Escola Politécnica Superior

Trabajo Fin de Grado
CURSO 2021/2022

ANCHOR HANDLING TUG SUPPLY VESSEL. 200 TPF.

CUADERNO 8: CUADERNA MAESTRA.

Grado en Ingeniería Naval y Oceánica

ALUMNA/O

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RESUMEN TFG. BUQUE DE APOYO A INSTALACIONES OFFSHORE.

RESUMEN

Este proyecto tiene como objetivo principal la realización de un anteproyecto de un buque AHTS. Estos buques se construyen principalmente para servir de apoyo a las plataformas petrolíferas, asegurándolas en su ubicación mediante anclas. También pueden desarrollar otras funciones como proporcionar suministros, prestar servicio de remolque, transportar personas y realizar operaciones de inspección subacuática mediante un ROV.

Además, nuestro buque cuenta con sistemas FIFI I para la lucha contra incendios, un sistema de posicionamiento dinámico DP2 para poder llevar a cabo sus operaciones de anclaje en unas condiciones meteorológicas adversas. Para poder conseguir este nivel de posicionamiento contamos con dos propulsores pods de transmisión eléctrica y tres thrusters de túnel.

Podemos considerar este tipo de buques como una de esas creaciones que no solo ayudan al crecimiento de la industria offshore, sino que a su vez ayudan a prevenir situaciones peligrosas en el mar.

RESUMO

O principal obxectivo deste proxecto é levar a cabo un anteproxecto dun buque AHTS. Estes buques están construídos principalmente para servir de apoio ás plataformas petrolíferas, fixándoas no seu lugar con áncoras. Tamén poden realizar outras funcións como proporcionar suministros, servizo de remolque, transporte de persoas e realizar operacións de inspección subacuática mediante un ROV.

Ademais, o noso buque conta con sistemas FIFI I para a loita contra incendios, un sistema de posicionamento dinámico DP2 para poder realizar as súas operacións de ancoraxe en condicións meteorolóxicas adversas. Para acadar este nivel de posicionamento, temos dous propulsores pods accionados eléctricamente e tres propulsores de túnel.

Podemos considerar este tipo de buques como unha desas creacións que non só axudan a crecer á industria offshore, senón que tamén axudan a previr situacións perigosas no mar.

SUMMARY

The main objective of this project is to carry out a preliminary project for an AHTS vessel. These vessels are built primarily to support oil rigs, securing them in place with anchors. They can also perform other functions such as providing supplies, providing towing service, transporting people and perform underwater inspection operations using a ROV.

In addition, our ship has FIFI I system for fire fighting, a DP2 dynamic positioning system to be able to carry out its anchoring operations in adverse weather conditions. In order to achieve this level of positioning we have two electrically driven pods and three tunnel thrusters.

We can consider this type of vessels as one of those developments that not only helps the offshore industry grow, but also prevents dangerous situations at sea.

REQUISITOS RPA. BUQUE DE APOYO A INSTALACIONES OFFSHORE.

UNIVERSIDADE DA CORUÑA

GRADO EN INGENIERÍA NAVAL Y OCEÁNICA
TRABAJO FIN DE GRADO

CURSO 2.021 - 2.022

PROYECTO NÚMERO: 2022-GENO-3.

TIPO DE BUQUE: Anchor handling tug supply vessel (AHTS).

CLASIFICACIÓN, COTA Y REGLAMENTOS DE APLICACIÓN:

DNV GL, SOLAS y MARPOL. AHTS, DK, E0, DPS 2, F(M), FIFI I.

CARACTERÍSTICAS DE LA CARGA: Material de fondeo, abastecimiento a plataformas petrolíferas y capacidad de remolque. 200 TPF.

VELOCIDAD Y AUTONOMÍA: velocidad de servicio de 15 kn y una autonomía de 4000 mn a la velocidad de servicio.

SISTEMAS Y EQUIPOS DE CARGA / DESCARGA: Los habituales en este tipo de buques.

PROPULSIÓN: Diésel-eléctrica. Propulsión de tipo pod.

TRIPULACIÓN Y PASAJE: 20 tripulantes.

OTROS EQUIPOS E INSTALACIONES:

– Sistema de recuperación y lanzamiento de un ROV.

Ferrol, septiembre 2022

ALUMNO/A: **D. Raúl Fernández Garda**

Escola Politécnica Superior

TRABAJO FIN DE GRADO

CURSO 2021/2022

ANCHOR HANDLING TUG SUPPLY VESSEL. 200 TPF.

Grado en Ingeniería Naval y Oceánica

CUADERNO VIII

CUADERNA MAESTRA

RAÚL FERNÁNDEZ GARDA

ÍNDICE

RESUMEN DE LAS CARACTERÍSTICAS PRINCIPALES DEL BUQUE

Las dimensiones principales de nuestro buque son las obtenidas en los Cuaderno I, II y III.

TPF	200
BHP / kW	27.952 CV / 20.844 kW
L	79,00 m
B	21,40 m
T	8,19 m
D	9,10 m
Cb	0,704
CM	0,986
CP	0,714
Fn	0,277
Δ	11.633,80 t

INTRODUCCIÓN

A lo largo de este cuaderno vamos a realizar el diseño y el cálculo de todos los componentes relacionados con la cuaderna maestra. También debemos de escoger el tipo de estructura con la que cuenta nuestro buque. Para todo esto seguiremos el reglamento de la sociedad de clasificación DNV GL.

1 DISEÑO CONCEPTUAL DE LA CUADERNA MAESTRA.

1.1 Tipo de estructura.

En la actualidad existe una gran variedad en lo que respecta al tamaño y tipo de buques, pero en cuanto a los sistemas de construcción, de sus estructuras fundamentales, responden a tres sistemas básicos. Sistema de construcción transversal, longitudinal y mixto.

- Sistema de construcción transversal. Se caracteriza por la presencia de elementos transversales principales como las varengas, que se extienden a lo ancho de la manga. Es muy común encontrar este tipo de estructura en buques de esloras menores de 65 m. En esos casos la resistencia longitudinal no tiene una importancia primaria y la elección entre una y otra solo se diferencia por el coste de producción, ya que la estructura longitudinal es más compleja.
- Sistema de construcción longitudinal. Se caracteriza por la presencia de elementos longitudinales principales como pueden ser los longitudinales. Es común encontrar este tipo de estructura en buques de esloras superiores a 100 m, ya que con este tipo de estructura se consigue un menor peso de aceros.
- Sistema de construcción mixto. Es una mezcla entre los dos descritos anteriormente.

Nuestro buque tiene una eslora entre perpendiculares de 79 m por tanto es decisión del diseñador escoger el tipo de estructura que quiere utilizar en el proyecto. En nuestro caso se ha decidido utilizar estructura longitudinal ya que esto indica un menor peso de acero y es un factor importante en buques de peso muerto.

En este tipo de estructura, los elementos primarios son los anillos transversales, es decir, el conjunto de las varengas, las bulárcamas y los baos. Obviamente también deberemos tener elementos secundarios que le proporcionen rigidez al buque y estos serán los longitudinales. Si cambiamos la zona de análisis del buque, la idea es la misma, pero cambia el nombre de los elementos dispuestos. Aquellos elementos primarios serán las cuadernas, donde aquellas reforzadas se llamarán bulárcamas, y los secundarios serán los palmejares.

La sección maestra se sitúa en la sección 60, en la parte central del buque donde este alcanza sus formas más llenas. Además, es aquí donde se instalará la cámara de máquinas.

En este cuaderno seguiremos lo estipulado en el reglamento de la sociedad de clasificación, en concreto será la parte 3 del DNV.

Empezaremos por el cálculo del módulo de la cuaderna porque será un valor necesario en posteriores cálculos.

1.2 Dimensiones básicas.

Para dar comiendo al diseño de la cuaderna maestra del buque deberemos comenzar previamente definiendo unas dimensiones básicas.

1.2.1 Calado de escantillonado.

Lo obtenemos del Cuaderno 5 cuando analizamos la condición en la que el buque navega con su máximo desplazamiento y calado. Este valor será de 6,60 m y se le añade un margen de 300 mm dando lugar a un calado de escantillonado de 6,90 m.

1.2.2 Eslora de escantillonado.

La eslora se define en el reglamento como lo siguiente.

“The rule length L is the distance, in m, measured on the waterline at the scantling draught TSC from the forward side of the stem to the centre of the rudder stock. L shall not be less than 96% and need not exceed 97% of the extreme length on the waterline at the scantling draught TSC.

In ships without rudder stock, e.g. ships fitted with azimuth thrusters, the rule length L shall be taken equal to 97% of the extreme length on the waterline at the scantling draught TSC. In ships with unusual stem or stern arrangements, the rule length shall be considered on a case-by-case basis and agreed with the Society.”

Por tanto, como en nuestro caso llevamos propulsión tipo Azipod sin timón le haremos caso al segundo apartado.

$$L = 0{,}97 * L_{max}\ al\ calado\ de\ escantillonado.$$

$$L = 0{,}97 * 84{,}66 = 82{,}12$$

1.2.3 Manga de escantillonado.

Es la manga máxima de diseño de nuestro buque. Tiene un valor de 21,40 m.

1.2.4 Calado de escantillonado.

Es el calado máximo que obtenemos en la condición más desfavorable de carga obtenida en el cuaderno 5. Este tiene un valor de 6,60 m y se le aplica un margen de 300 mm obteniendo así un calado de escantillonado de 6,90 m.

1.2.5 Coeficiente de bloque.

Lo calcularemos a partir del desplazamiento para el calado de escantillonado sacado a partir de las tablas de hidrostáticas del cuaderno 4. El desplazamiento será de 8423 t, por tanto.

$$Cb = \frac{8423}{1{,}025 * 82{,}12 * 21{,}4 * 6{,}90} = 0{,}70$$

1.2.6 Parámetros básicos.

Realizaremos una serie de cálculos de coeficientes que necesitaremos posteriormente en este cuaderno.

1.2.6.1 Parámetro de ola.

$$C_w = 0{,}0865 * L = 0{,}0865 * 82{,}12 = 7.10$$

1.2.6.2 Aceleración.

$$a_0 = \frac{3 * C_w}{L} + C_v * \frac{V}{L^{0{,}5}} = \frac{3 * 6{,}50}{82{,}12} + 0{,}18 * \frac{15}{82{,}12^{0{,}5}} = 0{,}54\ m/s^2$$

1.2.6.3 Aceleración vertical.

$$a_v = \frac{k_v * g_o * a_o}{C_b} = \frac{0.7 * 9.81 * 0.54}{0.7} = 5.25\ m/s^2$$

2 MÓDULO.

En esta sección del cuaderno debemos calcular el módulo mínimo requerido para la cuaderna maestra. Seguiremos con el cálculo del DNV ya que no disponemos de valores suficientes como para realizar el cálculo directamente. El valor del DNV es una estimación ya que con ella obtendremos un resultado, pero este no tiene por qué guardar semejanza con la realidad, ni en cuanto al momento en aguas tranquilas ni en olas.

DNV-RU-SHIP Pt.3 Ch.4 Loads.

2.1 Momentos.

2.1.1 Momento en aguas tranquilas.

– En quebranto.

$$M_{sw-h-min} = f_{sw} * (171C_W L^2 B(C_B + 0.7)10^{-3} - M_{wv-h-mid}$$

$$M_{sw-h-min} = 1 * (171 * 7.10 * 82{,}12^2 21.40(0.7 + 0.7)10^{-3} - 137620{,}28) = 107677{,}80 kNm$$

– En arrufo.

$$M_{sw-s-min} = -0.85 f_{sw} * (171C_W L^2 B(C_B + 0.7)10^{-3} + M_{wv-s-mid}$$

$$M_{sw-s-min} = -0.85 * 1 * (171 * 0.7 * 82.12^2 21.40(0.7 + 0.7)10^{-3} - 157781.18) = 113557.33 kNm$$

2.1.2 Momento en olas.

– En quebranto.

$$M_{wv-h} = 0{,}19 * \frac{f_R}{0{,}85} * f_{nl-vh} * f_m * f_p * C_w * L^2 * B * C_B$$

$$M_{wv-h} = 0{,}19 * \frac{0{,}85}{0{,}85} * 1 * 1 * 1 * 7.17 * 82{,}12^2 * 21.40 * 0.7 = 137620{,}28\ kNm$$

– En arrufo.

$$M_{wv-s} = -0{,}19 * \frac{f_R}{0{,}85} * f_{nl-vs} * f_m * f_p * C_w * L^2 * B * C_B$$

$$f_{nl-vs} = 0{,}5789 * (\frac{0{,}7 + 0{,}70}{0{,}7})$$

$$M_{wv-s} = -0{,}19 * \frac{0{,}85}{0{,}85} * 0{,}5789 * \left(\frac{0{,}7 + 0{,}70}{0{,}7}\right) * 1 * 1 * 7.10 * 82{,}12^2 * 21.4 * 0.7 = -157781.18\ kNm$$

2.1.3 Módulo de la sección maestra e inercia mínima.

El valor mínimo del módulo en la sección maestra con respecto al eje neutro transversal no será menor de:

$$Z_{R-gr} = k * \left(\frac{1 + f_R}{2}\right) * C_{w0} L^2 B(C_B + 0.7)10^{-6}$$

$$Z_{R-gr} = \left(\frac{1 + 1}{2}\right) * (5.7 + 0.0222 * 82{,}12) * 82{,}12^2 * 21.40 * (0.7 + 0.7)10^{-6} = 1.51\ m^3$$

El módulo de la sección maestra con respecto al fondo y cubierta del buque.

$$Z_{gr} = \frac{|M_s + M_{sw}|}{\sigma_{perm}} * 10^3$$

$$Z_{gr} = \frac{|113557.33 + 157781.18|}{175} * 10^3 = 1550505,77\ cm^3$$

En conclusión, el módulo de cubierta y el módulo del fondo deben ser como mínimo igual al mayor de los dos calculados anteriormente.

$$Z_{fondo} y\ Z_{cubierta} \geq 1550505,77\ cm^3$$

En cuanto a la inercia mínima se calcula también a partir del reglamento, DNV-RU-SHIP Pt.3 Ch.5 Hull girder strength.

$$I_{yR-gr} = 3 * f_r * C_w * L^3 * B * (C_B + 0.7) * 10^6$$

$$I_{yR-gr} = 3 * 1 * 7{,}10 * 82{,}12^3 * 21.40 * (0.7 + 0.7) * 10^{-8} = 353401374{,}70\ cm^4$$

3 ESCANTILLONADO DE LA CUADERNA MAESTRA.

En esta sección del cuaderno calcularemos el escantillonado local de la cuaderna maestra según el reglamento. Así podremos garantizar que las planchas, los refuerzos primarios y los secundarios que soportan las fuerzas locales tienen el suficiente escantillón necesario para hacerlo.

La separación de los refuerzos longitudinales será de 930 mm disponiendo así de 11 a cada costado. Los límites de los tanques de doble fondo coinciden con alguno de ellos. La separación de refuerzos transversales será igual que el espaciado entre cuadernas, 700 mm. Tendremos una bulárcama cada 5 cuadernas de forma constante todo a lo largo del buque, es decir, una cada 3500 mm.

Como estamos buscando una continuidad estructural, la disposición de refuerzos será simétrica babor estribor, la separación de longitudinales en fondo y cubierta será la misma y en los costados se mantendrá igual y constante.

3.1 Dimensionamiento del fondo.

3.1.1 Cálculo de las presiones.

Las aceleraciones ya las hemos calculado antes así que mostramos los resultados.

$$a_0 = 0{,}54 \frac{m}{s^2} \quad y \quad a_v = 5.25\, m/s^2$$

El parámetro de ola también lo habíamos calculado y es $C_w = 7{,}10$.

A continuación, calcularemos la presión que ejerce el mar sobre las chapas. Esta será la suma de la presión estática y la presión que ejercen las olas sobre el casco. Se encuentra en el DNV-RU-SHIP Pt.3 Ch.4 Loads como Hydrostatic pressure.

