*1*	*2*	*3*
Load model	*1* *Support*	*2* *Field*	*3* *Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 144: DNV

Caracterizaremos la varenga como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- <u>C_s</u>

  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar el bao es:

$$Z_{baos\ entrepunte} = 16{,}5\ cm^3$$

Introduciéndonos en el Anexo I de llantas bulbo, escogemos:

$$80\ x\ 5\ con\ W = 23\ cm^3$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3

b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$

2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk

3) $bL_2 \leq 2.0$

4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 145: espesor t refuerzos primarios

Para una cubierta, en este caso de entrepuente:

$$a = 5$$

$$b = 0{,}015$$

Con los demás parámetros definidos:

$$t_{mínimo\ bao\ cub.entrepuente} = 5{,}83\ mm$$

Por lo tanto, el refuerzo primario escogido que actuará como bao, no cumple el espesor mínimo.

Escogemos una llanta bulbo mayor que sí cumpla con dicho espesor:

$$\mathbf{80\ x\ 6\ con\ W = 117\ cm^3}$$

6.6.6. Cálculo de los refuerzos primarios. Esloras

Calculamos el módulo necesario que deben dar las esloras, colocadas con una separación entre ellas de 2800 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000\frac{|P|\, s\, \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1

C_s = permissible stress coefficient to be taken as:

C_s = 0.70 for AC-I

C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 146: módulo requerido en refuerzos primarios, DNV

- <u>P</u>
  Presión calculada en la cubierta de entrepuente determinada anteriormente
- <u>s</u>

$$s = 2800\ mm$$

- <u>l_{bdg}</u>
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 2{,}66\ m$$

- <u>f_{bdg}</u>

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

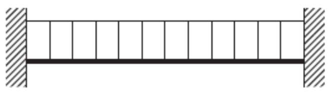
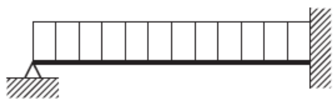
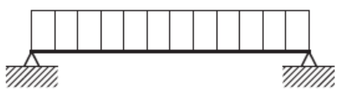
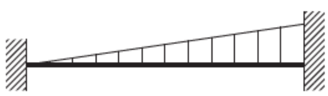
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
	Position			*1*	*2*	*3*
Load model	*1 Support*	*2 Field*	*3 Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 147: DNV

Caracterizaremos la varenga como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- <u>C_s</u>

  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar la eslora es:

$$Z_{esloras\ entrepunte} = 29{,}93\ cm^3$$

Introduciéndonos en el Anexo I de llantas bulbo, escogemos:

$$\mathbf{100\ x\ 6\ con\ W = 34{,}2\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3

b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$

2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk

3) $bL_2 \leq 2.0$

4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 148: espesor t refuerzos primarios

Para una cubierta, en este caso de entrepuente:

$$a = 5$$

$$b = 0{,}015$$

Con los demás parámetros definidos:

$$t_{mínimo\ eslora\ cub.entrepunte} = 5{,}83\ mm$$

Por lo tanto, el refuerzo primario escogido que actuará como eslora, sí cumple con el espesor mínimo.

6.7. Escantillonado de los elementos de la cubierta principal

Calculamos las características de los elementos estructurales de la cubierta principal del buque, que será de intemperie con posibilidad de embarque de agua, y con equipos a bordo tales como grúas o zodiacs que ejercerán una presión mayor sobre la cubierta y cuya estructura deberá soportar. En la zona de la cubierta donde se sitúen estos elementos pesados, se utilizarán refuerzos estructurales para que éstos vayan encima y dichos refuerzos soporten la carga sobre ellos.

Además, también contará con la primera zona de habilitación con cocina, salones y comedores, gimnasio y dos camarotes dobles.

Calculamos primeramente el espesor mínimo, para después calcular el espesor neto que debe tener la cubierta principal, y sus refuerzos tanto secundarios (longitudinales) como primarios (baos y esloras).

6.7.1. Espesor mínimo de la chapa de la cubierta principal

Siguiendo el DNV:

1.1 Minimum thickness requirements

1.1.1 The net thickness of plating, in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 1

b = coefficient as defined in Table 1.

For aluminum alloys, material factor $k$may be taken as equal to 1.

Table 1 Minimum net thickness for plating

Element	*Location*		*a*	*b*
Shell	Keel		5.0	0.05
	Bottom, bilge and sea chest boundaries		4.5	0.035
	Side shell and superstructure side	From upper end of bilge plating to T_{SC} + 4.6 m	4.0	0.035
		From T_{SC} + 4.6 m to T_{SC} + 6.9 m [6)]		0.025
		From T_{SC} + 6.9 m to T_{SC} + 9.2 m [6)]		0.015
		Elsewhere[6) 7)]		0.01
Deck	Weather deck[1),2),3),4), 5)] and strength deck[2),3)]		4.5	0.02
	Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk			0.015
	Other decks[3),4),5)]			0.01
Inner bottom	Cargo spaces loaded through cargo hatches except container holds		5.5	0.025
	Other spaces		4.5	0.02
Bulkheads	Bulkheads for cargo tanks, water ballast tanks and hold intended for cargo in bulk		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

Ilustración 149: espesores mínimos, DNV

Ya que la chapa que estamos calculando pertenece a la cubierta de entrepuente, que tiene debajo el espacio de máquinas, y por encima la cubierta principal e intemperie del buque:

$$a = 4{,}5$$

$$b = 0{,}02$$

$$L_2 = 55{,}29\ m$$

Por lo tanto, el espesor mínimo de la chapa de la cubierta principal será:

$$\boldsymbol{t_{min_{cub.\ principal}} = 6\ mm}$$

6.7.2. Espesor de la chapa sometida a presiones

Siguiendo el DNV:

1 Plating subjected to lateral pressure

1.1 General

1.1.1 Plating

The net thickness, in mm, shall not be taken less than the greatest value for all applicable design load sets, as defined in Sec.2 [2.1.3], given by:

$$t = 0{,}0158\alpha_p b \sqrt{\frac{|P|}{C_a R_{eH}}}$$

where:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{|\sigma_{hg}|}{R_{eH}}$$ not to be taken greater than $C_{a\text{-}max}$

β_a = coefficient as defined in Table 1

α_a = coefficient as defined in Table 1

$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Table 1 Plating, definition of β_a, α_a and $C_{a\text{-}max}$

Acceptance criteria	*Structural member*		β_a	α_a	$C_{a\text{-}max}$
AC-I	Longitudinal members	Longitudinal stiffened plating	0.90	0.50	0.80
		Transverse stiffened plating	0.90	1.00	0.80
	Other members		0.80	0.00	0.80
AC-II	Longitudinal members	Longitudinal stiffened plating	1.05	0.50	0.95
		Transverse stiffened plating	1.05	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal bulkhead members including possible bench structures between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo	Longitudinal stiffened plating	1.25	0.5	1.15
		Transverse stiffened plating	1.15	1.0	1.15
	Other longitudinal members	Longitudinal stiffened plating	1.10	0.50	1.00
		Transverse stiffened plating	1.10	1.00	1.00
	Transverse boundaries of ballast water tanks Transverse boundaries between tanks and dry spaces or dry cargo holds not intended to carry liquid or bulk cargo		1.15	0.00	1.15
	Other members		1.00	0.00	1.00
	Longitudinal watertight boundaries 1)	Longitudinal stiffened plating	1.25	0.50	1.15
		Transverse stiffened plating	1.15	1.00	1.15
	Other watertight boundaries 1)		1.15	0.00	1.15

1) Only applicable for flooding pressure

Ilustración 150: espesor de la chapa sometida a presiones, DNV

Calculamos α_p, siguiendo el DNV:

For symbols not defined in this section, see Ch.1 Sec.4.

α_p = correction factor for the panel aspect ratio to be taken as follows but not to be taken greater than 1.0:

$$\alpha_p = 1.2 - \frac{b}{2.1\,a}$$

a = length of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]
b = breadth of plate panel, in mm, as defined in Ch.3 Sec.7 [2.1.1]
P = design pressure for the considered design load set, see Sec.2 [2], calculated at the load calculation point defined in Ch.3 Sec.7 [2.2], in kN/m^2
σ_{hg} = hull girder longitudinal stress, in N/mm^2, as defined in Sec.2 [1], calculated at the load calculation point as defined in Ch.3 Sec.7 [2.2].

Ilustración 151: DNV

Siendo:

$$b = 700\ mm$$

$$a = 2400\ mm$$

Por lo que $\alpha_{p:}$

$$\boldsymbol{\alpha_p = 1,06}$$

Procedemos ahora a calcular las presiones a las que está sometida esa chapa de la cubierta principal.

				Design load scenario						
				1	2	3	4	5	6	7
				Normal operations at harbour and sheltered water	Normal operation at sea	Flow through ballast water exchange	Overfilling of ballast tanks and tank testing	Flooding	Special operation stillwater 3)	Special operations at sea 3)
				Static (S)	Static + dynamic (S + D)	Static + dynamic (S + D)	Accidental (A) and testing (T)	Accidental (A)	Static (S)	Static + dynamic (S+D)
Load component	Hull girder loads		VBM	M_{sw}	M_{sw} + $M_{wv\text{-}LC}$	M_{sw} + $M_{wv\text{-}LC}$	M_{sw}	M_{sw}	M_{sw_i}	M_{sw_i} + $M_{wv\text{-}LC}$
			HBM	-	$M_{wh\text{-}LC}$	$M_{wh\text{-}LC}$	-	-	-	$M_{wh\text{-}LC}$
			VSF	Q_{sw}	Q_{sw} + $Q_{wv\text{-}LC}$	Q_{sw} + $Q_{wv\text{-}LC}$	-	-	Q_{sw_i}	Q_{sw_i} + $Q_{wv\text{-}LC}$
			TM 2)	M_{st}	M_{st} + $M_{wt\text{-}LC}$	M_{st} + $M_{wt\text{-}LC}$	M_{st}	M_{st}	M_{st_i}	M_{st_i} + $M_{wt\text{-}LC}$
	Local loads	P_{ex}	Exposed decks	-	P_D	-	-	-	P_s	P_S + P_W
			External shell	P_S	P_S + P_W	P_S + P_W	P_S	-	P_s	P_S + P_W
			Superstructure sides	-	max(P_W; P_{SI})	-	-	-	P_s	P_S + P_W
			Superstructure end bulkheads and deckhouse walls	-	P_A	-	-	-	P_s	P_S + P_W
		P_{in}	Boundaries of water ballast tanks 1)	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}	$P_{ls\text{-}2}$ + P_{ld}	max($P_{ls\text{-}4}$, $P_{ls\text{-}ST}$)	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
			Boundaries of tanks other than water ballast tanks			-	$P_{ls\text{-}ST}$	-	$P_{ls\text{-}3}$	$P_{ls\text{-}1}$ + P_{ld}
			Watertight boundaries	-	-	-	-	P_{fs}	-	-
			Boundaries of bulk cargo holds	P_{bs}	P_{bs} + P_{bd}	-	-	-	-	-
			Internal structures in tanks	P_{int}		-	-	-	-	-
		P_{dl}	Exposed decks and non-exposed decks and platforms	$P_{dl\text{-}s}$	$P_{dl\text{-}s}$ + $P_{dl\text{-}d}$	-	-	-	$P_{dl\text{-}s}$	$P_{dl\text{-}s}$ + $P_{dl\text{-}d}$

Ilustración 152: escenarios de diseño y cargas, DNV

2.3.1 Pressure due to distributed load

The static and dynamic pressures due to distributed load shall be considered, for example deck cargo or other equipment.

The total pressure, in kN/m^2, for the static (S) design load scenario shall be taken as:

$$P_{dl} = P_{dl-s}$$

The pressure, in kN/m^2, for the static plus dynamic (S + D) design load scenario shall be derived for each dynamic load case and shall be taken as:

$$P_{dl} = P_{dl-s} + P_{dl-d}$$

where:

$P_{dl\text{-}s}$ = static pressure, in kN/m^2, due to the distributed load, minimum 2.5 kN/m^2, including selfweight, unless a higher load is defined by the designer

$P_{dl\text{-}d}$ = dynamic pressure, in kN/m^2, due to the distributed load

= $P_{dl\text{-}s} \cdot a_z/g$

a_Z = vertical envelope acceleration, in m/s^2, as defined in Sec.3 [3.3.3]. Optionally, the acceleration for the considered dynamic load case, according to Sec.3 [3.2.3], may be applied.

Ilustración 153: presiones sobre cubiertas, DNV

Calculamos la presión a la que estará sometida la chapa que será la del peso de los equipos y grúas dispuestos en la cubierta principal más las personas que sostiene encima, estática y sometida a la aceleración en el eje z, más el embarque de agua debido a que es una cubierta expuesta:

- Presión dinámica debido a los embarques de agua (green seas) por ser cubierta expuesta (P_D)
- Presión sobre cubierta estática ($P_{dl\text{-}s}$)
- Presión sobre cubierta dinámica ($P_{dl\text{-}d}$)

Presión debido a 'green seas' (P_D)

Siguiendo el DNV:

2.2 Green sea loads

2.2.1 Pressure on exposed deck

The external dynamic pressure due to green sea loading, P_D, at any point of an exposed deck, in kN/m^2, for the static plus dynamic (S + D) design load scenarios shall be derived for each dynamic load case and shall be taken as defined in [2.2.3] to [2.2.4].

The external dynamic pressure due to green sea loading, P_D, at any point of an exposed deck for the static (S) design load scenarios is zero.

2.2.2 If a wave breaker is fitted on the exposed deck, no reduction in the green sea pressure is allowed for the area of the exposed deck located aft of the wave breaker.