1 Sea pressure

1.1 Total pressure

1.1.1 The external pressure P_{ex} at any load point of the hull, in kN/m^2, for the static (S) design load scenarios, given in Sec.7, shall be taken as:

$$P_{ex} = P_S \text{ but not less than 0.}$$

The total pressure P_{ex} at any load point of the hull for the static plus dynamic (S + D) design load scenarios, given in Sec.7, shall be derived from each dynamic load case and shall be taken as:

$$P_{ex} = P_S + P_W \text{ but not less than 0.}$$

where:

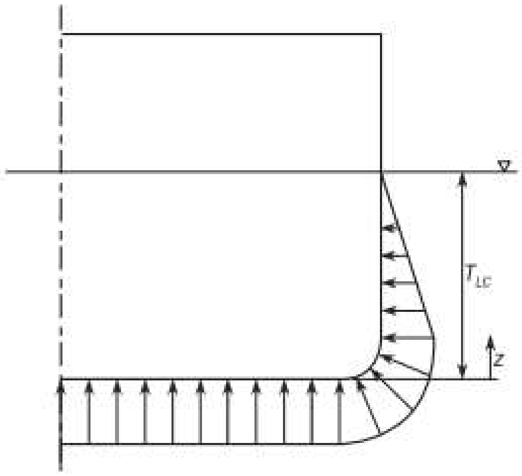
P_S = hydrostatic pressure, in kN/m^2, is defined in [1.2]
P_W = wave pressure, in kN/m^2, is defined in [1.3].

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



Por tanto, la presión estática debido al mar es la siguiente.

$$P_s = \rho * g * (T_{LC} - z) = 1.025 * 9.81 * (6{,}9 - 0) = 69{,}38\ kN/m^2$$

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

Load case	Wave pressure [kN/m^2]		
	$z \le T_{LC}$	$T_{LC} < z \le h_W + T_{LC}$	$z > h_W + T_{LC}$
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:

$$f_h = 3.0\left(1.21 - 0.66 f_T\right)$$

f_h = coefficient to be taken as:

$$f_h = 3.0(1.21 - 0.66 f_T)$$

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

$$k_a = (0.5 + f_T)\left[\left(3 - 2\sqrt{f_{yB}}\right) - \frac{20}{9} f_{xL}\left(7 - 6\sqrt{f_{yB}}\right)\right] + \frac{2}{3}(1 - f_T) \quad \text{for } f_{xL} < 0.15$$

$$k_a = 1.0 \quad \text{for } 0.15 \le f_{xL} < 0.7$$

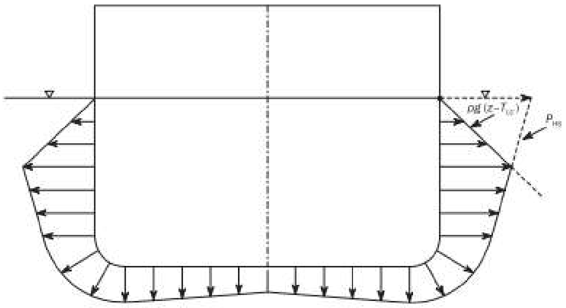
$$k_a = 1 + (f_{xL} - 0.7)\left\{\left(\frac{40}{3} f_T - 5\right) + 2\left(1 - f_{yB}\right)\left[\frac{18}{C_B} f_T (f_{xL} - 0.7) - 0.25(2 - f_T)\right]\right\} \quad \text{for } f_{xL} \ge 0.7$$

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.

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



Comenzaremos con el cálculo de la presión debido a olas.

$$f_T = \frac{T_{SC}}{T_{LC}} = \frac{6,9}{6,9} = 1$$
$$C_{fT} = f_T + 0.5 - (0.7 * f_T - 0.2) * C_b = 1,15$$
$$f_{ps} = 1$$
$$f_{xl} = \frac{x}{L} = \frac{42}{82,12} = 0,51$$
$$f_{nl} = 0.9$$
$$f_h = 3 * (1.21 - 0.66 f_T) = 1,65$$
$$k_a = 1 \; y \; k_p = 1$$
$$C_x = 1.5 - \frac{|x - 0.5L|}{L} = 1.5 - \frac{|42 - 0.5 * 82.12|}{82.12} = 1,49$$
$$f_{yb} = 0$$
$$f_{yz} = C_x * \frac{z}{T_{SC}} + (2 - C_x) * f_{yb} + 1 = 1.49 * \frac{0}{6,9} + (2 - 1.49) * 0 + 1 = 1$$
$$L_0 = 110 \; m$$
$$\lambda = 0.6 * (1 + f_T) * L = 0.6 * (1 + 1) * 82.12 = 98,54 \; m$$

Entonces;

$$P_{HS} = C_{fT} * f_{ps} * f_{nl} * f_h * k_a * k_p * f_{yz} * C_w * \sqrt{\frac{L_0 + \lambda - 125}{L}}$$
$$P_{HS} = 1.15 * 1 * 0.9 * 1.6 * 1 * 1 * 1 * 7.1 * \sqrt{\frac{110 + 98.54 - 125}{82.12}} = 11.86 \; kN/m^2$$
$$1.025 * 9.81 * (0 - 6.9) = -69,38 \; kN/m^2$$
$$P_w = \max(11,86; -69,38) = 11,86 \; kN/m^2$$

La presión debido al mar será entonces de:

$$P_S + P_w = 69.38 + 11.86 = 81.24 \; kN/m^2$$

También debemos de incluir la presión que ejerce el tanque de lastre situado en el compartimento de doble fondo.

1.1 Total pressure

1.1.1 Pressures for the strength and fatigue assessments of intact conditions

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 (S) design load scenarios, given in Sec.7, shall be taken as:

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

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].

1.2 Static liquid pressure

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.

Entonces:

$$\rho_l = 1.025\ t/m^3$$

$$Z_{top} = punto\ más\ alto\ del\ tanque\ en\ coordenada\ z\ (m).$$

Como nuestro tanque no tiene una válvula de seguridad.

$$P_{ls-1} = 1.025 * 9.81 * (1.4 - 0) = 14.1\ kN/m^2$$

A la presión estática que ejerce el tanque también deberemos añadir la presión dinámica.

1.3 Dynamic liquid pressure

1.3.1 The dynamic pressure due to liquid in tanks and ballast holds, in kN/m^2 shall be taken as:

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

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:

$f_{ull-\ell} = 0.5 + \frac{\left|z_0 - z\right|}{\ell_{fs}} \frac{180}{\varphi\pi}$ 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:

$$f_{ull-t} = 0.5 + \frac{|z_0 - z|}{b_{top}} \frac{180}{\theta\pi}$$ 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.

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.

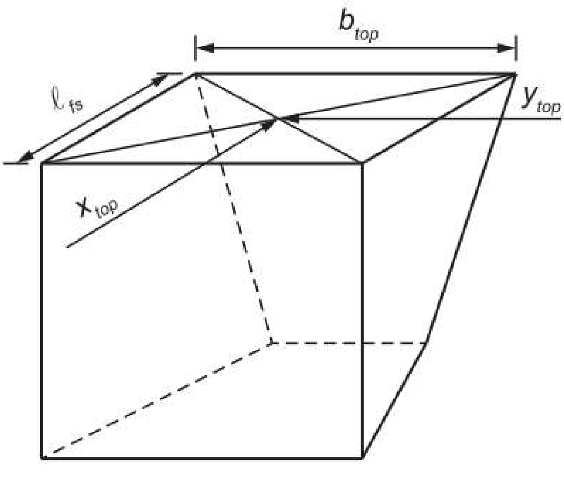


Figure 1 Area of a rectangular shape at the top of a tank

Debemos de conocer las coordenadas de referencia para el tanque de agua de lastre del fondo de cámara de máquinas. Seguiremos la siguiente formulación:

$$x_j = x_{top} \pm 0.5 * l_{fs}$$

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

Tanque de lastre de babor:

$$x_{j1} = 8.4$$

$$y_{j1} = 5.3$$

Entonces:

$$v_j = a_x(x_j - x_g) + a_y(y_j - y_g) + (a_z + g)(z_j - z_g)$$

$$v_j = 0.54 * (8.4) + 0(5.3) + (5.25 + 9.81)(1.4) = 25.26$$

La presión dinámica será la siguiente:

$$P_{ld} = f_{cd}\rho_L[a_z(z_0 - z) + f_{ull-l}a_x(x_0 - x) + f_{ull-t}a_y(y_0 - y)]$$

$$P_{ld} = 0.88 * 1.025[5.25(1.4) + 0.62 * 0.54 * (8.4) + 0.67 * 0 * (5.3)]$$

$$P_{ld} = 9.16\ kN/m^2$$

La presión interior total será de:

$$P_{ls-1} + P_{ld} = 14.1 + 9.16 = 23.26\ kN/m^2$$

La presión que debe soportar la chapa de fondo será la suma de la presión del mar y la presión del tanque superior.

$$P_{chapa\ fondo} = 81.24 + 23.26 = 104.5\ kN/m^2$$

3.1.2 Cálculo del espesor de la chapa de fondo.

En este apartado calcularemos el espesor que debe tener la chapa del fondo y de la quilla. El material que utilizaremos será acero clase A de 235 N/mm^2.

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

Los espesores mínimos los calcularemos según el reglamento DNV-RU-SHIP Pt.3 Ch.6 Hull local scantling. A continuación, se muestran los cálculos del espesor mínimo requerido para la quilla y para las chapas de doble fondo.

SECTION 3 MINIMUM THICKNESSES

Symbols

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

1 Plating

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 [9)]		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8) 9)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

El espesor mínimo requerido para la quilla es de:

$$t = 5 + 0.05 * 82{,}12 * \sqrt{1} = 9{,}11\ mm$$

El espesor mínimo requerido para las chapas de fondo es de:

$$t = 4.5 + 0.035 * 82{,}12 * \sqrt{1} = 7.37\ mm$$

Una vez calculados los espesores mínimos vamos a calcular con mayor detalle el espesor que tendrá la chapa de fondo.

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					

Tendremos lo siguiente. Los valores de a y b son el lado largo y corto del panel que estamos dimensionando.

$$\alpha_p = 1.2 - \frac{b}{2.1 * a} = 1.2 - \frac{700}{2.1 * 3000} = 1$$

$$C_\alpha = B_\alpha - \alpha_a * \frac{\sigma_{hg}}{R_{eh}} = 1.05 - 0.5 * \frac{205}{235} = 0{,}61$$

$$t = 0.0158 * \alpha_p * b * \sqrt{\frac{|P|}{C_\alpha * R_{eh}}} = 0.0158 * 1 * 700 * \sqrt{\frac{|104.5\,|}{0.61 * 235}} = 9{,}44\ mm$$

Si lo comparamos con el valor mínimo calculado antes, el resultado es mayor así que será válido. Finalmente tendremos un espesor normalizado

Espesor quilla = 10 mm y Espesor chapa fondo = 10 mm

3.1.3 Cálculo de la chapa de pantoque.

Debemos realizar el cálculo para el espesor mínimo que recomienda el reglamento.

2.1.3 Thickness of curved bilge plating

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

$$t = 6.45 \cdot 10^{-4} \cdot (P_{ex} s_b)^{0.4} \cdot R^{0.6}$$

where:

P_{ex} = design sea pressure for the design load set SEA-1 as defined in Sec.2 [2.1.3] calculated at the lower turn of the bilge, in kN/m^2

R = effective bilge radius, in mm, taken as:

$$R = R_0 + 0.5(\Delta s_1 + \Delta s_2)$$

R_0 = radius of curvature, in mm, see Figure 1

Δs_1 = distance between the lower turn of bilge and the outermost bottom longitudinal, in mm, see Figure 1. Where the outermost bottom longitudinal is within the curvature, this distance shall be taken as zero

Δs_2 = distance between the upper turn of bilge and the lowest side longitudinal, in mm, see Figure 1. Where the lowest side longitudinal is within the curvature, this distance shall be taken as zero

s_b = distance between transverse stiffeners, webs or bilge brackets, in mm.

A bilge keel is not considered as an effective 'longitudinal stiffening' member.

2.1.4 Transverse extension of bilge minimum plate thickness

Where a plate seam is located in the straight plate just below the lowest stiffener on the side shell, any increased thickness required for the bilge plating does not have to be extended to the adjacent plate above the bilge provided the plate seam is not more than $s_2/4$ below the lowest side longitudinal. Similarly, for the flat part of adjacent bottom plating, any increased thickness for the bilge plating does not have to be extended to the adjacent plate provided that the plate seam is not more than $s_1/4$ beyond the outboard bottom longitudinal. For definition of s_1 and s_2, see Figure 1.

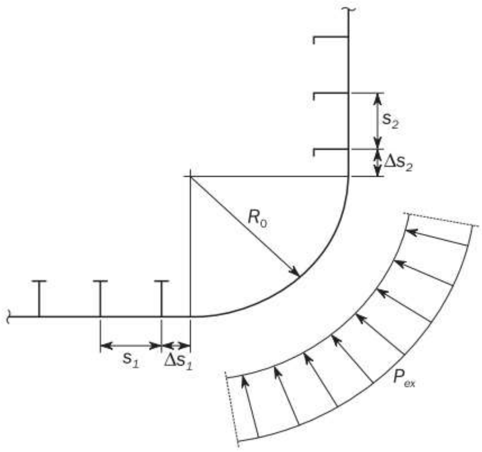


Figure 1 Bilge plating without longitudinal stiffening

La fórmula es la siguiente.

$$t = 6.45 * 10^{-4} * (P_{ex} * s_b)^{0.4} * R^{0.6}$$

$$t = 6.45 * 10^{-4} * (81.24 * 700)^{0.4} * 1400^{0.6} = 3.97\ mm$$

También debe cumplir el espesor mínimo de cualquier chapa del buque. Además, este espesor no puede ser inferior al de las chapas adyacentes.

$$\alpha_p = 1.2 - \frac{b}{2.1 * a} = 1.2 - \frac{500}{2.1 * 3000} = 1$$

$$C_\alpha = B_\alpha - \alpha_a * \frac{\sigma_{hg}}{R_{eh}} = 1.05 - 0.5 * \frac{205}{235} = 0{,}61$$

$$t = 0.0158 * \alpha_p * b * \sqrt{\frac{|P|}{C_\alpha * R_{eh}}} = 0.0158 * 1 * 700 * \sqrt{\frac{|81.24|}{0.61 * 235}} = 8{,}33\ mm$$

Si lo comparamos con el valor calculado antes, el resultado es mayor así que será válido. Finalmente tendremos un espesor normalizado para la chapa de pantoque de 10 mm. Esto se debe a que no puede ser menor que la chapa de fondo, que tiene este mismo valor.

3.1.4 Cálculo de las vagras.

El cálculo de las vagras se realizará determinando el espesor de estos elementos.

3 Primary supporting members

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 below longitudinal bulkhead in cargo area if arranged Bottom centreline girder outside cargo area in general for cargo ships Bottom centreline girder over full length of other ship types than cargo ships	5.0	0.03
Bottom longitudinal girders in general	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.		

Para la vagra que tienen un puntal encima.

$$t = a + bL_2\sqrt{k} = 5 + 0.03 * 82.12\sqrt{1} = 7.46\ mm = 8\ mm$$

Para la vagra límite de tanque.

$$t = a + bL_2\sqrt{k} = 4.5 + 0.015 * 82.12\sqrt{1} = 5.763mm = 6\ mm$$

Para el resto de las vagras.

$$t = a + bL_2\sqrt{k} = 4.5 + 0.01 * 82.12\sqrt{1} = 5.32\ mm = 6\ mm$$

También deberemos calcular el espesor de las vagras como si se tratase de un mamparo límite de tanque sometido a presión lateral. Para ello seguiremos lo siguiente expuesto en el DNV.