2.2.3 HSM, HSA and FSM load cases

The external pressure, P_D, for HSM, HSA and FSM load cases, at any load point of an exposed deck shall be obtained, in kN/m^2, from the following formula, see Figure 2 and Figure 3:

$$P_D = \max\left(\chi P_{D\text{-}min},\ P_{W,D} - \rho g\,(z - z_{dk})\right), \text{ but not to be taken less than } 0$$

where:

$P_{W,D}$ = pressure in kN/m^2 obtained at ship's side, at vertical coordinate equal to z_{dk} for HSM, HSA and FSM load cases as defined in [1.3]

$P_{D\text{-}min}$ = minimum pressure on exposed freeboard deck, in kN/m^2, to be taken as:

for global or partial ship finite element analysis according to Ch.7: $P_{D\text{-}min} = 0$

for PSM grillage according to Ch.6 Sec.6: $P_{D\text{-}min} = 0$

for other cases: $P_{D\text{-}min}$ as defined in Table 31

χ = reduction factor for pressure on exposed deck above freeboard deck:

$\chi = 0.75^C$, when $C < 3$

$\chi = 2.5 / P_{D\text{-}min}$, when $C \geq 3$

$\chi = 0$, when $P_{D\text{-}min} = 0$

$\chi = 1.0$ for freeboard deck

C = $(z_{dk} - z_{fdk})/2.3$

z_{fdk} = distance from baseline to freeboard deck considered at side, in m

z_{dk} = distance from baseline to lowest point of the exposed deck considered, in m

z = distance from baseline to load point, in m.

If a recess without coaming is arranged in the weather deck, P_D shall be tapered linearly down to the edge of the recess, but not to be taken less than $\chi P_{D\text{-}min}$, see Figure 12. Forward and aft of the recess the pressure may be tapered linearly down to the line as shown in Figure 12. The minimum pressure $\chi P_{D\text{-}min}$ for the weather deck shall be applied to the exposed deck in way of the recess.

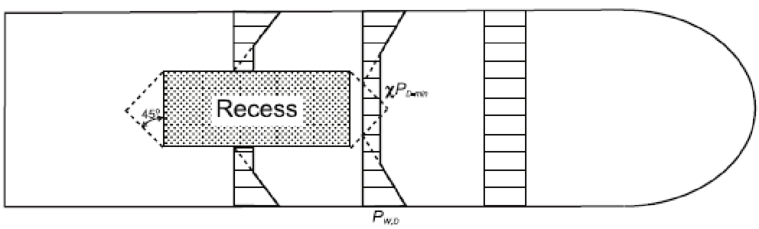


Figure 12 Transverse distribution of green sea pressure head sea

Table 31 Minimum pressures on exposed decks for HSM, HSA, FSM load cases

Location	*Minimum pressure on exposed freeboard deck, $P_{D\text{-}min}$, [kN/m^2]*	
	$L_{LL} \geq 100$ m	*$L_{LL} < 100$ m*
$\frac{x_{LL}}{L_{LL}} \leq 0.75$	34.3	$14.9 + 0.195\, L_{LL}$
$\frac{x_{LL}}{L_{LL}} > 0.75$	$34.3 + \left[14.8 + a(L_{LL} - 100)\right]\left(4\frac{x_{LL}}{L_{LL}} - 3\right)$	$12.2 + \frac{L_{LL}}{9}\left(5\frac{x_{LL}}{L_{LL}} - 2\right) + 3.6\frac{x_{LL}}{L_{LL}}$

where:

a = coefficient taken equal to:

$a = 0.356$ for type A, type B-60 and type B-100 freeboard ships

$a = 0.0726$ for type B freeboard ships

x_{LL} = X-coordinate of the load point measured from the aft end of the freeboard length L_{LL}.

Ilustración 154: cargas debidas a 'green seas'

Calculamos la primera expresión para después determinar el máximo entre ellas:

- <u>*X*</u>

$$X = 1$$

- <u>$P_{D\text{-}min}$</u>

Para un X_{LL}/L_{LL} = 0.546 con un L_{LL} = 57,7 m

$$P_{D-min} = 14{,}9 + 0{,}195\ x\ L_{LL}$$
$$P_{D-min} = 26{,}15\ {}^{kN}/_{m^2}$$

Y, por último, calculamos la segunda expresión según el reglamento:

- <u>P_{WD}</u>

	Wave pressure [kN/m²]		
Load case	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
	Wave pressure [kN/m²]		
HSM-1	$P_W = \max\{-P_{HS}; \rho g(z - T_{LC})\}$	$P_W = P_{W,WL} - \rho g(z - T_{LC})$	$P_W = 0.0$
HSM-2	$P_W = \max\{P_{HS}; \rho g(z - T_{LC})\}$		

Ilustración 155: presión debido a las olas, DNV

En nuestro caso, para la cubierta expuesta:

$$P_W = P_{W,WL} - \rho g(z - T_{LC})$$

Siendo $P_{W,WL}$ la presión dinámica generada por el oleaje en la flotación, que será igual al P_{HS} calculado anteriormente:

$$P_{HS}(z = 4{,}8\ m) = 23{,}9\ {}^{kN}/_{m^2}$$

Por lo tanto, para una altura z considerada de la cubierta principal e igual a 7,8 m:

$$P_w = -4{,}26\ {}^{kN}/_{m^2}$$

Por lo tanto, calculando el máximo:

$$P_D = max\left(XP_{D-min}, P_{W,D} - \rho g(z - z_{dk})\right)$$
$$P_D = max(26{,}15, -4{,}26 - \rho g(7{,}8 - 7{,}8))$$

$$\boldsymbol{P_D = 26,15\ {}^{kN}/_{m^2}}$$

<u>*Presión sobre cubierta estática ($P_{dl\text{-}s}$)*</u>

2 Non-exposed decks and platforms

2.1 Application

2.1.1 General

The loads on non-exposed decks including inner bottom are given in Sec.5 [2.3], except accommodation decks, wheelhouse decks and platforms in machinery space. For these decks loads defined in [2.2] and [2.3] are applicable.

2.2 Pressure due to distributed load

2.2.1 The static and dynamic pressures due to distributed load shall be considered. The distributed loads shall be calculated according to Sec.5 [2.3.1].

The static distributed load P_{dl-s}, including selfweight, shall be defined by the designer without being less than:

— 2.5 kN/m² (0.25 t/m² distributed mass) for accommodation decks, tween decks and platforms in general
— 3.5 kN/m² (0.35 t/m² distributed mass) for wheelhouse deck
— 8 kN/m² (0.8 t/m² distributed mass) for platforms in machinery space.