1 Plating

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

<table>
<tr><th>Element</th><th colspan="2">Location</th><th>a</th><th>b</th></tr>
<tr><td rowspan="6">Shell</td><td colspan="2">Keel</td><td>5.0</td><td>0.05</td></tr>
<tr><td colspan="2">Bottom, bilge and sea chest boundaries</td><td>4.5</td><td>0.035</td></tr>
<tr><td rowspan="4">Side shell and superstructure side</td><td>From upper end of bilge plating to T_{SC} + 4.6 m</td><td rowspan="4">4.0</td><td>0.035</td></tr>
<tr><td>From T_{SC} + 4.6 m to T_{SC} + 6.9 m [6)]</td><td>0.025</td></tr>
<tr><td>From T_{SC} + 6.9 m to T_{SC} + 9.2 m [6)]</td><td>0.015</td></tr>
<tr><td>Elsewhere[6) 7)]</td><td>0.01</td></tr>
<tr><td rowspan="3">Deck</td><td colspan="2">Weather deck[1),2),3),4), 5)] and strength deck[2),3)]</td><td rowspan="3">4.5</td><td>0.02</td></tr>
<tr><td colspan="2">Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk</td><td>0.015</td></tr>
<tr><td colspan="2">Other decks[3),4),5)]</td><td>0.01</td></tr>
<tr><td rowspan="2">Inner bottom</td><td colspan="2">Cargo spaces loaded through cargo hatches except container holds</td><td>5.5</td><td>0.025</td></tr>
<tr><td colspan="2">Other spaces</td><td>4.5</td><td>0.02</td></tr>
<tr><td rowspan="6">Bulkheads</td><td colspan="2">Bulkheads for cargo tanks, water ballast tanks and hold intended for cargo in bulk [9)]</td><td rowspan="3">4.5</td><td rowspan="2">0.015</td></tr>
<tr><td colspan="2">Peak bulkheads</td></tr>
<tr><td colspan="2">Watertight bulkheads and other tanks bulkheads [8) 9)]</td><td>0.01</td></tr>
<tr><td colspan="2">Non-tight bulkheads in tanks</td><td rowspan="2">5.0</td><td>0.005</td></tr>
<tr><td colspan="2">Other non-tight bulkheads</td><td>0</td></tr>
<tr><td colspan="2">Walls in accommodation</td><td>4.5</td><td>0</td></tr>
</table>

$$t = 4.5 + 0.015 * 82{,}12 * \sqrt{1} = 5.76\ mm$$

Este es el espesor mínimo que debe tener la vagra si fuese calculada como una chapa límite de tanque. Ahora deberemos calcular cuál es el valor que le corresponde realmente y comprobar que cumple el mínimo anteriormente calculado.

El espesor de la chapa de las vagras viene definido por lo siguiente.

$$t = 0.0158\alpha_p b \sqrt{\frac{|P|}{C_a R_{eH}}}$$

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

$$\alpha_p = 1.2 - \frac{b}{2.1 * a} = 1.2 - \frac{700}{2.1 * 3500} = 1.1$$

$$C_\alpha = \beta_\alpha - \alpha_a * \frac{\sigma_{hg}}{R_{eh}} = 1.05 - 0.5 * \frac{205}{235} = 0{,}62$$

$$t = 0.0158 * \alpha_p * b * \sqrt{\frac{|P|}{C_\alpha * R_{eh}}} = 0.0158 * 1.1 * 700 * \sqrt{\frac{|104.5|}{0.62 * 235}} = 9{,}92\ mm$$

Espesor mayor que el mínimo, por lo tanto, válido. El espesor final de las vagras estancas será de 10 mm. Las vagras no estancas tendrán el espesor calculado anteriormente que ya cumple con el mínimo si fuesen calculadas como chapas límites de tanques, 6 mm.

Estas vagras también llevarán refuerzos. El módulo de los longitudinales se obtiene de la siguiente forma.

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 stiffeners with one or both end fixed	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 stiffeners with simply supported ends	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	

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 stiffeners with fixed ends		For stiffeners with one fixed end and one simply supported end	For 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	

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 104.5 * 460 * 3.5^2}{12 * 0.23 * 235} = 935\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta bulbo de: 340*12 un módulo de 947 cm^3.

3.1.5 Cálculo de las varengas.

Las varengas son refuerzos primarios que actúan en sentido transversal en el fondo del buque, que junto con las bulárcamas de los costados y los baos de cubierta forman los anillos de resistencia transversal del buque.

Las varengas pueden ser de tres tipos, llenas, estancas o abiertas, dependiendo de si constitución, además, al tratarse de un buque de estructura longitudinal, estas varengas tienen escotes, es decir, aberturas en el alma de la varenga realizadas para permitir el paso de los elementos longitudinales secundarios, que calcularemos en el siguiente apartado.

Según el DNV en el caso de tener varengas estancas, estas se calcularían como mamparos transversales estancos. Las varengas no estancas no soportarán la presión de ningún líquido por lo que el espesor de la varenga será el espesor mínimo requerido.

3 Primary supporting members

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 below longitudinal bulkhead in cargo area if arranged Bottom centreline girder outside cargo area in general for cargo ships Bottom centreline girder over full length of other ship types than cargo ships	5.0	0.03
Bottom longitudinal girders in general	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.

Espesor de las varengas no estancas del buque.

$$t = a + b * L_2 * \sqrt{k} = 4.5 + 0.015 * 82.12 * \sqrt{1} = 5.32\ mm = 6\ mm$$

También deberemos calcular el espesor de las varengas como si se tratase de un mamparo límite de tanque sometido a presión lateral. Para ello seguiremos lo siguiente expuesto en el DNV.

1 Plating

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 9)	4.5	0.015
	Peak bulkheads		
	Watertight bulkheads and other tanks bulkheads 8) 9)		0.01
	Non-tight bulkheads in tanks	5.0	0.005
	Other non-tight bulkheads		0
	Walls in accommodation	4.5	0

$$t = 4.5 + 0.015 * 82{,}12 * \sqrt{1} = 5.76\ mm$$

Este es el espesor mínimo que debe tener la varenga si fuese calculada como una chapa límite de tanque. Ahora deberemos calcular cuál es el valor que le corresponde realmente y comprobar que cumple el mínimo anteriormente calculado. El espesor de la chapa de las varengas viene definido por lo siguiente.

$$t = 0.0158\alpha_p b \sqrt{\frac{|P|}{C_a R_{eH}}}$$

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

$$\alpha_p = 1.2 - \frac{b}{2.1 * a} = 1.2 - \frac{700}{2.1 * 3500} = 1.1$$

$$C_\alpha = \beta_\alpha - \alpha_a * \frac{\sigma_{hg}}{R_{eh}} = 1.05 - 0.5 * \frac{205}{235} = 0{,}62$$

$$t = 0.0158 * \alpha_p * b * \sqrt{\frac{|P|}{C_\alpha * R_{eh}}} = 0.0158 * 1.1 * 700 * \sqrt{\frac{|104.5|}{0.62 * 235}} = 9{,}92\ mm$$

Espesor mayor que el mínimo, por lo tanto, válido. El espesor final de las varengas estancas será de 10 mm. Las varengas no estancas tendrán el espesor calculado anteriormente que ya cumple con el mínimo si fuesen calculadas como chapas límites de tanques, 6 mm.

3.1.6 Cálculo de los refuerzos secundarios del fondo.

Necesitaremos un módulo de:

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 stiffeners with one or both end fixed	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 stiffeners with simply supported ends	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	

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 stiffeners with fixed ends		For stiffeners with one fixed end and one simply supported end	For 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	

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 104.5 * 500 * 3.5^2}{12 * 0.23 * 235} = 290\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta bulbo de: 220*10 con un módulo de 302 cm^3. Deberemos calcular si cumple con el espesor mínimo.

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

También es necesario calcular la altura efectiva de los refuerzos.

1.4.3 Effective shear depth of stiffeners

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

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

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

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.

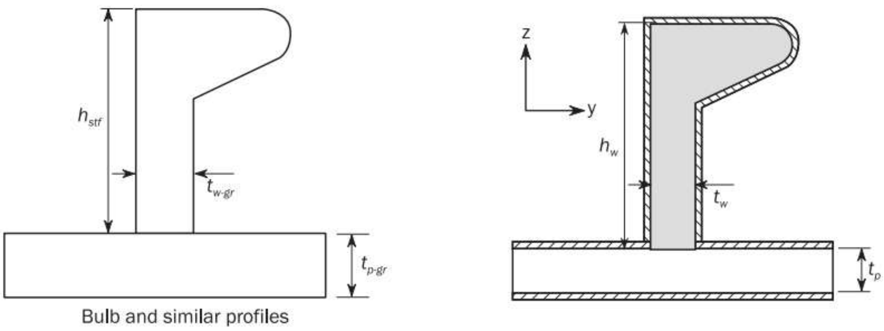


Figure 2 Net sectional properties of local supporting members (continued)

Entonces:

$$d_{shr} = 220 + 10 = 230\ mm$$

Calculamos el espesor mínimo del refuerzo.

$$t_w = \frac{C_m * f_{shr} * |P| * s * l_{shr}}{d_{shr} * C_t * \tau_{eH}} = \frac{1 * 0.5 * |104.5| * 500 * 3.5}{230 * 0.9 * 135.7} = 3.25\ mm$$

Como se observa, el perfil cumple con el espesor mínimo por tanto es adecuado.

3.2 Dimensionamiento del doble fondo.

3.2.1 Cálculo de las presiones.

Realizaremos estudios de la presión para dimensionar el doble fondo. Tendremos en cuenta la presión de los tanques de agua de lastre, los tanques de aceite centrales y los tanques de barro de perforación situados en encima del doble fondo.

Primero calcularemos la presión de los tanques de lastre.

Internal structures in tanks	INT-1	1	P_{int}	T_{SC}	AC-I	-

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].

Siendo:

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.

Entonces:

$$\rho_l = 1.025\ t/m^3$$

$$Z_{top} = punto\ más\ alto\ del\ tanque\ en\ coordenada\ z\ (m).$$

Como nuestro tanque no tiene una válvula de seguridad.

$$P_{ls-1} = 1.025 * 9.81 * (1.4 - 0) = 14.1\ kN/m^2$$

1.3 Dynamic liquid pressure

1.3.1 The dynamic pressure due to liquid in tanks and ballast holds, in kN/m^2 shall be taken as:

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

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:

$f_{ull\text{-}t}$ = 0.62 for cargo tanks filled with any liquids inclusive water ballast

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

for fatigue assessment:

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

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

$f_{ull\text{-}t}$ 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.

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.

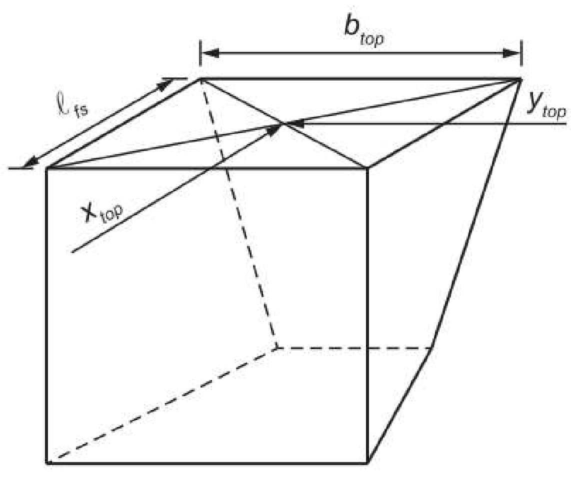


Figure 1 Area of a rectangular shape at the top of a tank

Debemos de conocer las coordenadas de referencia para el tanque de agua de lastre del fondo de cámara de máquinas. Seguiremos la siguiente formulación:

$$x_j = x_{top} \pm 0.5 * l_{fs}$$

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

Tanque de lastre de babor:

$$x_{j1} = 8.4$$

$$y_{j1} = 5.3$$

Entonces:

$$v_j = a_x(x_j - x_g) + a_y(y_j - y_g) + (a_z + g)(z_j - z_g)$$

$$v_j = 0.54 * (8.4) + 0(4.5) + (5.25 + 9.81)(1.4) = 25.26$$

La presión dinámica será la siguiente:

$$P_{ld} = f_{cd}\rho_L[a_z(z_0 - z) + f_{ull-l}a_x(x_0 - x) + f_{ull-t}a_y(y_0 - y)]$$

$$P_{ld} = 0.88 * 1.025[5.25(1.4) + 0.62 * 0.54 * (8.4) + 0.67 * 0 * (5.3)]$$

$$P_{ld} = 9.16\ kN/m^2$$

La presión interior total será de:

$$P_{ls-1} + P_{ld} = 14.1 + 9.16 = 23.26\ kN/m^2$$

A continuación, calcularemos la presión ejercida por los tanques de barro de perforación. Calcularemos esto como situación más crítica, a pesar de que estos tanques no se encuentren justo en la cámara de máquinas, porque su peso es mayor que el de los cuatro diésel generadores juntos.

Boundaries of tanks other than ballast water tanks	TK-1	2	$P_{ls\text{-}1} + P_{ld} - (P_S + P_W)^{(1)}$	T_{BAL}	AC-II	Normal ballast condition
	TK-2	4	$P_{ls\text{-}ST} - P_S$ 1)	max(T_{BAL}; $0.25T_{SC}$)	AC-III	
	TK-3	1	$P_{ls\text{-}3} - P_S$ 1)	max(T_{BAL}; $0.25T_{SC}$)	AC-I	-

Siendo:

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

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

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

z_{ST} = testing load height, in m, as defined in Table 1.

The actual tank testing shall be carried out in accordance with Pt.2 Ch.4 Sec.8.

Table 1 Design testing load height z_{ST}

Compartment	z_{ST}
Double bottom tanks	The greater of the following: $z_{ST} = z_{top} + h_{air}$ $z_{ST} = z_{top} + 2.4$ $z_{ST} = z_{bd}$
Hopper side tanks 1), topside tanks 1), double side tanks 1), fore and aft peaks used as tank	The greater of the following: $z_{ST} = z_{top} + h_{air}$ $z_{ST} = z_{top} + 2.4$ $z_{ST} = z_{bd}$
Tanks, deep tanks, fuel oil bunkers, cargo tanks 2)	The greater of the following: z_{ST} 3) $= z_{top} + h_{air}$ $z_{ST} = z_{top} + 2.4$ $z_{ST} = z_{top} + 0.1\ P_{PV}$
Ballast hold	$z_{ST} = z_h + 0.9$
Chain locker	$z_{ST} = z_c$
Independent tanks	The greater of the following: $z_{ST} = z_{top} + h_{air}$ $z_{ST} = z_{top} + 0.9$
Ballast ducts	The greater of the following: — testing load height corresponding to ballast pump maximum pressure — stetting of any pressure relief valve.

where:
z_{bd} = Z coordinate, in m, of the bulkhead deck
z_h = Z coordinate, in m, of the top of hatch coaming
z_c = Z coordinate, in m, of the top of chain pipe.

1) Applicable to double bottom tank connected with hopper side tanks, topside tanks or double side tanks.
2) Tank test load is not applicable for cargo tanks carrying LNG.
3) Not applicable for cargo tanks.

$$z_{ST} = z_{TOP} + h_{ai} \quad = 6.7\ m$$

$$z_{ST} = z_{TOP} + 2.4 = 6.7 + 2.4 = 9.1\ m$$

$$z_{ST} = z_{TOP} + 0.1 * P_{PV} = 6.7 + 0.1 * 30 = 9.7\ m$$

Tomaremos el tercer valor puesto que es el más elevado.

$$P_S = \rho_L * g * (z_{top} - z) = 2.6 * 9.81 * (9.7 - 2.4) = 186\ kN/m^2$$

Esta será la presión para determinar el doble fondo.

3.2.2 Cálculo del espesor de la chapa del doble fondo.

Calculamos el espesor mínimo que debe de tener la chapa de doble fondo según el DNV.