Ilustración 156: cargas en cubierta, DNV

Para la cubierta principal, que llevará encima los equipos de amarre y fondeo, las grúas (con una capacidad de hasta 2,5 t y un peso muerto de 1,2 t), 2 Zodiacs, y demás equipos a bordo tales como los ROVs, además de a zona de habilitación de cubierta, estimaremos un peso de hasta 0,4 t/m^2, por lo tanto:

$$\boldsymbol{P_{dl-s} = 4\ {}^{kN}/_{m^2}}$$

Presión sobre cubierta dinámica (P_{dl-d})

La presión dinámica a la que estará sometida la cubierta será la presión que ejerzan los equipos y personas que estén sobre ella sometidos a la aceleración sobre el eje Z:

$$P_{dl-d} = P_{dl-s}\ x\ {}^{a_z}/_{g}$$

Por lo tanto, calculamos la aceleración en el eje Z del buque en ese punto:

Aceleración vertical (a_z)

3.2.3 Vertical acceleration

The vertical acceleration at any position for each dynamic load case, in m/s^2, shall be taken as:

$$a_Z = f_\beta\left[C_{ZH}a_{heave} + C_{ZR}a_{roll}y - C_{ZP}a_{pitch}(x - 0{,}45L)\right]$$

Ilustración 157: aceleración vertical a_z, DNV

Calculamos a_z:

- *f_β*

$$f_\beta = 1$$

- *C_{ZH}*

2.2 Load combination factors

2.2.1 The load combinations factors (LCFs) for the global loads and inertia load components for strength assessment are defined in:

— Table 4: LCFs for HSM, HSA and FSM load cases.
— Table 5: LCFs for BSR and BSP load cases.
— Table 6: LCFs for OST and OSA load cases.

Table 4 Load combination factors for HSM, HSA and FSM load cases - strength assessment

Load component		*LCF*	*HSM-1*	*HSM-2*	*HSA-1*	*HSA-2*	*FSM-1*	*FSM-2*
Hull girder loads	M_{WV}	C_{WV}	−1	1	−0.7	0.7	$-0.4f_T - 0.6$	$0.4f_T + 0.6$
	Q_{WV}	C_{QW}	$-1.0f_{lp}$	$1.0f_{lp}$	$-0.6f_{lp}$	$0.6f_{lp}$	$-1.0f_{lp}$	$1.0f_{lp}$
	M_{WH}	C_{WH}	0	0	0	0	0	0
	M_{WT}	C_{WT}	0	0	0	0	0	0
Longitudinal accelerations	a_{surge}	C_{XS}	$0.6 - 0.2f_T$	$0.2f_T - 0.6$	0.2	−0.2	$0.2 - 0.4f_T$	$0.4f_T - 0.2$
	$a_{pitch\text{-}x}$	C_{XP}	$-0.15\text{-}L_1/300$	$0.15+L_1/300$	−1.0	1.0	0.15	−0.15
	$g\sin\varphi$	C_{XG}	0.6	−0.6	$0.4f_T + 0.1$	$-0.4f_T - 0.1$	−0.2	0.2
Transverse accelerations	a_{sway}	C_{YS}	0	0	0	0	0	0
	$a_{roll\text{-}y}$	C_{YR}	0	0	0	0	0	0
	$g\sin\theta$	C_{YG}	0	0	0	0	0	0
Vertical accelerations	a_{heave}	C_{ZH}	$0.5f_T - 0.15$	$0.15 - 0.5f_T$	0.4	−0.4	0	0
	$a_{roll\text{-}z}$	C_{ZR}	0	0	0	0	0	0
	$a_{pitch\text{-}z}$	C_{ZP}	−0.7	0.7	−1.0	1.0	0.15	−0.15

Ilustración 158: factores de combinación de cargas, DNV

Como estamos en el caso HSM-1:

$$C_{ZH} = 0{,}35$$

- *a_{heave}*

2.2.3 Heave acceleration

The vertical acceleration due to heave, in m/s², shall be taken as:

$$a_{heave} = 0{,}8(1 + 0{,}03v)\left(0{,}72 + \frac{2L}{700}\right)\left(1{,}15 - \frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad L < 100 \text{ m}$$

$$a_{heave} = \left(0{,}4 + \frac{L}{250}\right)\left(1 + 0{,}03v\left(3 - \frac{L}{50}\right)\right)\left(1{,}15 - \frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad 100 \le L < 150 \text{ m}$$

$$a_{heave} = \left(1.15 - \frac{6{,}5}{\sqrt{gL}}\right)f_p a_0 g \qquad L \ge 150 \text{ m}$$

where:

v = unless otherwise specified in Pt.5, to be taken as:
0 kt for $L < 100$ m
5 kt for $L \ge 150$ m
linear interpolation for L between 100 m and 150 m.

f_p = coefficient shall be taken as:

$f_p = f_{ps}$ for strength assessment

$f_p = f_R\left[\left(0{,}27 + 0{,}02f_T\right) - 17L \cdot 10^{-5}\right]$ for fatigue assessment.

Ilustración 159: a_{heave}, DNV

- $v = 0$
- $f_p = f_{ps} = 1$
- $a_0 = 0{,}962$

a_0 = acceleration parameter, shall be taken as:

$$a_0 = \left(1{,}58 - 0{,}47C_B\right)\left(\frac{2{,}4}{\sqrt{L}} + \frac{34}{L} - \frac{600}{L^2}\right)$$

Ilustración 160: parámetro de la aceleración, DNV

$$a_{heave} = 5{,}775 \ {}^{m}/_{s^2}$$

➢ <u>C_{ZR}</u>

$$C_{ZR} = 0$$

Al ser C_{ZR} nulo, el cálculo de a_{roll} e 'y' no es necesario por el momento.

➢ <u>C_{ZP}</u>

$$C_{ZP} = -0{,}7$$

➢ <u>a_{pitch}</u>

2.2.5 Pitch acceleration

The pitch acceleration, in rad/s², shall be taken as:

$$a_{pitch} = 0{,}8(1 + 0{,}05v)f_p\left(0{,}72 + \frac{2L}{700}\right)\left(1{,}75 - \frac{22}{\sqrt{gL}}\right)\varphi\frac{\pi}{180}\left(\frac{2\pi}{T_\varphi}\right)^2 \qquad L < 100 \text{ m}$$

Ilustración 161: a_{pitch}, DNV

- $\varphi = 33{,}86$ º

The pitch angle, in deg, shall be taken as given in formula below and need not to be taken greater than 20 degree in general, and not to taken greater than 20 f_r degrees for ships with service area restrictions:

$$\varphi = 920 f_p L^{-0.84}\left\{1.0 + \left(\frac{2.57}{\sqrt{gL}}\right)^{1.2}\right\}$$

where:

f_p = coefficient shall be taken as:

$f_p = f_{ps}$ for strength assessment

$f_p = f_R\left[\left(0.27 - 0.02 f_T\right) - \left(13 - 5 f_T\right) \cdot L \cdot 10^{-5}\right]$ for fatigue assessment.