1 Plating

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 [9)]		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8) 9)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

$$t = 5.5 + 0.025 * 82{,}12 * \sqrt{1} = 7.55\ mm$$

Espesor mínimo del doble fondo = 8 mm.

Una vez calculado el espesor mínimo general debemos calcular el espesor propio de esta chapa y comparar si cumple el requisito.

$$t = 0.0158\alpha_p b\sqrt{\frac{|P|}{C_a R_{eH}}}$$

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

$$\alpha_p = 1.2 - \frac{b}{2.1 * a} = 1.2 - \frac{500}{2.1 * 3000} = 1$$

$$C_\alpha = \beta_\alpha - \alpha_a * \frac{\sigma_{hg}}{R_{eh}} = 0.9 - 0.5 * \frac{205}{235} = 0{,}46$$

$$t = 0.0158 * \alpha_p * b * \sqrt{\frac{|P|}{C_\alpha * R_{eh}}} = 0.0158 * 1 * 500 * \sqrt{\frac{|186|}{0.46 * 235}} = 10.36\ mm$$

El espesor final de la chapa de doble fondo será de 11 mm.

3.2.3 Cálculo de los refuerzos secundarios del doble fondo.

El módulo de los longitudinales se obtiene mediante la siguiente fórmula.

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 stiffeners with one or both end fixed	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 stiffeners with simply supported ends	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	$C_{s\text{-}max}$
AC-I	Longitudinal members		0.95	1.00	0.85
	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 stiffeners with fixed ends*		*For stiffeners with one fixed end and one simply supported end*	*For 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	

Entonces:

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 186 * 500 * 3.5^2}{12 * 0.23 * 235} = 1809.17\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta bulbo de: 430*15 con un módulo de 1935 cm3. Deberemos calcular si cumple con el espesor mínimo.

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

También es necesario calcular la altura efectiva de los refuerzos.

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.

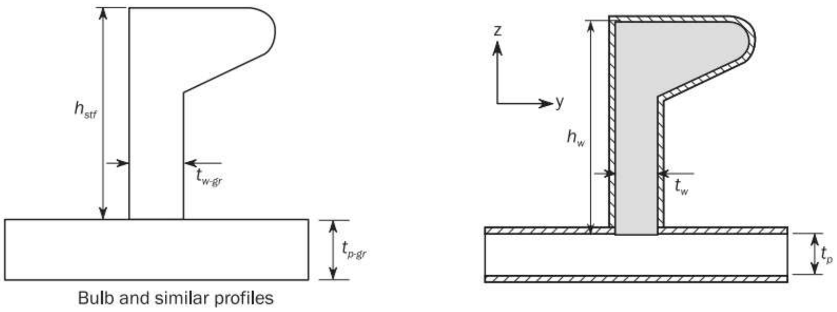


Figure 2 Net sectional properties of local supporting members (continued)

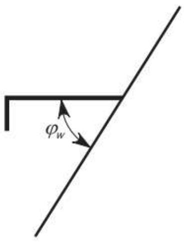


Figure 17 Angle between stiffener web and attached plating

Entonces:

$$d_{shr} = 430 + 11 = 441\ mm$$

Calculamos el espesor mínimo del refuerzo.

$$t_w = \frac{C_m * f_{shr} * |P| * s * l_{shr}}{d_{shr} * C_t * \tau_{eH}} = \frac{1 * 0.5 * |186| * 500 * 3.5}{441 * 0.9 * 135.7} = 3\ mm$$

Como se observa, el perfil cumple con el espesor mínimo por tanto es adecuado.

3.3 Dimensionamiento del costado.

3.3.1 Cálculo de las presiones.

Para el cálculo de las presiones en el costado se distinguirán dos secciones:

1. Presión externa debida al mar, hasta el calado de verano.
2. Presión interna debida al tanque de agua de lastre situado en el doble caso.

Primero se calcula la presión estática externa debida al mar (la altura del punto para mediar la presión se sitúa a un tercio de la distancia del costado). Seguiremos el mismo proceso que un par de páginas más arriba.

Por tanto, la presión estática debido al mar es la siguiente.

$$P_s = \rho * g * (T_{LC} - z) = 1.025 * 9.81 * (6{,}9 - 3.23) = 36.90\ kN/m^2$$

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:

$$f_h = 3.0\left(1.21 - 0.66 f_T\right)$$

f_h = coefficient to be taken as:

$$f_h = 3.0(1.21 - 0.66 f_T)$$

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

$$k_a = (0.5 + f_T)\left[\left(3 - 2\sqrt{f_{yB}}\right) - \frac{20}{9} f_{xL}\left(7 - 6\sqrt{f_{yB}}\right)\right] + \frac{2}{3}(1 - f_T) \quad \text{for } f_{xL} < 0.15$$

$$k_a = 1.0 \quad \text{for } 0.15 \le f_{xL} < 0.7$$

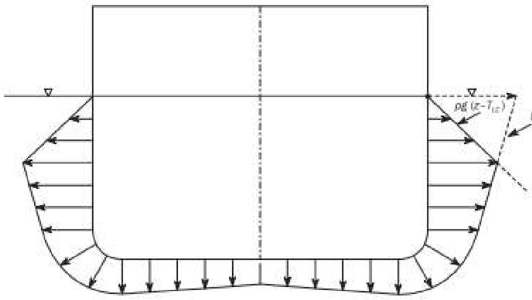
$$k_a = 1 + (f_{xL} - 0.7)\left\{\left(\frac{40}{3} f_T - 5\right) + 2\left(1 - f_{yB}\right)\left[\frac{18}{C_B} f_T (f_{xL} - 0.7) - 0.25(2 - f_T)\right]\right\} \quad \text{for } f_{xL} \ge 0.7$$

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.

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



Comenzaremos con el cálculo de la presión dinámica.

$$f_T = \frac{T_{SC}}{T_{LC}} = \frac{6{,}9}{6{,}9} = 1$$

$$C_{fT} = f_T + 0.5 - (0.7 * f_T - 0.2) * C_b = 1{,}15$$

$$f_{ps} = 1$$

$$f_{xl} = \frac{x}{L} = \frac{42}{82{,}12} = 0{,}51$$

$$f_{nl} = 0.9$$

$$f_h = 3 * (1.21 - 0.66 f_T) = 1{,}65$$

$$k_a = 1 \; y \; k_p = 1$$

$$C_x = 1.5 - \frac{|x - 0.5L|}{L} = 1.5 - \frac{|42 - 0.5 * 82.12|}{82.12} = 1{,}49$$

$$f_{yb} = 0$$

$$f_{yz} = C_x * \frac{z}{T_{SC}} + (2 - C_x) * f_{yb} + 1 = 1.49 * \frac{2.3}{6{,}9} + (2 - 1.49) * 0 + 1 = 1.50$$

$$L_0 = 110 \; m$$

$$\lambda = 0.6 * (1 + f_T) * L = 0.6 * (1 + 1) * 82.12 = 98{,}54 \; m$$

Entonces;

$$P_{HS} = C_{fT} * f_{ps} * f_{nl} * f_h * k_a * k_p * f_{yz} * C_w * \sqrt{\frac{L_0 + \lambda - 125}{L}}$$

$$P_{HS} = 1.15 * 1 * 0.9 * 1.65 * 1 * 1 * 1.50 * 7.1 * \sqrt{\frac{110 + 98.54 - 125}{82.12}} = 18.34 \; kN/m^2$$

$$1.025 * 9.81 * (2.3 - 6.9) = -46.25 \; kN/m^2$$

$$P_w = \max(18.34; -46.25) = 18.34 \; kN/m^2$$

La presión debido al mar será entonces de:

$$P_S + P_w = 36.90 + 18.34 = 55.24 \; kN/m^2$$

La presión debido al tanque de agua de lastre lateral se calcula mediante la siguiente fórmula.

Internal structures in tanks	INT-1	1	P_{int}	T_{SC}	AC-I	-

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].

$$P_{ls-1} = \rho_L * g * (z_{top} - z) = 1.025 * 9.81 * (7.7 - 1.4) = 63.64\ kN/m^2$$

Para el cálculo de P_{ld} debemos hallar el punto de referencia del tanque.

$$x_{j1} = x_{top} \pm 0.5 * l_{fs}$$

$$y_{j1} = y_{top} \pm 0.5 * b_{top}$$

Entonces:

$$x_{j1} = 8.4\ m$$

$$x_{j2} = 0\ m$$

$$y_{j1} = 1.4\ m$$

$$y_{j2} = 0\ m$$

Entonces:

$$v_j = a_x(x_j - x_g) + a_y(y_j - y_g) + (a_z + g)(z_j - z_g)$$

$$v_j = 0.54 * (8.4) + 0(1.4 - 0) + (5.25 + 9.81)(9.1 - 5.25) = 60.249$$

La presión dinámica será la siguiente:

$$P_{ld} = f_{cd}\rho_L[a_z(z_0 - z) + f_{ull-l}a_x(x_0 - x) + f_{ull-t}a_y(y_0 - y)]$$

$$P_{ld} = 0.88 * 1.025 * [5.25 * (7.7 - 1.4) + 0.62 * 0.54 * (42 - 33.6) + 0.67 * 0 * (1.4)]$$

$$P_{ld} = 32.37\ kN/m^2$$

La presión interior total será de:

$$P_{in} = P_{ls-} \ + P_{ld} = 55.24 + 32.37 = 87.61\ kN/m^2$$

3.3.2 Cálculo del espesor de la chapa de costado.

El espesor mínimo de la chapa se calculará según lo que establece el reglamento.

1 Plating

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 [9)]		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8) 9)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

$$t = 4 + 0.035 * 82{,}12 * \sqrt{1} = 6.87\ mm$$

Este es el espesor mínimo que debe tener la chapa del costado. Ahora deberemos calcular cuál es el valor que le corresponde realmente y comprobar que cumple el mínimo anteriormente calculado.

El espesor de la chapa de costado viene definido por lo siguiente.

$$t = 0.0158\alpha_p b\sqrt{\frac{|P|}{C_a R_{eH}}}$$

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

La separación entre refuerzos en el costado es condición de proyecto y se considera 700mm.

$$\alpha_p = 1.2 - \frac{b}{2.1 * a} = 1.2 - \frac{700}{2.1 * 3500} = 1.1$$

$$C_\alpha = \beta_\alpha - \alpha_a * \frac{\sigma_{hg}}{R_{eh}} = 1.05 - 0.5 * \frac{205}{235} = 0{,}62$$

$$t = 0.0158 * \alpha_p * b * \sqrt{\frac{|P|}{C_\alpha * R_{eh}}} = 0.0158 * 1.1 * 700 * \sqrt{\frac{|87.61|}{0.62 * 235}} = 9.43\ mm$$

Espesor mayor que el mínimo, por lo tanto, válido. El espesor final de la chapa de costado será de 10 mm.

3.3.3 Cálculo de las cuadernas.

El módulo de la cuaderna se obtiene mediante la siguiente fórmula.

2.1.1 Section modulus

The section modulus, in cm³, 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:

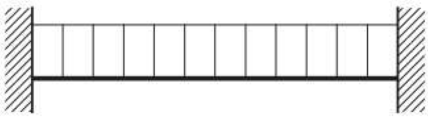
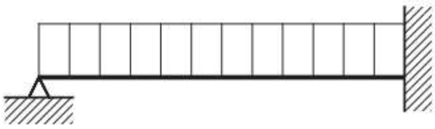
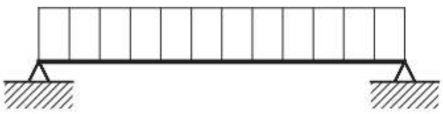
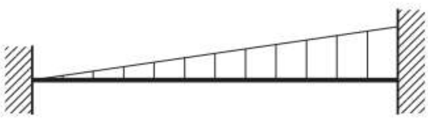
C_s = 0.70 for AC-I

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].

La bulárcama se debe dimensionar suponiendo que ambos extremos se encuentran empotrados, evitando así el giro de esta. Entonces tendremos el modelo A.

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

$$Z = 1000 * \frac{|P| * S * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}}$$

$$Z = 1000 * \frac{|P| * S * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = 1000 * \frac{|87.61| * 0.7 * 7.7^2}{12 * 0.85 * 235} = 1516.93\ cm^3$$

Se escogen los siguientes perfiles tipo bulbo. Estos deben tener las siguientes medidas 400*14 mm y un módulo de 15580 cm^3.

¿Cumple este perfil con el espesor mínimo?

En este caso se hará la comprobación mediante el espesor mínimo recomendado y el área mínima recomendado, debido a que es un elemento sometido a presión lateral.

El espesor se calcula mediante la fórmula:

3 Primary supporting members

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 below longitudinal bulkhead in cargo area if arranged Bottom centreline girder outside cargo area in general for cargo ships Bottom centreline girder over full length of other ship types than cargo ships	5.0	0.03
Bottom longitudinal girders in general	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.		

$$t = a + b * L_2 * \sqrt{k} = 4.5 + 0.015 * 82.12 * \sqrt{1} = 5.54\ mm$$

El perfil escogido cumple con el requisito del espesor mínimo, podemos afirmar que la elección es válida.

El área, por otro lado, se calcula de la siguiente manera:

2.1.2 Shear area

The shear area, in cm^2, 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:

$$A_{shr} = 10\frac{f_{shr}|P|S\ \ell_{shr}}{C_t \tau_{eH}}$$

where:

f_{shr} = shear force distribution factor, as given in Table 1

C_t = permissible shear stress coefficient to be taken as:

C_t = 0.70 for AC-I

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

$$A_{shr} = 10 * \frac{f_{shr}|P| * S * l_{shr}}{c_t\ \tau_{eH}} = 10 * \frac{0.5 * |87.61| * 0.7 * 7.7}{0.85 * 135.7} = 20.47\ cm^2$$

El área del perfil escogido anteriormente es de 63.9 cm^2 por tanto cumple este requisito. Además, también cumplimos con el espesor así que es totalmente válido.

3.3.4 Cálculo de los refuerzos secundarios del costado.

El módulo de los longitudinales se obtiene de la siguiente forma.

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 stiffeners with one or both end fixed	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 stiffeners with simply supported ends	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	

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 stiffeners with fixed ends		For stiffeners with one fixed end and one simply supported end	For 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	

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 87.61 * 700 * 3.5^2}{12 * 0.23 * 235} = 1193\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta bulbo de: 370*13 un módulo de 1210 cm^3. Ahora deberemos calcular si cumple con el espesor mínimo.

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

También es necesario calcular la altura efectiva de los refuerzos.

1.4.3 Effective shear depth of stiffeners

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

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

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

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.

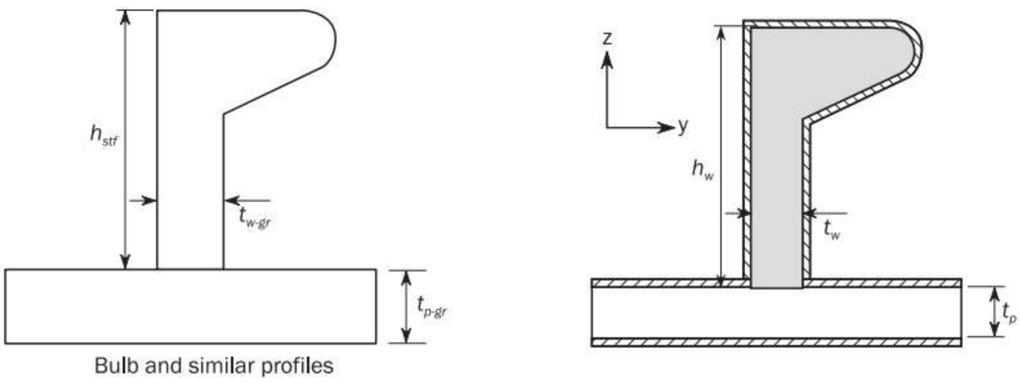


Figure 2 Net sectional properties of local supporting members (continued)

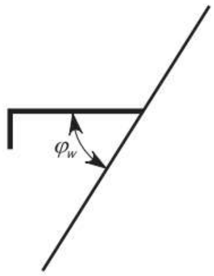


Figure 17 Angle between stiffener web and attached plating

Entonces:

$$d_{shr} = 370 + 10 = 380\ mm$$

Calculamos el espesor mínimo del refuerzo.

$$t_w = \frac{C_m * f_{shr} * |P| * s * l_{shr}}{d_{shr} * C_t * \tau_{eH}} = \frac{1 * 0.5 * |87.61| * 700 * 3.5}{380 * 0.9 * 135.7} = 2.31\ mm$$

Como se observa, el perfil cumple con el espesor mínimo por tanto es adecuado.

3.3.5 Cálculo de palmejares.

Se estudiará el palmejar como elemento estructural de refuerzo del costado.

Se dispondrán dos palmejares. Uno coincidirá con la cubierta intermedia así que será esta la que realice la función de “palmejar” en la cámara de máquinas. El otro está situado a una altura de 4.10 m sobre la línea base, la manga abarcará el doble costado del buque, 1.4 m. El espesor mínimo viene dado por la siguiente fórmula.

2 Stiffeners and tripping brackets

2.1 Minimum thickness requirements

2.1.1 The net thickness of the web and face plate, if any, of stiffeners and tripping brackets in mm, shall comply with the minimum net thickness given in Table 2.

In addition, the net thickness of the web of stiffeners and tripping brackets, in mm, shall be:

— not less than 40% of the net required thickness of the attached plating, to be determined according to Sec.4.

Table 2 Minimum net thickness for stiffeners and tripping brackets

Element	*Location*	*Net thickness*
Stiffeners and attached end brackets	Tank boundary, boundary of cargo holds for dry bulk cargo, single strength deck and shell up to freeboard deck	$4.5 + 0.01\ L_1$
	Structures in deckhouse and superstructure and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.0
	Other structure	$4.5 + 0.005\ L_1$
Tripping brackets		$4.5 + 0.01\ L_1$

$$t = 4.5 + 0.01 * L_1 = 4.5 + 0.01 * 82.12 = 12.71\ mm$$

El módulo mínimo requerido se calcula mediante la fórmula:

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 stiffeners with fixed ends*		*For stiffeners with one fixed end and one simply supported end*	*For 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	

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 87.61 * 2700 * 3.5^2}{12 * 0.23 * 235} = 4601.65\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta L de: 675*200 con un módulo 4602 cm^3. Cuenta con un espesor de 12 mm. Como su espesor es inferior al mínimo deberemos aumentar. La siguiente llanta tipo L de la tabla con estas características es 830*200 mm con un espesor de 14mm.

3.3.1 Cálculo de la bulárcama.

La bulárcama tendrá un ancho de 1400 mm lo que equivale a la separación del doble casco del buque. Situaremos una cada 3500 mm que es equivalente a una separación de 5 claras de cuadernas de trazado. Seguiremos la siguiente fórmula.

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

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 below longitudinal bulkhead in cargo area if arranged Bottom centreline girder outside cargo area in general for cargo ships Bottom centreline girder over full length of other ship types than cargo ships	5.0	0.03
Bottom longitudinal girders in general	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.		

Entonces:

$$t = a + b * L_2 * \sqrt{k} = 4.5 + 0.015 * 82.12 * \sqrt{1} = 5.54\, mm = 6\, mm$$

El espesor final de la bulárcama será de 6 mm.

3.4 Dimensionamiento de la cubierta principal.

3.4.1 Cálculo de las presiones.

Para el cálculo de las presiones tendremos en cuenta que se trata de la cubierta principal y es una cubierta expuesta. Esta cubierta debe soportar carga así que supondremos que las cargas son siempre distribuidas a lo largo de esta.

Exposed decks and non-exposed decks and platforms with distributed load	UDL-1 2)5)	2 5)	$P_{dl\text{-}s} + P_{dl\text{-}d}$ $F_{U\text{-}s} + F_{U\text{-}d}$	T_{BAL} 3)	AC-II	3)
	UDL-2 2)5)	1 5)	$P_{dl\text{-}s}$ $F_{U\text{-}s}$	-	AC-I	-

2.3 Load carried on decks and platforms

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.

Las cargas que debe soportar este tipo de buque en cubierta suelen variar desde las 5t/m^2 hasta las 10 t/m^2. En nuestro caso el elemento más pesado encubierta será el cabrestante principal de remolque con un peso de 93,50 t y un ancho de 6 m. Esto supone una carga distribuida a soportar de 15 t/m^2. Será nuestro caso más extremo para considerar en el análisis de las presiones en cubierta.

$$P_{dl-s} = 15\ t/m^2 = 147.10\ kN/m^2$$

Para el cálculo de la presión dinámica utilizaremos la aceleración vertical calculada anteriormente.

$$P_{dl-d} = P_{dl-s} * \frac{a_z}{g} = 147.10 * \frac{5.25}{9.81} = 78.72\ kN/m^2$$

La presión total que ha de soportar la cubierta debe ser la siguiente.

$$P_{dl} = P_{dl-s} + P_{dl-d} = 147.10 + 78.72 = 225.82\ kN/m^2$$

3.4.2 Cálculo del espesor de la chapa de la cubierta principal.

El espesor mínimo de la chapa debe ser el siguiente.

1 Plating

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 [9)]		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8) 9)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

$$t = 4.5 + 0.02 * 82{,}12 * \sqrt{1} = 7.39\ mm$$

El espesor de la chapa de cubierta viene definido por lo siguiente.

$$t = 0.0158\alpha_p b\sqrt{\frac{|P|}{C_a R_{eH}}}$$

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

$$\alpha_p = 1.2 - \frac{b}{2.1 * a} = 1.2 - \frac{700}{2.1 * 3500} = 1.1$$

$$C_\alpha = \beta_\alpha - \alpha_a * \frac{\sigma_{hg}}{R_{eh}} = 1.05 - 0.5 * \frac{205}{235} = 0{,}62$$

$$t = 0.0158 * \alpha_p * b * \sqrt{\frac{|P|}{C_\alpha * R_{eh}}} = 0.0158 * 1.1 * 700 * \sqrt{\frac{|225.82|}{0.62 * 235}} = 15.40\ mm$$

Espesor mayor que el mínimo, por lo tanto, válido. El espesor final de la cubierta será de 16 mm.

3.4.3 Puntales a la cubierta principal.

Para dimensionar los baos de la cubierta disponemos de puntales, para que así estos actúen como soporte de los baos, disminuyendo su luz y así su tamaño. La separación de los puntales será de cinco claras de cuaderna para que formen parte de los anillos transversales. Estos anillos están formados por la unión de las bulárcamas con las varengas y a su vez con los baos. La máxima distancia transversal de separación de los baos será de 6 m, que corresponde con la máxima luz que tendremos.

El dimensionamiento de los puntales debe realizarse por pandeo y para ello utilizaremos la siguiente sección del reglamento DNV-RU-SHIP Pt.3 Ch.8 Buckling. Primero estableceremos un tipo de perfil a utilizar, el nuestro será un HEA 140. Ahora debemos calcular si cumple los requerimientos de pandeo o no.

Las características del perfil son las siguientes:

$$E = 2.06 * 10^5 N/mm^2$$

$$I = 1033\ cm^4$$

$$A = 31.4\ cm^2$$

$$l = Puntal - Altura\ cubierta\ inermedia - Alma\ del\ bao = 9.10 - 6.40 - 0.785 = 1.915\ m$$

Por tanto, del reglamento obtenemos lo siguiente.

Lateral buckling mode

For longitudinals subject to longitudinal hull girder compressive stresses, supporting bulkhead stiffeners, pillars, cross ties, panting beams etc., the ideal elastic lateral buckling stress may be taken as:

$$\sigma_{el} = 0.001\ E\ \frac{I_A}{A l^2} \quad (\text{N/mm}^2)$$

I_A = moment of inertia in cm^4 about the axis perpendicular to the expected direction of buckling
A = cross-sectional area in cm^2.

$$\sigma_{el} = 0.001 * E * \frac{I_A}{A * l^2}$$

$$\sigma_{el} = 0.001 * 2.06 * 10^5 * \frac{1033}{31.4 * 1.915^2} = 1847\ N/mm^2$$

For pillars, cross ties and panting beams the critical buckling stress as calculated in 201 shall not be less than:

$$\sigma_c = \frac{10P}{A\eta} \quad (\text{N/mm}^2)$$

$\eta = \dfrac{k}{\left(1 + \frac{l}{i}\right)}$, minimum 0.3

P = axial load in kN as given for various strength members in 204 and 205. Alternatively, P may be obtained from direct stress analysis, see Sec.12

l = length of member in m

i = radius of gyration in cm = $\sqrt{\frac{I_A}{A}}$

I_A and A as given in 201

k = 0.5 for pillars below exposed weather decks forward of 0.1 L from F.P.
= 0.6 for pillars below weather decks when sea loads are applied
= 0.7 in all other cases.

Entonces tendremos los siguientes datos.

- P es la presión que utilizamos en cubierta: 225.82 kN/m^2.
- L es la longitud del puntal = 1.915 m.
- s es la separación entre puntales= 4.5 m.
- i es el radio de giro = 5.73 cm.
- K es una constante = 0.7

Por tanto, tendremos lo siguiente.

$$\eta = \frac{0.7}{1 + \frac{1.915}{5.73}} = 0.53$$

$$A_D = s * l = 4.5 * 1.915 = 8.62\ m^2$$

$$F = P * A_D = 225.82 * 8.62 = 1946.56\ kN$$

$$\sigma_c = \frac{10 * P}{A * \eta} = \frac{10 * 1946.56}{31.4 * 0.53} = 1169.66\ N/mm^2$$

El perfil cumple ya que $\sigma_{el} > \sigma_c$. Finalmente, los puntales que soportan el peso de la cubierta principal son del tipo HEA 140.

3.4.4 Cálculo de los baos que soportan la cubierta principal.

El módulo de los baos se obtiene mediante la siguiente fórmula. Además, el bao se va a dimensionar suponiendo que los extremos se encuentran empotrados, es decir, no va a permitir el giro.

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

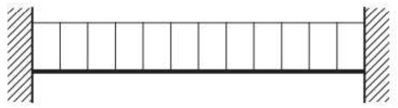
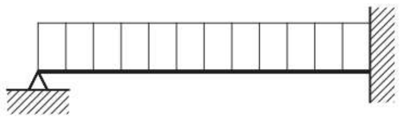
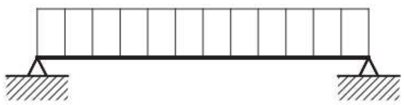
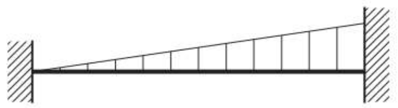
C_s = permissible stress coefficient to be taken as:

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].

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

$$Z = 1000 * \frac{|P| * S * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}}$$

$$Z = 1000 * \frac{|P| * S * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = 1000 * \frac{|225.82| * 3.5 * 4.5^2}{12 * 0.85 * 235} = 6677{,}09\ cm^3$$

Se escogen los siguientes perfiles de llanta tipo T: 785*200 mm con un espesor de 12 mm y un módulo de 6870 cm^3.

¿Cumple este perfil con el espesor mínimo?

En este caso se hará la comprobación mediante el espesor mínimo recomendado. El espesor se calcula mediante la fórmula:

3 Primary supporting members

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 below longitudinal bulkhead in cargo area if arranged Bottom centreline girder outside cargo area in general for cargo ships Bottom centreline girder over full length of other ship types than cargo ships	5.0	0.03
Bottom longitudinal girders in general	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.

$$t = a + b * L_2 * \sqrt{k} = 4.5 + 0.015 * 82.12 * \sqrt{1} = 5.54\ mm$$

El perfil escogido cumple con el requisito del espesor mínimo, podemos afirmar que la elección es válida.

3.4.5 Cálculo de las esloras de la cubierta principal.

Encima de los puntales se situarán esloras para que hagan continuación con los puntales y soporten mejor las cargas. El espesor mínimo viene dado por la fórmula:

2 Stiffeners and tripping brackets

2.1 Minimum thickness requirements

2.1.1 The net thickness of the web and face plate, if any, of stiffeners and tripping brackets in mm, shall comply with the minimum net thickness given in Table 2.

In addition, the net thickness of the web of stiffeners and tripping brackets, in mm, shall be:

— not less than 40% of the net required thickness of the attached plating, to be determined according to Sec.4.

Table 2 Minimum net thickness for stiffeners and tripping brackets

Element	*Location*	*Net thickness*
Stiffeners and attached end brackets	Tank boundary, boundary of cargo holds for dry bulk cargo, single strength deck and shell up to freeboard deck	$4.5 + 0.01\,L_1$
	Structures in deckhouse and superstructure and decks for vessels with more than 2 continuous decks above 0.7 *D* from baseline	4.0
	Other structure	$4.5 + 0.005\,L_1$
Tripping brackets		$4.5 + 0.01\,L_1$

$$t = 4.5 + 0.01 * L_1 = 4.5 + 0.01 * 82.12 = 5.32\ mm$$

El módulo mínimo requerido se calcula mediante la fórmula:

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 stiffeners with fixed ends*		*For stiffeners with one fixed end and one simply supported end*	*For 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	

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 225.82 * 1500 * 3.5^2}{12 * 0.23 * 235} = 6589.46\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta tipo T de: 785*200 con un espesor de 12 mm y un módulo de 6870 cm^3. Como su espesor es mayor que el mínimo requerido, nuestras esloras serán válidas.

3.4.6 Cálculo de los refuerzos secundarios de la cubierta principal.

El módulo de los longitudinales se obtiene de la siguiente forma.

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 stiffeners with one or both end fixed	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 stiffeners with simply supported ends	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	

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 stiffeners with fixed ends*		*For stiffeners with one fixed end and one simply supported end*	*For 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	

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 225.82 * 500 * 3.5^2}{12 * 0.23 * 235} = 2196.48\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta bulbo con las siguientes dimensiones 450*12 mm con un módulo de 2457 cm^3. Ahora deberemos calcular si cumple con el espesor mínimo.

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

También es necesario calcular la altura efectiva de los refuerzos.

1.4.3 Effective shear depth of stiffeners

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

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

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

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.

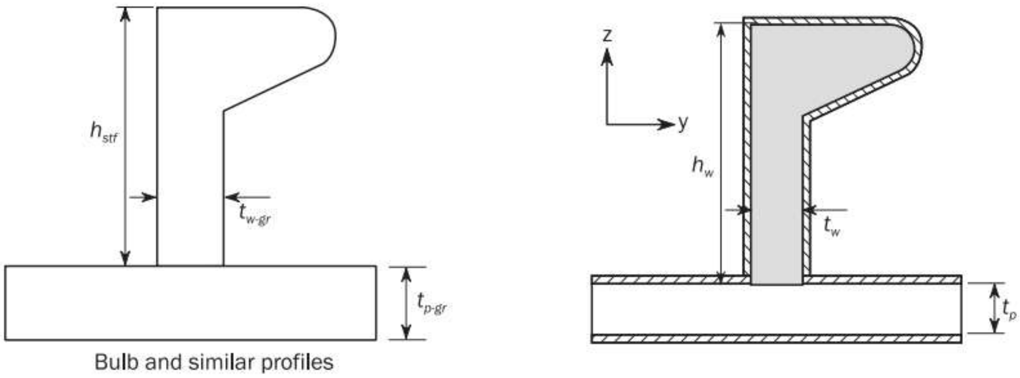


Figure 2 Net sectional properties of local supporting members (continued)

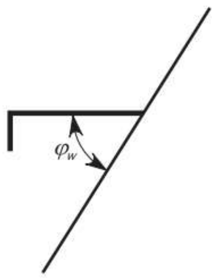


Figure 17 Angle between stiffener web and attached plating

Entonces:

$$d_{shr} = 450 + 16 = 466\ mm$$

Calculamos el espesor mínimo del refuerzo.

$$t_w = \frac{C_m * f_{shr} * |P| * s * l_{shr}}{d_{shr} * C_t * \tau_{eH}} = \frac{1 * 0.5 * |225.82| * 500 * 3.5}{466 * 0.9 * 135.7} = 3.47\ mm$$

Como se observa, el perfil cumple con el espesor mínimo por tanto es adecuado.