Ilustración 162: ángulo φ, DNV

- T_φ = 6,52 s

The pitch period, in s, shall be taken as:

$$T_\varphi = \sqrt{\frac{2\pi\lambda_\varphi}{g}}$$

where:

$\lambda_\varphi = 0.6\left(1 + f_T\right)L$

Ilustración 163: Tφ, DNV

$$a_{pitch} = 0{,}31 \ {rad}/{s^2}$$

Para x = 0.5L, calculamos a_z:

$$\boldsymbol{a_z = 2{,}62 \ {m}/{s^2}}$$

Por lo que la presión dinámica será:

$$\boldsymbol{P_{dl-d} = 1{,}07 \ {kN}/{m^2}}$$

<u>*Presión total sobre cubierta principal*</u>

Por lo tanto, la presión total sobre la cubierta principal será:

$$\boldsymbol{P_{cub.\ principal} = (26{,}15 + 4 + 1{,}07) \ {kN}/{m^2}}$$

$$\boldsymbol{P_{cub.\ principal} = 31{,}22 \ {kN}/{m^2}}$$

Continuamos con los cálculos de los demás parámetros necesarios para hallar el espesor de la chapa de la cubierta principal:

C_a = permissible bending stress coefficient for plate taken equal to:

$$C_a = \beta_a - \alpha_a \frac{\left|\sigma_{hg}\right|}{R_{eH}}$$ not to be taken greater than $C_{a\text{-}max}$

β_a = coefficient as defined in Table 1

α_a = coefficient as defined in Table 1

$C_{a\text{-}max}$ = maximum permissible bending stress coefficient as defined in Table 1.

Ilustración 164: C_a, DNV

- <u>β_a</u>

$$\beta_a = 0{,}95$$

- <u>α_a</u>

$$\alpha_a = 0$$

Por lo tanto:

$$\boldsymbol{C_a = 0{,}95}$$

Y el coeficiente del material:

$$R_{eH} = 235 \ ^{N}/_{mm^2}$$

Por lo que el espesor de la chapa es:

$$t = 4,5 \ mm$$

6.7.3. Espesor final de la chapa de la cubierta principal

El espesor de la chapa de la cubierta principal, en base a los cálculos realizados anteriormente será de:

$$t_{cub.\ principal} = 6 \ mm$$

6.7.4. Cálculo de los refuerzos secundarios. Longitudinales

A continuación, vamos a calcular los refuerzos longitudinales de la cubierta principal.

El módulo requerido será:

1.1.2 Section modulus

The minimum net section modulus, in cm^3, shall not be taken less than the greatest value calculated for all applicable design load sets as defined in Sec.2 [2.1.3], given by:

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

where:

f_{bdg}	=	bending moment factor as defined in Table 5. For stiffeners with end fixity deviating from the ones included in Table 5, with complex load pattern, or being part of a grillage, the requirement given in [1.2] applies
f_m	=	bending moment ratio between end support and midspan as defined in Table 5
f_u	=	factor for unsymmetrical profiles, to be taken as:
	=	1.00 for flat bars and symmetrical profiles (T-profiles)
	=	1.03 for bulb profiles
	=	1.15 for unsymmetrical profiles (L-profiles)
C_s	=	permissible bending stress coefficient as defined in Table 3 for the acceptance criteria given in Table 4
$C_{s\text{-}max}$	=	coefficient, as defined in Table 4
α_s	=	coefficient, as defined in Table 4
β_s	=	coefficient, as defined in Table 4.

Table 3 Stiffeners, definition of C_s

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

Table 4 Stiffeners, definition of β_s, α_s and $C_{s\text{-}max}$

Acceptance criteria	*Structural member*		β_s	α_s	$C_{s\text{-}max}$
	Other members		0.85	0.00	0.85
AC-II	Longitudinal members		1.10	1.00	0.95
	Other members		0.95	0.00	0.95
AC-III	Longitudinal members	In general	1.20	1.00	1.00
		On watertight boundaries 1)	1.20	1.00	1.15
	Other members	In general	1.00	0.00	1.00
		On watertight boundaries 1)	1.15	0.00	1.15
1) Only applicable for flooding pressure					

Table 5 Stiffeners, definition of f_{bdg} and f_m

Coefficient	*Acceptance criteria*	*For continuous stiffeners with fixed ends*		*For continuous stiffeners with one fixed end and one simply supported end*	*For non-continuous stiffeners with simply supported ends*
		Horizontal stiffeners and upper end of vertical stiffeners	*Lower end of vertical stiffeners*	*Horizontal and vertical stiffeners*	*Horizontal and vertical stiffeners*
f_{bdg}	AC-I, AC-II, AC-III	12.00	10.00	8.00	8.00
f_m	AC-I	2.00	2.33	1.77	-
	AC-II, AC-III	1.60	1.86	1.42	

Ilustración 165: módulo de la sección DNV

- f_u

$$f_u = 1{,}03$$

- P

$$P = 31{,}22\ {}^{kN}/_{m^2}$$

- s

$$s = 700\ mm$$

- l_{bdg}

$$l_{bdg} = 2{,}4\ m$$

- f_{bdg}

$$f_{bdg} = 12$$

- C_s
  - β_S

$$\beta_S = 1{,}1$$

  - α_S

$$\alpha_S = 1$$

  - σ_{hg}

$$\sigma_{hg} = 98{,}595\ {}^{N}/_{mm^2}$$

$$C_s = 0{,}68$$

Por lo que el módulo necesario que debe dar el perfil es:

$$Z_{longitudinal\ cub.\ principal} = 67{,}57\ cm^3$$

Introduciéndonos en el catálogo del Anexo I de llantas bulbo, escogemos:

$$\mathbf{140\ x\ 7\ con\ W = 80\ cm^3}$$

Comprobamos, a continuación, que el perfil de llanta bulbo escogido cumple con el espesor mínimo determinado por el reglamento:

1.1 General

1.1.1 Web plating

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

$$t_w = \frac{C_m f_{shr} |P| s\, \ell_{shr}}{d_{shr} C_t \tau_{eH}}$$

where:

f_{shr} = shear force distribution factor as defined in Table 1. For stiffeners with end fixity deviating from the ones included in Table 1, with complex load pattern, or being part of a grillage, the requirements given in [1.2] apply.

C_t = permissible shear stress coefficient for the acceptance criteria being considered, as defined in Table 2

C_m = coefficient for combined axial stress, bending stress and shear stress in stiffener

= 1.0 for ships of length less than 90 m and for flat bars and bulb profiles

= $0{,}71\left(1-\left(\frac{0{,}75}{C_{xt}}\cdot\frac{Z}{Z_a}\right)^{e_0}\right)^{-\frac{1}{e_0}}$, not less than 1 in other cases

C_{xt} = $0.52C_{st} + 0.56$

C_{st} = 0.5 for $C_s \leq 0{,}5$

= C_s for $0{,}5 < C_s < 0{,}95$

= 0.95 for $C_s \geq 0.95$

C_s = permissible bending stress coefficient as defined in [1.1.2]

Z = required net section modulus according to [1.1.2] in cm^3, shall not be taken greater than Z_a

Z_a = actual net elastic section modulus in cm^3, as defined in Ch.3 Sec.7 [1.4.4]

e_0 = $e_0 = 9{,}23\left(\frac{h_w}{t_{wa}}\sqrt{R_{eH}}\right)^{-0{,}25}$

t_{wa} = actual net web thickness of stiffener, in mm

h_w = depth of stiffener web, in mm, as shown in Ch.8 Sec.2.

Table 1 Definition of f_{shr}

Coefficient	For continuous stiffeners with fixed end			For non-continuous stiffeners with simply supported ends
	Horizontal stiffeners	Upper end of vertical stiffeners	Lower end of vertical stiffeners	All stiffeners
f_{shr}	0.5	0.4	0.7	0.5

Table 2 Stiffeners, definition of C_t

Acceptance criteria	Structural member	C_t
AC-I	All stiffeners	0.75
AC-II	All stiffeners	0.90
AC-III	All stiffeners	0.95

Ilustración 166: espesor refuerzo, DNV

- <u>*Cm*</u>

$$C_m = 1$$

- <u>*f_{shr}*</u>

$$f_{shr} = 0{,}5$$

- <u>*P*</u>
Presión en el fondo calculada anteriormente

- <u>*l_{shr}*</u>

$$l_{shr} = l - \frac{s}{2000}$$

Siendo 'l' la separación entre refuerzos primarios, igual a 2,4 m.

$$l_{shr} = 2{,}05$$

- <u>*d_{shr}*</u>

1.4.3 Effective shear depth of stiffeners

The effective shear depth of stiffeners, in mm, shall be taken as:

$$d_{shr} = h_{stf} + t_p \qquad \text{for } 75° \le \varphi_w \le 90°$$

$$d_{shr} = (h_{stf} + t_p)\sin\varphi_w \qquad \text{for } \varphi_w < 75°$$

where:

h_{stf} = height of stiffener, in mm, as defined in Sec.2 Figure 1
t_p = net thickness of the attached plating, in mm, as defined in Sec.2 Figure 1
φ_w = angle, in deg, as defined in Figure 17.

Ilustración 167: profundidad de corte efectiva para los refuerzos

- <u>*h_{stf} y t_p*</u>

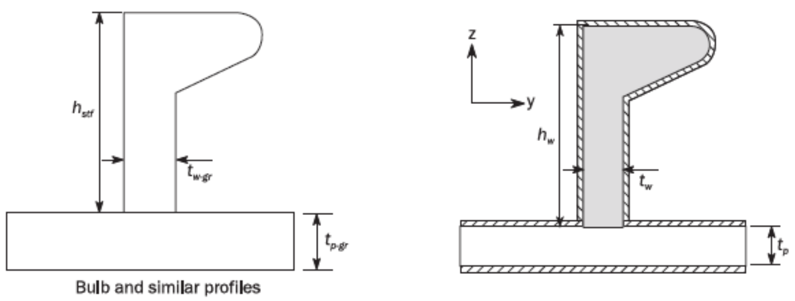


Figure 2 Net sectional properties of local supporting members (continued)

Ilustración 168: perfil bulbo, DNV

$$h_{stf} = b\,(tabla\ llanta\ bulbo) = 140\ mm$$
$$t_p = 6\ mm$$
$$d_{shr} = 146\ mm$$

- <u>*C_t*</u>

$$C_t = 0{,}9$$

- <u>*T_{eH}*</u>

τ_{eH}	specified shear yield stress, $\tau_{eH} = \frac{R_{eH}}{\sqrt{3}}$	N/mm²

$$\tau_{eH} = 135{,}68\ {}^{N}/_{mm^2}$$

Por lo que el espesor del refuerzo debe ser:

$$t_w = 1{,}26\ mm$$

Por lo que el perfil escogido cumple los requisitos de espesor.

6.7.5. Cálculo de los refuerzos primarios. Baos

Calculamos el módulo necesario que deben dar los baos, colocados cada 2400 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000 \frac{|P| s \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1

C_s = permissible stress coefficient to be taken as:

C_s = 0.70 for AC-I

C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 169: módulo requerido en refuerzos primarios, DNV

- <u>P</u>
  Presión calculada en la cubierta principal determinada anteriormente
- <u>s</u>

$$s = 2400\ mm$$

- <u>l_{bdg}</u>
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 2{,}28\ m$$

- <u>f_{bdg}</u>

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

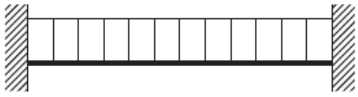
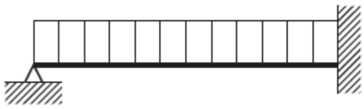
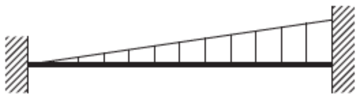
Load and boundary condition				*Bending moment and shear force distribution factors (based on load at mid span, where load varies)*		
	Position			*1*	*2*	*3*
Load model	*1 Support*	*2 Field*	*3 Support*	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 170: DNV

Caracterizaremos la varenga como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- <u>C_s</u>

Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar el bao es:

$$Z_{baos\ cub.\ principal} = 162{,}5\ cm^3$$

Introduciéndonos en el Anexo I llantas bulbo, escogemos:

$$\mathbf{180\ x\ 9\ con\ W = 653\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3
b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \leq 5.0$
2) $bL_2 \leq 2.5$ for stringers in double side next to dry space not intended for cargo in bulk
3) $bL_2 \leq 2.0$
4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 171: espesor t refuerzos primarios

Para una cubierta, en este caso la principal:

$$a = 5$$

$$b = 0{,}015$$

Con los demás parámetros definidos:

$$t_{mínimo\ bao\ cub.\ principal} = 5{,}83\ mm$$

Por lo tanto, el refuerzo primario escogido que actuará como bao, cumple el espesor mínimo dictado por el reglamento.

6.7.6. Cálculo de los refuerzos primarios. Esloras

Calculamos el módulo necesario que deben dar las esloras, colocadas con una separación entre ellas de 2800 mm, según indica el DNV:

2 Primary supporting members

2.1 Scantling requirements

2.1.1 Section modulus

The section modulus, in cm^3, of primary supporting members subjected to lateral pressure, calculated in accordance with Ch.3 Sec.7 [1.4.6], shall not be taken less than the greatest value for all applicable design load sets defined in Sec.2 [2], given by:

$$Z = 1000\frac{|P|\, s\, \ell_{bdg}^2}{f_{bdg} C_s R_{eH}}$$

where:

f_{bdg} = bending moment distribution factor, as given in Table 1
C_s = permissible stress coefficient to be taken as:
C_s = 0.70 for AC-I
C_s = 0.85 for AC-II and AC-III.

The section modulus shall be based on the effective breadth of attached plating, b_{eff}, as defined in Ch.3 Sec.7 [1.3.2].