3.5 Dimensionamiento de la cubierta Intermedia.

Realizaremos el mismo procedimiento utilizado para dimensionar la cubierta principal solo que ahora se trata de la cubierta intermedia. Para ello debemos de cambiar las presiones que le afectan ya que esta no tiene que soportar material de cubierta, solo tanques o el peso de los equipos eléctricos y de control de la cámara de máquinas entre otros sistemas del buque. Elegimos para realizar el cálculo los tanques de fuel porque son los elementos más pesados que se instalarán en esta cubierta.

3.5.1 Cálculo de las presiones.

Para el cálculo de las presiones tendremos en cuenta que en esta cubierta disponemos de los tanques de fuel de sedimentación y uso diario del buque.

Internal structures in tanks	INT-1	1	P_{int}	T_{SC}	AC-I	-

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].

Siendo:

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.

Entonces, la presión estática será la siguiente:

$$\rho_l = 0.9443\ t/m^3$$

$$Z_{top} = punto\ más\ alto\ del\ tanque\ en\ coordenada\ z\ (m).$$

Como nuestro tanque no tiene una válvula de seguridad.

$$P_{ls-1} = 0.9443 * 9.81 * (9.1 - 6.4) = 25\ kN/m^2$$

$$P_{ls-1} = \rho_L * g * \left(z_{top} - z\right) = 0.9443 * 9.81 * (9.1 - 6.4) = 25\ kN/m^2$$

Para el cálculo de P_{ld} debemos hallar el punto de referencia del tanque.

$$x_{j1} = x_{top} \pm 0.5 * l_{fs}$$

$$y_{j1} = y_{top} \pm 0.5 * b_{top}$$

Siendo:

$$x_{j1} = 4.2\ m;\ x_{j2} = 0\ m$$

$$y_{j1} = 7.9\ m;\ y_{j2} = 0\ m$$

Entonces:

$$v_j = a_x(x_j - x_g) + a_y(y_j - y_g) + (a_z + g)(z_j - z_g)$$

$$v_j = 0.54 * (4.2) + 0(7.9) + (5.25 + 9.81)(2.7) = 42.93$$

La presión dinámica será la siguiente:

$$P_{ld} = f_{cd}\rho_L[a_z(z_0 - z) + f_{ull-l}a_x(x_0 - x) + f_{ull-t}a_y(y_0 - y)]$$

$$P_{ld} = 0.88 * 0.9443 * [5.25 * (7.45) + 0.62 * 0.54 * (2.1) + 0.67 * 0 * (7.9)]$$

$$P_{ld} = 33\ kN/m^2$$

La presión interior total del tanque de sedimentación y uso diario que utilizaremos para dimensionar la cubierta intermedia y los mamparos de los tanques será de:

$$P_{ls-1} + P_{ld} = 25 + 33 = 58\ kN/m^2$$

3.5.2 Cálculo del espesor de la chapa de la cubierta intermedia.

El espesor mínimo de la chapa de la cubierta intermedia debe ser el siguiente.

1 Plating

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)			0.02
	Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk		4.5	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 9)		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads 8) 9)			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

$$t = 4.5 + 0.015 * 82{,}12 * \sqrt{1} = 5.73\ mm$$

El espesor de la chapa de cubierta viene definido por lo siguiente.

$$t = 0.0158\alpha_p b\sqrt{\frac{|P|}{C_a R_{eH}}}$$

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

$$\alpha_p = 1.2 - \frac{b}{2.1 * a} = 1.2 - \frac{700}{2.1 * 3500} = 1.1$$

$$C_\alpha = \beta_\alpha - \alpha_a * \frac{\sigma_{hg}}{R_{eh}} = 1.05 - 0.5 * \frac{205}{235} = 0{,}62$$

$$t = 0.0158 * \alpha_p * b * \sqrt{\frac{|P|}{C_\alpha * R_{eh}}} = 0.0158 * 1.1 * 700 * \sqrt{\frac{|58|}{0.62 * 235}} = 8.67\ mm$$

Espesor mayor que el mínimo, por lo tanto, válido. El espesor final de la cubierta intermedia será de 9 mm.

3.5.1 Cálculo del espesor de la chapa del tanque central.

El espesor mínimo de la chapa se calculará según lo que establece el reglamento.

1 Plating

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)]			0.02
	Boundary for cargo tanks, water ballast tanks and hold intended for cargo in bulk		4.5	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 [9)]		4.5	0.015
	Peak bulkheads			
	Watertight bulkheads and other tanks bulkheads [8) 9)]			0.01
	Non-tight bulkheads in tanks		5.0	0.005
	Other non-tight bulkheads			0
	Walls in accommodation		4.5	0

$$t = 4.5 + 0.015 * 82{,}12 * \sqrt{1} = 5.54\ mm$$

Este es el espesor mínimo que debe tener la chapa del costado del tanque. Ahora deberemos calcular cuál es el valor que le corresponde realmente y comprobar que cumple el mínimo anteriormente calculado.

El espesor de la chapa de costado viene definido por lo siguiente.

$$t = 0.0158\alpha_p b \sqrt{\frac{|P|}{C_a R_{eH}}}$$

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

La separación entre refuerzos en el costado es condición de proyecto y se considera 700mm.

$$\alpha_p = 1.2 - \frac{b}{2.1 * a} = 1.2 - \frac{700}{2.1 * 3500} = 1.1$$

$$C_\alpha = \beta_\alpha - \alpha_a * \frac{\sigma_{hg}}{R_{eh}} = 1.05 - 0.5 * \frac{205}{235} = 0{,}62$$

$$t = 0.0158 * \alpha_p * b * \sqrt{\frac{|P|}{C_\alpha * R_{eh}}} = 0.0158 * 1.1 * 700 * \sqrt{\frac{|58|}{0.62 * 235}} = 7.67\ mm$$

Espesor mayor que el mínimo, por lo tanto, válido. El espesor final de la chapa de costado será de 8 mm.

3.5.2 Cálculo de los refuerzos secundarios del costado del tanque central.

El módulo de los longitudinales se obtiene de la siguiente forma.

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:

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

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 stiffeners with one or both end fixed	Tension (positive)	Stiffener side	$C_s = \beta_s - \alpha_s \frac{\left|\sigma_{hg}\right|}{R_{eH}}$ but not to be taken greater than $C_{s\text{-}max}$
	Compression (negative)	Plate side	
	Tension (positive)	Plate side	$C_s = f_m\left(\beta_s - \alpha_s \frac{\left|\sigma_{hg}\right|}{R_{eH}}\right)$ but not to be taken greater than $C_{s\text{-}max}$
	Compression (negative)	Stiffener side	
For stiffeners with simply supported ends	Tension (positive)	Plate side	$C_s = \beta_s - \alpha_s \frac{\left|\sigma_{hg}\right|}{R_{eH}}$ 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	

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 stiffeners with fixed ends		For stiffeners with one fixed end and one simply supported end	For 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	

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 58 * 540 * 3.5^2}{12 * 0.23 * 235} = 609.3\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta bulbo de: 300*11 un módulo de 671 cm^3. Ahora deberemos calcular si cumple con el espesor mínimo.

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

También es necesario calcular la altura efectiva de los refuerzos.

1.4.3 Effective shear depth of stiffeners

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

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

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

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.

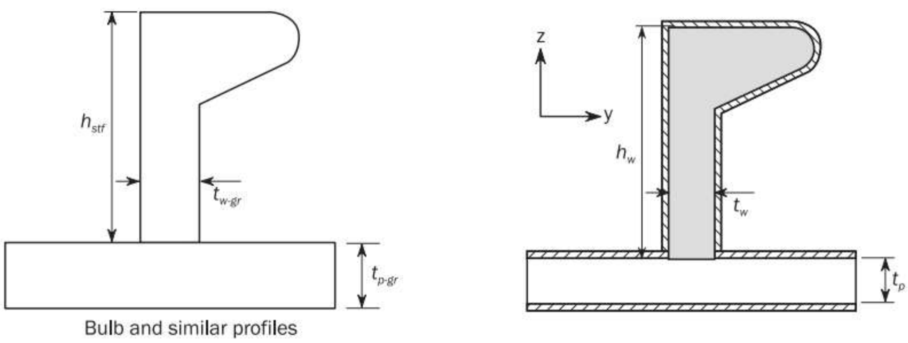


Figure 2 Net sectional properties of local supporting members (continued)

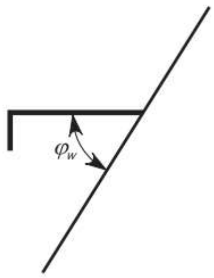


Figure 17 Angle between stiffener web and attached plating

Entonces:

$$d_{shr} = 300 * 8 = 308\,mm$$

Calculamos el espesor mínimo del refuerzo.

$$t_w = \frac{C_m * f_{shr} * |P| * s * l_{shr}}{d_{shr} * C_t * \tau_{eH}} = \frac{1 * 0.5 * |58| * 540 * 3.5}{308 * 0.9 * 135.7} = 1.46\,mm$$

Como se observa, el perfil cumple con el espesor mínimo por tanto es adecuado.

3.5.3 Puntales a la cubierta intermedia.

Para dimensionar los baos de la cubierta disponemos de puntales, para que así estos actúen como soporte de los baos, disminuyendo su luz y así su tamaño. La separación de los puntales será de cinco claras de cuaderna para que formen parte de los anillos transversales. Estos anillos están formados por la unión de las bulárcamas con las varengas y a su vez con los baos. La máxima distancia transversal de separación de los baos será de 6 m, que corresponde con la máxima luz que tendremos.

El dimensionamiento de los puntales debe realizarse por pandeo y para ello utilizaremos la siguiente sección del reglamento DNV-RU-SHIP Pt.3 Ch.8 Buckling. Primero estableceremos un tipo de perfil a utilizar, el nuestro será un HEA 200. Ahora debemos calcular si cumple los requerimientos de pandeo o no.

Las características del perfil son las siguientes:

$$E = 2.06 * 10^5 N/mm^2$$

$$I = 3693\,m^4$$

$$A = 53.8\,cm^2$$

$$l = Altura\ cubierta\ inermedia - Altura\ DF - Alma\ del\ bao = 6.4 - 1.4 - 0.785 = 4.215\,m$$

Por tanto, del reglamento obtenemos lo siguiente.

Lateral buckling mode

For longitudinals subject to longitudinal hull girder compressive stresses, supporting bulkhead stiffeners, pillars, cross ties, panting beams etc., the ideal elastic lateral buckling stress may be taken as:

$$\sigma_{el} = 0.001\,E\,\frac{I_A}{A l^2} \quad (N/mm^2)$$

I_A = moment of inertia in cm^4 about the axis perpendicular to the expected direction of buckling
A = cross-sectional area in cm^2.

$$\sigma_{el} = 0.001 * E * \frac{I_A}{A * l^2}$$

$$\sigma_{el} = 0.001 * 2.06 * 10^5 * \frac{3693}{53.8 * 4.215^2} = 795.92\,N/mm^2$$

For pillars, cross ties and panting beams the critical buckling stress as calculated in 201 shall not be less than:

$$\sigma_c = \frac{10P}{A\eta} \quad (\text{N/mm}^2)$$

$$\eta = \frac{k}{\left(1 + \frac{l}{i}\right)}, \quad \text{minimum } 0.3$$

P = axial load in kN as given for various strength members in 204 and 205. Alternatively, P may be obtained from direct stress analysis, see Sec.12

l = length of member in m

i = radius of gyration in cm = $\sqrt{\frac{I_A}{A}}$

I_A and A as given in 201

k = 0.5 for pillars below exposed weather decks forward of 0.1 L from F.P.
= 0.6 for pillars below weather decks when sea loads are applied
= 0.7 in all other cases.

Entonces tendremos los siguientes datos.

- P es la presión que utilizamos en cubierta: 58 kN/m^2.
- L es la longitud del puntal = 4.215 m.
- s es la separación entre puntales= 6 m.
- i es el radio de giro = 8.28 cm.
- K es una constante = 0.7

Por tanto, tendremos lo siguiente.

$$\eta = \frac{0.7}{1 + \frac{4.215}{8.28}} = 0.46$$

$$A_D = s * l = 6 * 4.215 = 25.29\, m^2$$

$$F = P * A_D = 58 * 25.29 = 1466.82\, kN$$

$$\sigma_c = \frac{10 * P}{A * \eta} = \frac{10 * 1466.82}{53.8 * 0.46} = 592.7\, N/mm^2$$

El perfil cumple ya que $\sigma_{el} > \sigma_c$. Finalmente, los puntales que soportan el peso de la cubierta principal son del tipo HEA 200.

3.5.4 Cálculo de los baos que soportan la cubierta intermedia.

El módulo de los baos se obtiene mediante la siguiente fórmula. Además, el bao se va a dimensionar suponiendo que los extremos se encuentran empotrados, es decir, no va a permitir el giro.

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

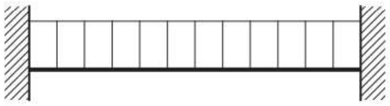
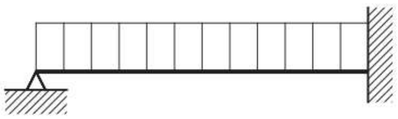
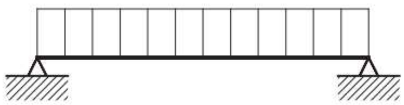
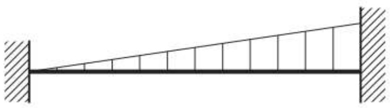
C_s = permissible stress coefficient to be taken as:

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].

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

$$Z = 1000 * \frac{|P| * S * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}}$$

$$Z = 1000 * \frac{|P| * S * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = 1000 * \frac{|58| * 3.5 * 6^2}{12 * 0.85 * 235} = 3048.8\ cm^3$$

Se escogen los siguientes perfiles de llanta tipo T: 535*150 mm con un espesor de 12 mm y un módulo de 3364 cm^3.

¿Cumple este perfil con el espesor mínimo?

En este caso se hará la comprobación mediante el espesor mínimo recomendado. El espesor se calcula mediante la fórmula:

3 Primary supporting members

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 below longitudinal bulkhead in cargo area if arranged Bottom centreline girder outside cargo area in general for cargo ships Bottom centreline girder over full length of other ship types than cargo ships	5.0	0.03
Bottom longitudinal girders in general	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.

$$t = a + b * L_2 * \sqrt{k} = 4.5 + 0.015 * 82.12 * \sqrt{1} = 5.54\ mm$$

El perfil escogido cumple con el requisito del espesor mínimo, podemos afirmar que la elección es válida.

3.5.5 Cálculo de las esloras de la cubierta intermedia.

Encima de los puntales se situarán esloras para que hagan continuación con los puntales y soporten mejor las cargas. El espesor mínimo viene dado por la fórmula:

2 Stiffeners and tripping brackets

2.1 Minimum thickness requirements

2.1.1 The net thickness of the web and face plate, if any, of stiffeners and tripping brackets in mm, shall comply with the minimum net thickness given in Table 2.

In addition, the net thickness of the web of stiffeners and tripping brackets, in mm, shall be:

— not less than 40% of the net required thickness of the attached plating, to be determined according to Sec.4.

Table 2 Minimum net thickness for stiffeners and tripping brackets

Element	*Location*	*Net thickness*
Stiffeners and attached end brackets	Tank boundary, boundary of cargo holds for dry bulk cargo, single strength deck and shell up to freeboard deck	$4.5 + 0.01\, L_1$
	Structures in deckhouse and superstructure and decks for vessels with more than 2 continuous decks above 0.7 D from baseline	4.0
	Other structure	$4.5 + 0.005\, L_1$
Tripping brackets		$4.5 + 0.01\, L_1$

$$t = 4.5 + 0.01 * L_1 = 4.5 + 0.01 * 82.12 = 5.32\ mm$$

El módulo mínimo requerido se calcula mediante la fórmula:

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 stiffeners with fixed ends*		*For stiffeners with one fixed end and one simply supported end*	*For 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	

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * l_{bdg}{}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 58 * 1500 * 3.5^2}{12 * 0.23 * 235} = 1692\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta tipo T de: 450*120 con un espesor de 12 mm y un módulo de 1885 cm^3. Como su espesor es mayor que el mínimo requerido, nuestras esloras serán válidas.

Como excepción, para conseguir una mejor unión entre elementos, las esloras que coinciden con los puntales tendrán el mismo ancho que el bao. Por tanto, las cuatro esloras mencionadas deben medir 535*150 y tener un espesor de 12 mm.

3.5.6 Cálculo de los refuerzos secundarios de la cubierta intermedia.

El módulo de los longitudinales se obtiene de la siguiente forma.

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-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 stiffeners with one or both end fixed	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-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-max}
	Compression (negative)	Stiffener side	
For stiffeners with simply supported ends	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-max}
	Compression (negative)	Stiffener side	
	Tension (positive)	Stiffener side	$C_s = C_{s-max}$
	Compression (negative)	Plate side	

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 stiffeners with fixed ends		For stiffeners with one fixed end and one simply supported end	For 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	

$$C_S = \beta_S - \alpha_S * \frac{|\sigma_{hg}|}{R_{eH}}$$

$$C_S = 1.10 - 1 * \frac{205}{235} = 0{,}23$$

$$Z = \frac{f_u * |P| * s * {l_{bdg}}^2}{f_{bdg} * C_S * R_{eH}} = \frac{1.03 * 58 * 500 * 3.5^2}{12 * 0.23 * 235} = 584.2\ cm^3$$

Con este valor en tablas comerciales tenemos una llanta bulbo con las siguientes dimensiones 280*12 mm con un módulo de 590 cm^3. Ahora deberemos calcular si cumple con el espesor mínimo.

El espesor mínimo se calcula de la siguiente manera.

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

También es necesario calcular la altura efectiva de los refuerzos.

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.

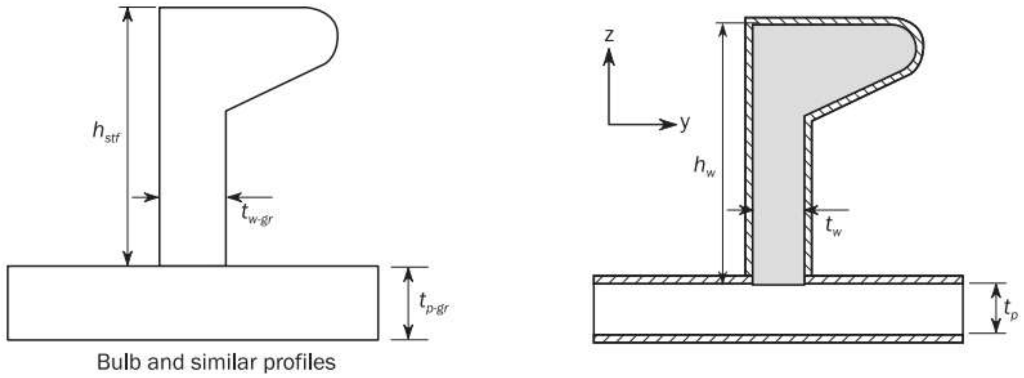


Figure 2 Net sectional properties of local supporting members (continued)

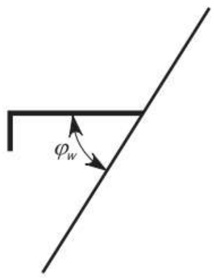


Figure 17 Angle between stiffener web and attached plating

Entonces:

$$d_{shr} = 280 + 8 = 288\ mm$$

Calculamos el espesor mínimo del refuerzo.

$$t_w = \frac{C_m * f_{shr} * |P| * s * l_{shr}}{d_{shr} * C_t * \tau_{eH}} = \frac{1 * 0.5 * |58| * 500 * 3.5}{288 * 0.9 * 135.7} = 3\ mm$$

Como se observa, el perfil cumple con el espesor mínimo por tanto es adecuado.

4 CÁLCULO DEL MÓDULO Y DE LA INERCIA.

Una vez realizado el escantillonado de la cuaderna maestra se procede a realizar el cálculo del módulo resistente y de la inercia de dicha sección, y para ello se tendrán en cuenta aquellos elementos que influyen en la resistencia longitudinal.

A continuación, se muestra una tabla con los cálculos realizados, entre ellos el cálculo del módulo de la cubierta y del fondo, así como de la inercia. Estos se deben comparar con el módulo e inercia mínimos.

4.1 Proceso de cálculo.

Para los debidos cálculos deberemos tener en cuenta las siguientes fórmulas:

- Inercia respecto a la línea de base.

$$I_0 = \sum A * Z^2{}_g + \sum Ip$$

- Posición del eje neutro respecto al fondo.

$$e_B = \frac{\sum A * Z_g}{\sum A}$$

- Posición del eje neutro respecto a la cubierta.

$$e_D = D - e_B$$

- Inercia respecto al eje neutro.

$$I = I_0 - \sum A * e^2{}_B$$

- Módulo en el fondo.

$$W_B = \frac{1}{e_B}$$

- Módulo en la cubierta.

$$W_D = \frac{1}{e_D}$$

Posición		Elementos planos	Número	Ly (m)	Lz (m)	A (m2)	Zg (m)	A*Zg (m3)	A*Zg^2 (m4)	Ip (m4)	It	Sum It (m4)
FONDO		Ch. quilla	1,000	1,50	0,010	0,0150	0,00500	0,00008	0,00000	0,00001	0,00001	0,00001
		Ch. fondo (tipo 1)	6,000	2,00	0,010	0,1200	0,00500	0,00060	0,00000	0,00001	0,00001	0,00007
		Ch. fondo (tipo 2)	2,000	2,50	0,010	0,0500	0,00500	0,00025	0,00000	0,00001	0,00001	0,00002
		Ch. doble fondo (tipo 1)	10,000	1,86	0,011	0,2046	1,40550	0,28757	0,40417	0,00001	0,40419	4,04188
		Ch. doble fondo (tipo 2)	2,000	1,40	0,011	0,0308	1,40550	0,04329	0,06084	0,00001	0,06086	0,12172
		Ch. pantoque	2,000	2,20	0,010	0,0440	0,70000	0,03080	0,02156	0,00001	0,02157	0,04314
		Vagras estancas	6,000	0,01	1,400	0,0840	0,70000	0,05880	0,04116	0,00001	0,04117	0,24700
		Vagras no estancas	7,000	0,01	1,400	0,0588	0,70000	0,04116	0,02881	0,00000	0,02881	0,20170
CUBIERTA		Ch. cubierta principal	10,000	2,14	0,016	0,3424	9,09200	3,11310	28,30431	0,00014	28,30445	283,04455
		Ch. cubierta intermedia	10,000	1,86	0,016	0,2976	9,09200	2,70578	24,60094	0,00014	24,60109	246,01087
		Ch. Superior	2,000	2,30	0,011	0,0506	11,89450	0,60186	7,15884	0,00003	7,15888	14,31775
COSTADO	FORRO EXTERIOR	z=2,1	2,000	0,01	2,100	0,0420	2,45000	0,10290	0,25211	0,00001	0,25212	0,50423
		z=4,2	2,000	0,01	2,100	0,0420	4,55000	0,19110	0,86951	0,00001	0,86952	1,73903
		z=6,3	2,000	0,01	2,100	0,0420	6,65000	0,27930	1,85735	0,00001	1,85736	3,71471
		z=8,4	2,000	0,01	2,100	0,0420	8,75000	0,36750	3,21563	0,00001	3,21564	6,43127
		z=10,5	2,000	0,01	2,100	0,0420	10,85000	0,45570	4,94435	0,00001	4,94436	9,88871
	FORRO INTERIOR	z=2,5	2,000	0,01	2,500	0,0500	2,65000	0,13250	0,35113	0,00001	0,35114	0,70227
		z=5	2,000	0,01	2,500	0,0500	5,15000	0,25750	1,32613	0,00001	1,32614	2,65227
		z=6,35	2,000	0,01	1,350	0,0270	5,82500	0,15728	0,91613	0,00001	0,91614	1,83227
		z=7,7	2,000	0,01	1,350	0,0270	7,17500	0,19373	1,38998	0,00001	1,38999	2,77997
	FORRO SUPERIOR INTERIOR	z=9,1	2,000	0,01	1,400	0,0280	9,80000	0,27440	2,68912	0,00001	2,68913	5,37826
		z=10,5	2,000	0,01	1,400	0,0280	11,20000	0,31360	3,51232	0,00001	3,51233	7,02466
						1,72	110,05	9,61	81,94			590,68

Posición	Refuerzo	Número	A refuerzo m2	area total m2	Zg (m)	A*Zg (m3)	A*Zg^2 (m4)	Ip (m4)	It	Sum It (m4)
FONDO	Longitudinales del fondo	32	0,002560	0,0819	0,32	0,026214	0,008389	0,000055	0,000000	0,000015
	Longitudinales del doble fondo	28	0,009410	0,2635	1,19	0,312224	0,369985	0,000173	0,000064	0,001788
CUBIERTA	Longitudinales de la cubierta intermedia	26	0,004550	0,1183	6,90	0,816270	5,632263	0,000036	0,000200	0,005199
	Longitudinales de la cubierta principal	26	0,009810	0,2551	8,88	2,263658	20,089960	0,000189	0,003797	0,098722
	Longitudinales de la cubierta superior	4	0,007700	0,0308	11,72	0,360976	4,230639	0,000105	0,000444	0,001775
	Esloras de la cubierta intermedia (tipo 1)	7	0,011250	0,0788	6,15	0,484313	2,978522	0,000326	0,000971	0,006795
	Esloras de la cubierta intermedia (tipo 2)	4	0,008100	0,0324	6,19	0,200556	1,241442	0,000173	0,000214	0,000857
	Esloras de la cubierta principal	11	0,016000	0,1760	8,73	1,536480	13,413470	0,001029	0,013805	0,151857
COSTADO	Longitudinales costado exterior (tipo 1)	22	0,008140	0,1791	6,65	1,190882	7,919365	0,000129	0,001024	0,022527
	Longitudinales costado exterior (tipo 2)	16	0,008140	0,1302	7,65	0,996336	7,621970	0,000129	0,000986	0,015768
	Longitudinales costado interior	22	0,008140	0,1791	5,25	0,940170	4,935893	0,000129	0,000638	0,014041
	Longitudinales cubierta superior interior	8	0,008140	0,0651	10,50	0,683760	7,179480	0,000129	0,000928	0,007426
				1,5902	80,12	9,811838	75,621378			0,326770

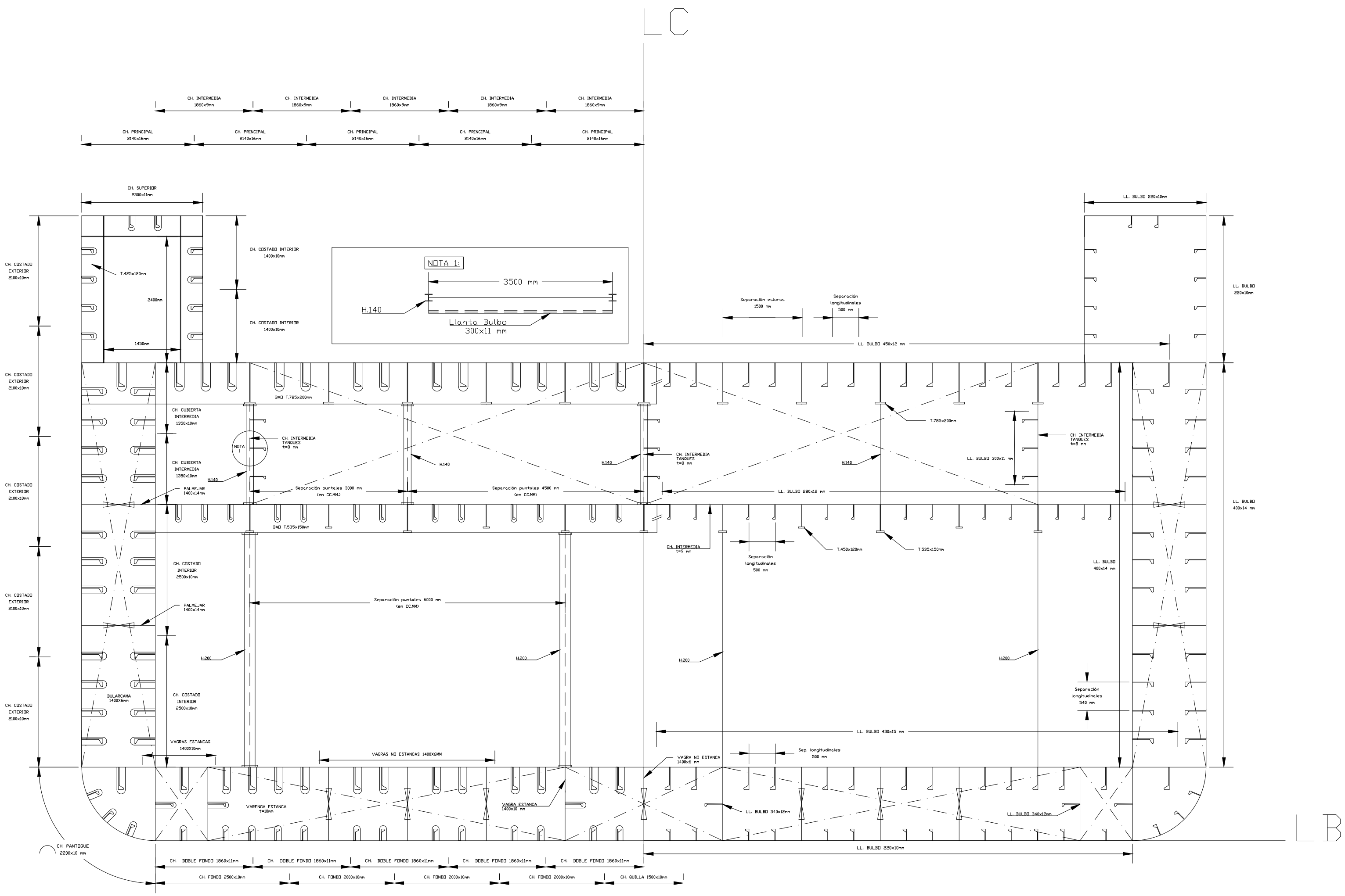
4.2 Comprobación de los resultados finales.

Como podemos comprobar en la siguiente tabla, los valores del módulo en el fondo como en cubierta son mayores que los requeridos.

CRITERIOS		COMPROBACIÓN	
INERCIA FINALES DESDE BASE [m^4]	672,62	MÓDULO MÍNIMO REQUERIDO EN FONDO [m^3]	110,64
INERCIA REQUERIDA [m^4]	618,87	MÓDULO MÍNIMO REQUERIDO EN CUBIERTA [m]	176,50
EJE NEUTRO DESDE L.B [m]	5,59	MÓDULO EN EL FONDO [m^3]	120,25
EJE NEUTRO DESDE CUBIERTA [m]	3,51	MÓDULO EN LA CUBIERTA [m^3]	191,83

5 PLANO DE LA CUADERNA MAESTRA

En esta sección del cuaderno se muestra la cuaderna maestra de nuestro buque sobre la cual se indican todos los valores de los elementos calculados a lo largo de este cuaderno.