Ilustración 172: módulo requerido en refuerzos primarios, DNV

- <u>P</u>
  Presión calculada en la cubierta principal determinada anteriormente
- <u>s</u>

$$s = 2800\ mm$$

- <u>l_{bdg}</u>
  En este caso no es la separación entre refuerzos sino ligeramente inferior. Se estimará en un 95%

$$l_{bdg} = 0{,}95\ x\ s$$
$$l_{bdg} = 2{,}66\ m$$

- <u>f_{bdg}</u>

Table 1 Definition of bending moment and shear force factors, f_{bdg} and f_{shr}

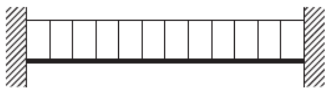
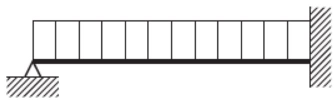
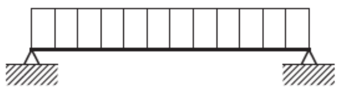
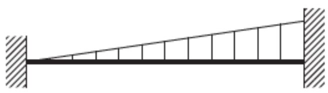
Load and boundary condition				Bending moment and shear force distribution factors (based on load at mid span, where load varies)		
Position				1	2	3
Load model	1 Support	2 Field	3 Support	f_{bdg1} f_{shr1}	f_{bdg2} -	f_{bdg3} f_{shr3}
A				12.0 0.50	24.0 -	12.0 0.50
B				- 0.38	14.2 -	8.0 0.63
C				- 0.50	8.0 -	- 0.50
D				15.0 0.30	23.3 -	10.0 0.70

Ilustración 173: DNV

Caracterizaremos la varenga como una viga doblemente empotrada, es decir, el caso A, por lo que f_{bdg} será de:

$$f_{bdg} = 12$$

- <u>C_s</u>
  Para el criterio AC-II será de:

$$C_s = 0{,}85$$

Por lo tanto, el valor del módulo que debe entregar la eslora es:

$$Z_{esloras\ cubierta\ principal} = 294{,}91\ cm^3$$

Introduciéndonos en el Anexo I de llantas bulbo, escogemos:

$$\mathbf{220\ x\ 10\ con\ W = 302\ cm^3}$$

Comprobamos si cumple con el espesor requerido según el reglamento:

3.1 Minimum thickness requirements

3.1.1 The net thickness of web plating and flange of primary supporting members in mm, shall not be taken less than:

$$t = a + bL_2\sqrt{k}$$

where:

a = coefficient as defined in Table 3
b = coefficient as defined in Table 3.

Table 3 Minimum net thickness for primary supporting members

Element	*a*	*b*
Bottom centreline girder and lower strake of centreline wash bulkhead	5.0	0.03
Other bottom longitudinal girders	5.0	0.017
Floors in aft peak tanks including reduced floors or floors with large opening 4)	5.0	0.025 1)
Floors in general	5.0	0.015
PSM at tank boundaries, boundaries of holds intended for cargo in bulk, single strength deck and shell up to freeboard deck	4.5	0.015 2)
PSM in deckhouses and superstructures and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.5	0.01 3)
PSM in general	4.5	0.01

1) $bL_2 \le 5.0$
2) $bL_2 \le 2.5$ for stringers in double side next to dry space not intended for cargo in bulk
3) $bL_2 \le 2.0$
4) See Ch.3 Sec.5 [4] for arrangement requirement of aft peak tank.

Ilustración 174: espesor t refuerzos primarios

Para una cubierta, en este caso la principal:

$$a = 5$$

$$b = 0{,}015$$

Con los demás parámetros definidos:

$$t_{mínimo\ eslora\ cub.\ principal} = 5{,}83\ mm$$

Por lo tanto, el refuerzo primario escogido que actuará como eslora, cumple el espesor mínimo.

6.8. Módulo mínimo de la cuaderna maestra

Siguiendo el DNV, calculamos el módulo mínimo que debe dar la sección maestra:

1.3 Minimum section modulus midship

The gross midship section modulus, in m^3, at equivalent deck line as defined in [1.2.3], and bottom shall not be less than the value obtained from the following formula:

$$Z_{R\text{-}gr} = k\left(\frac{1+f_r}{2}\right)C_{w0}\,L^2\,B\left(C_B + 0.7\right)10^{-6}$$

where:

f_r = reduction factor related to service restrictions, defined in Ch.4 Sec.3.
C_{w0} = wave parameter taken as:
= C_w for L > 90 m
= 5.7 + 0.0222L for $L \le$ 90 m.

Ilustración 175: módulo mínimo, DNV

- *f_r*

$$f_r = 1$$

- *C_{w0}*

$$C_{w0} = 6{,}927$$

Con todos los demás parámetros ya determinados:

$$\boldsymbol{Z_{R-gr} = 0,316\ m^3}$$

7. BIBLIOGRAFÍA

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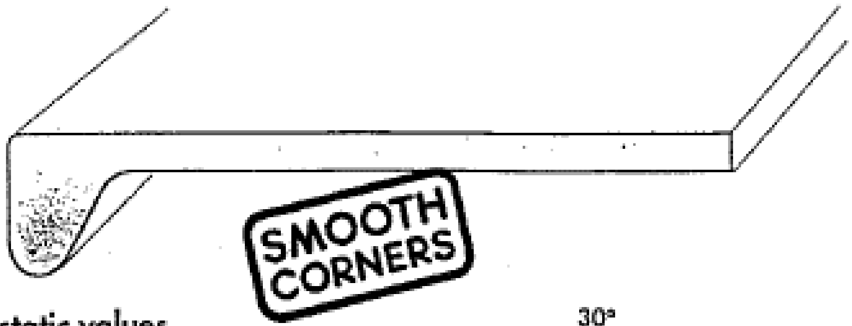
- *Det Norske Veritas, DNV. Rules for classification. Ships, Part 6 Hull. Chapter 6, Cold Climate*

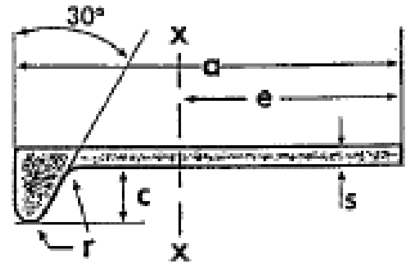
ANEXO I

LLANTAS BULBO

Bulb Flats



Dimension range, weight/m and static values



Width a mm	Thickness s mm	Height c mm	Radius r mm	Area A cm²	Weight kg/m	e cm	I_x cm⁴	W_x* cm³
60	4	13	3.5	3.58	2.81	3.82	12.2	13
	5	13	3.5	4.18	3.28	3.70	14.4	14
	6	13	3.5	4.78	3.75	3.62	16.4	16
80	5	14	4	5.40	4.24	4.89	33.8	23
	6	14	4	6.20	4.87	4.78	39.0	25
	7	14	4	7.00	5.50	4.69	43.3	27
		Delivery by special agreement. Standard lengths 6–12 m						
100	6	15.5	4.5	7.74	6.08	5.98	76.1	38
	7	15.5	4.5	8.74	6.86	5.87	85.3	41
	8	15.5	4.5	9.74	7.65	5.78	94.3	45
120	6	17	5	9.31	7.31	7.20	133	54
	7	17	5	10.5	8.25	7.07	148	59
	8	17	5	11.7	9.19	6.96	164	63
140	7	19	5.5	12.4	9.74	8.31	241	80
	8	19	5.5	13.8	10.8	8.18	266	87
	9	19	5.5	15.2	11.9	8.07	291	93
160	7	22	6	14.6	11.4	9.66	373	110
	8	22	6	16.2	12.7	9.49	411	118
	9	22	6	17.8	14.0	9.36	448	126
180	8	25	7	18.9	14.8	10.9	609	157
	9	25	7	20.7	16.2	10.7	663	166
	10	25	7	22.5	17.6	10.6	717	177
200	9	28	8	23.6	18.5	12.1	941	225
	10	28	8	25.6	20.1	11.9	1020	237
	11.5	28	8	28.6	22.5	11.7	1126	255
220	10	31	9	29.0	22.8	13.4	1400	302
	11.5	31	9	32.3	25.4	13.1	1550	323
240	10	34	10	32.4	25.4	14.7	1860	368
	11	34	10	34.9	27.4	14.6	2000	391
	12	34	10	37.3	29.3	14.4	2130	406
260	10	37	11	36.1	28.3	16.2	2477	455
	11	37	11	38.7	30.3	16.0	2610	474
	12	37	11	41.3	32.4	15.8	2770	493
280	11	40	12	42.6	33.5	17.4	3330	566
	12	40	12	45.5	35.7	17.2	3550	590
300	11	43	13	46.7	36.7	18.9	4190	671
	12	43	13	49.7	39.0	18.7	4460	701
	13	43	13	52.8	41.5	18.5	4720	728
320	12	46	14	54.2	42.5	20.1	5530	819
	13	46	14	57.4	45.0	19.9	5850	849
340	12	49	15	58.8	46.1	21.5	6760	947
	14	49	15	65.5	51.5	21.1	7540	1014
370	13	53.5	16.5	69.6	54.6	23.5	9470	1210
	15	53.5	16.5	77.0	60.5	23.0	10490	1278
400	14	58	18	81.4	63.9	25.5	12930	1580
	16	58	18	89.4	70.2	25.0	14220	1666
430	15	62.5	19.5	94.1	73.9	27.4	17260	1935
	17	62.5	19.5	103.0	80.6	26.9	18860	2036

Plate cross sectional area 60 cm² (widths 100–180)

Plate cross sectional area 100 cm² (widths 200–370)

Plate cross sectional area 150 cm² (widths 400–430)

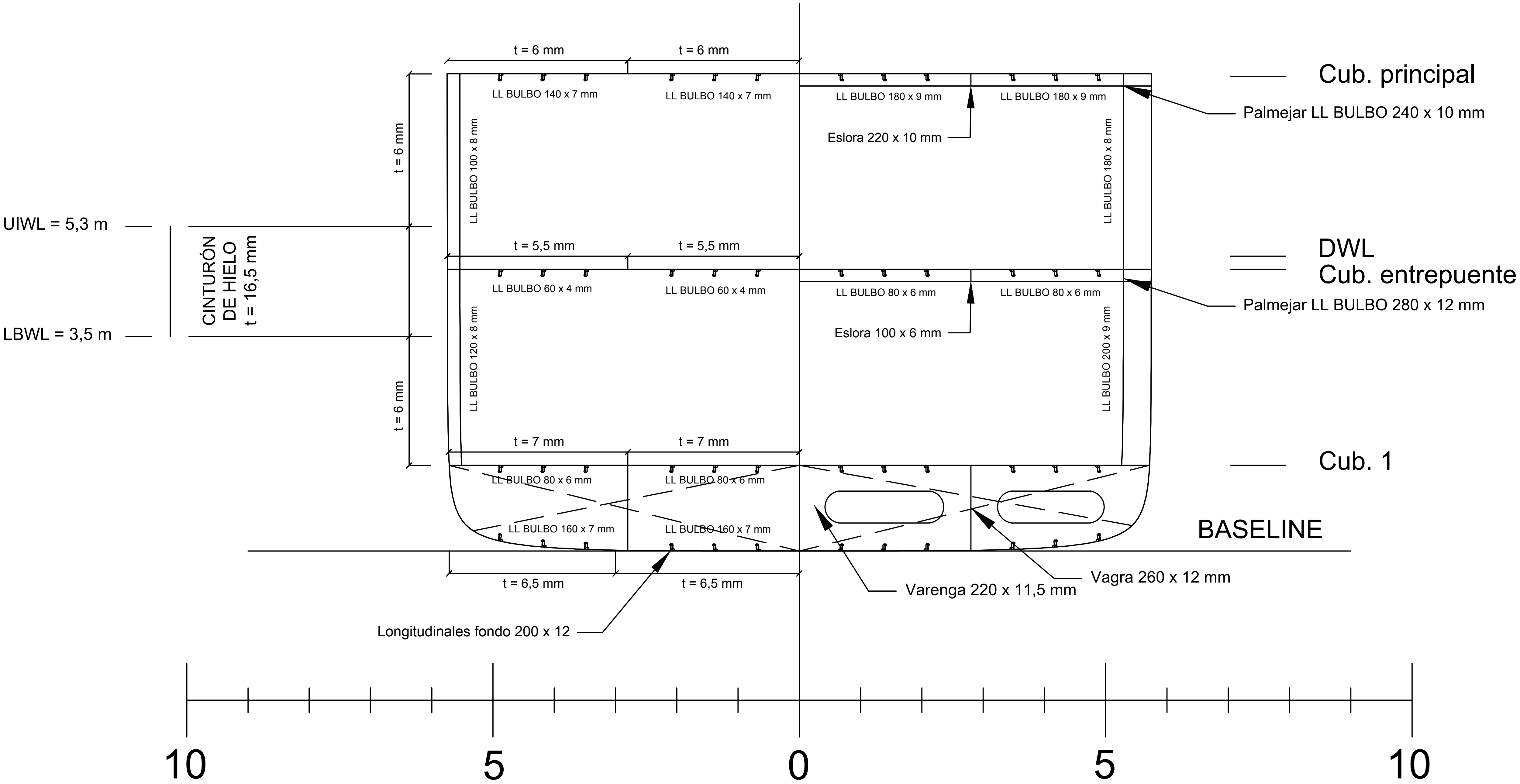
* Inclusive plate as noted

Standard lengths
6–18 m.
Other lengths by special agreeme[nt]

Orders
must include the following measurements:
a x s.

ANEXO II

CUADERNA MAESTRA



	TFG BUQUE OCEANOGRÁFICO 55 m	
	MAR AURORA	
PLANO:	CUADERNA MAESTRA	FECHA: Septiembre 2022
		TAMAÑO: A3
NOMBRE:	DAVID MARTÍN ARGIBAY	ESCALA: 1/75
ESCALA GRÁFICA:	ESCALA 1 : 75 (0 – 5 – 8m)	