Sociedad de clasificación:

Det Norske Veritas

Material empleado:

Acero normal de grado A.

Límite elástico: 235 N/mm^2.

Características principales:

Eslora total: 85,68 m.

Eslora entre perpendiculares: 79 m.

Manga de tratado: 21,40 m.

Calado de diseño: 8,19 m.

Altura del doble fondo: 1,40 m.

Puntal a la cubierta intermedia: 6,40 m.

Puntal a la cubierta principal: 9,10 m.

Separaciones entre elementos:

Separación entre cuadernas: 700 mm

Separación entre bulárcamas: 3500 mm

Separación entre refuerzos secundarios de las cubiertas: 500 mm

Separación entre refuerzos secundarios del costado: 540 mm

Separación entre vagras: 1500 mm

Separación entre varengas: 3500 mm

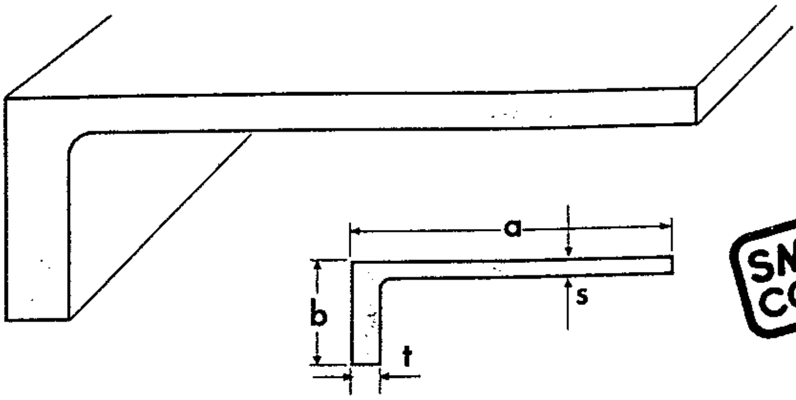
PROYECTO: ANCHOR HANDLING TUG SUPPLY VESSEL

C8. Cuaderna maestra.	
Autor: Raúl Fernández Garda	Universidade da Coruña
Tutor: Marcos Míguez González	Escola Politécnica Superior
Plano I — Escala 1:300	Trabajo Fin de Grado. 2022-GENO-3

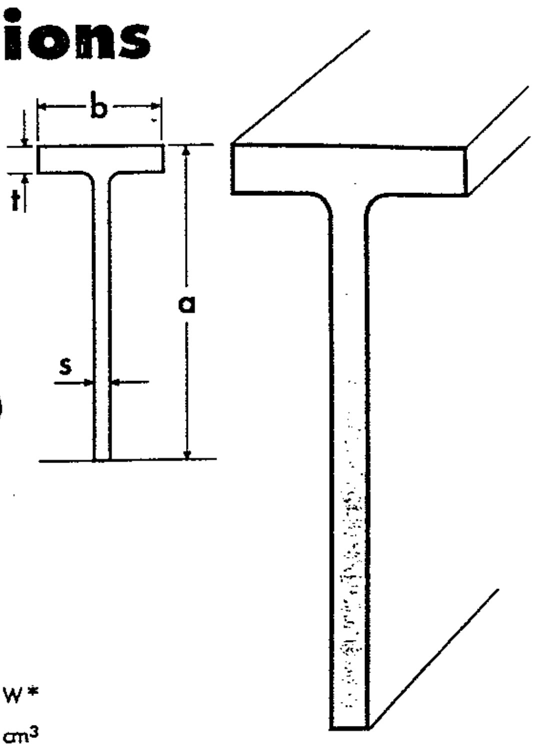
ANEXO: CATÁLOGO DE PERFILES

Se adjunta el catálogo de perfiles comerciales utilizados a lo largo de este cuaderno.

Welded Angles and T-Sections



SMOOTH CORNERS



Dimension range, weight/m and static values

Section	Width a mm	Height b mm	Thickness s mm	Thickness t mm	Area A cm²	Weight kg/m	e cm	I_x cm⁴	W* cm³	Plate
T-Sections	315	100	12	15	51.0	40.8	19.6	5329	764	Plate cross sectional area 100 cm²
	340	120	12	15	57.0	45.6	21.6	6995	946	
	370	120	12	20	66.0	52.8	24.2	9523	1235	
	395	120	12	20	69.0	55.2	25.6	11387	1350	
	425	120	12	25	78.0	62.4	28.2	14750	1682	
Angles and T-Sections	450	120	12	25	81.0	64.8	29.6	17250	1885	Plate cross sectional area 150 cm²
	455	120	12	30	87.0	69.6	30.7	18630	2118	
	460	120	12	35	93.0	74.4	31.6	19900	2350	
	475	120	12	25	84.0	67.2	31.0	20010	2030	
	525	120	12	25	90.0	72.0	33.8	26300	2330	
	525	150	12	25	97.5	78.0	35.1	28420	2685	
	530	150	12	30	105.0	84.0	36.4	30590	3026	
	535	150	12	35	112.5	90.0	37.5	32590	3364	
	575	150	12	25	103.5	82.8	37.9	36420	3033	
	585	150	12	35	118.5	94.8	40.5	41710	3775	
	625	150	12	25	109.5	87.6	40.7	45700	3395	
	630	150	12	30	117.0	93.6	42.1	49110	3799	
	635	150	12	35	124.5	99.6	43.4	52260	4200	
	625	200	12	25	122.0	97.6	42.8	50440	4096	
	630	200	12	30	132.0	105.6	44.3	54120	4636	
	635	200	12	35	142.0	113.6	45.7	57450	5172	
	675	200	12	25	128.0	102.4	45.7	62190	4602	Plate cross sectional area 175 cm²
	685	200	12	35	148.0	118.4	48.7	70810	5782	
	725	200	12	25	134.0	107.2	48.5	75510	5054	
	735	200	12	35	154.0	123.2	51.7	85940	6319	
	775	200	12	25	140.0	112.0	51.3	90480	5520	
	780	200	12	30	150.0	120.0	53.1	96990	6197	
	785	200	12	35	160.0	128.0	54.7	102920	6870	
	830	200	14	30	172.0	137.6	54.5	127070	7003	
	835	200	14	35	182.0	145.6	56.1	134890	7707	
	880	200	14	30	179.0	143.2	57.2	148920	7572	
	885	200	14	35	189.0	151.2	58.9	158020	8317	
	930	200	15	30	195.0	156.0	59.3	180990	8331	
	935	200	15	35	205.0	164.0	61.0	191950	9110	
	985	200	15	35	212.5	170.0	63.7	221100	9768	
	1035	200	15	35	220.0	176.0	66.5	252890	10440	

* Inclusive plate as noted

Welded I-Sections are also available in heights from 350 – 1500 mm

Butt /Fillet welded

Full penetration welds by special agreement.

Orders

must include the following measurements: a x b x s x t.

Standard lengths

8 – 18 m,

Other lengths by special agreement.

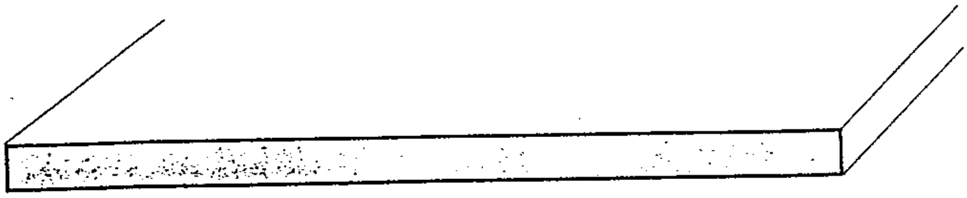
By special agreement other dimensions and combinations can be offered to satisfy required area and/or strength.

Heights up to 1500 mm can be offered.

Static values for required combination can be given.

INEXA PROFIL

Universals



SMOOTH CORNERS

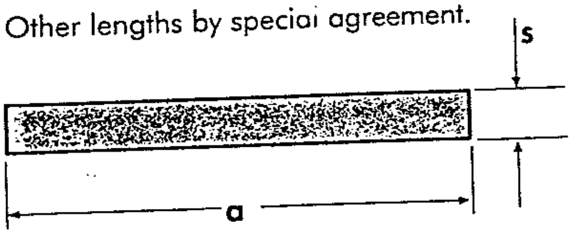
Dimension range and weight/m

Width a mm	Thickness s mm 12	14	15	20	25	30	35	40
150						35.3	41.2	47.1
175						41.2	48.1	55.0
200			23.6	31.4	39.3	47.1	55.0	62.8
225			26.5	35.3	44.2	53.0	61.8	70.7
250	23.6	27.5	29.4	39.3	49.1	58.9	68.7	78.5
275	25.9	30.2	32.4	43.2	54.0	64.8	75.6	86.4
300	28.3	33.0	35.3	47.1	58.9	70.7	82.4	94.2
325	30.6	35.7	38.3	51.0	63.8	76.5	89.3	102.1
350	33.0	38.5	41.2	55.0	68.7	82.4	96.2	109.9
375	35.3	41.2	44.2	58.9	73.6	88.3	103.0	117.8
400	37.7	44.0	47.1	62.8	78.5	94.2	109.9	125.6
425	40.0	46.7	50.0	66.7	83.4	100.1	116.8	133.5
450	42.4	49.5	53.0	70.7	88.3	106.0	123.6	141.3
475	44.7	52.2	55.9	74.6	93.2	111.9	130.5	149.2
500	47.1	55.0	58.9	78.5	98.1	117.8	137.4	157.0
525	49.5	57.7	61.8	82.4	103.0	123.6		
550	51.8	60.4	64.8	86.4	107.9	129.5		
575	54.2	63.2	67.7	90.3	112.8	135.4		
600	56.5	65.9	70.7	94.2	117.8	141.3		
625	58.9	68.7	73.6	98.1	122.7	147.2		
650	61.2	71.4	76.5	102.1	127.6	153.1		
700	65.9	76.9	82.4	109.9	137.4	164.9		
750	70.7	82.4	88.3	117.8				
800	75.4	87.9	94.2	125.6				
850	80.1	93.4	100.1	133.5				
900	84.8	98.9	106.0	141.3				
1000	94.2	109.9	117.8	157.0				
1035	97.5	113.7	121.9	162.5				

Other dimensions are rolled by special agreement.
Static values available upon request.

Standard lengths

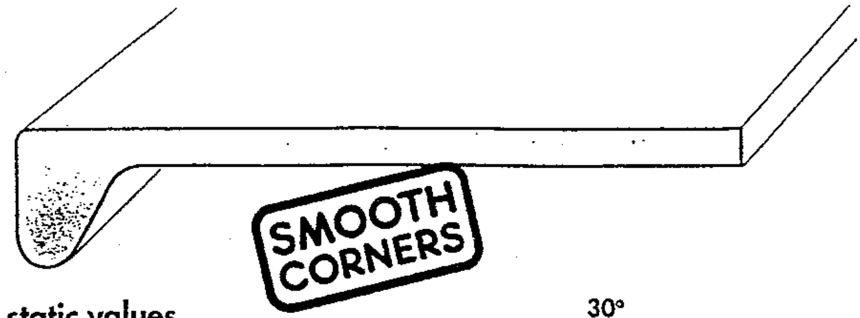
8 – 18 m.
Other lengths by speciai agreement.



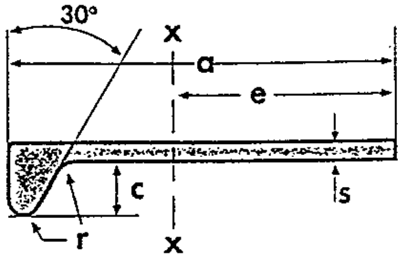
Orders

must include the following measurements:
a x s.

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

Widths 60–180: Plate cross sectional area 60 cm²

Widths 200–370: Plate cross sectional area 100 cm²

Widths 400–430: Plate cross sectional area 150 cm²

* Inclusive plate as noted

Standard lengths

6–18 m.

Other lengths by special agreeme[illegible]

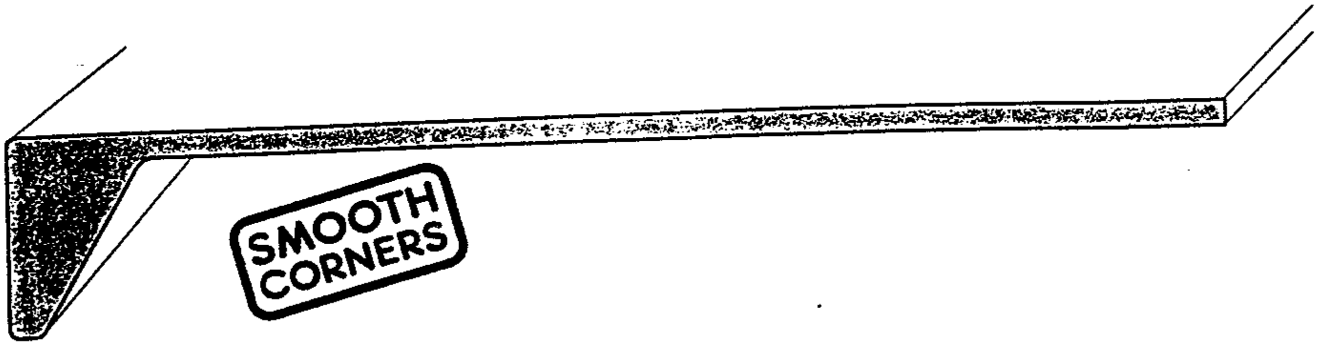
Orders

must include the following measurements:

a x s.

Jumbo Bulb Flats

Welded bulb flats, for very large and ultra large carrier/vessels



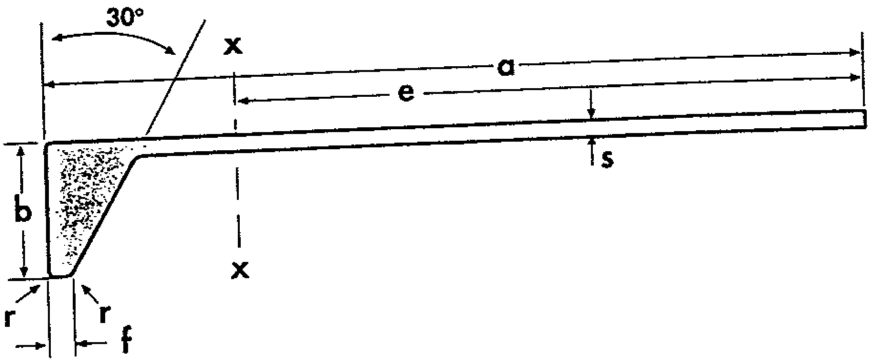
Dimension range, weight/m and static values

Width mm	Thickness s mm	Height b mm	Bulb bottom f mm	Radius r mm	Area A cm^2	Weight kg/m	e cm	I_x cm^4	W_x* cm^3
400	12	110	17	5.0	92.1	72.3	28.4	13530	2104
	14	110	17	5.0	98.7	77.5	27.6	14990	2144
450	12	110	17	5.0	98.1	77.0	31.5	18900	2457
	14	110	17	5.0	105.7	83.0	30.6	20920	2512
500	12	110	17	5.0	104.1	81.7	34.5	25440	2825
	14	110	17	5.0	112.7	88.5	33.5	28110	2897
550	12	110	17	5.0	110.1	86.4	37.5	33220	3208
	14	110	17	5.0	119.7	94.0	36.4	36670	3298
600	12	110	17	5.0	116.1	91.1	40.4	42340	3604
	14	110	17	5.0	126.7	99.5	39.3	46700	3714
650	12	110	17	5.0	122.1	95.9	43.3	52870	4014
	14	110	17	5.0	133.7	105.0	42.1	58290	4147

Plate cross sectional area 150 cm^2

* Inclusive plate as noted

Other dimensions by special agreement.



Standard lengths

8 – 18 m.
Other lengths by special agreement.

Orders

must include the following measurements:
a x s.

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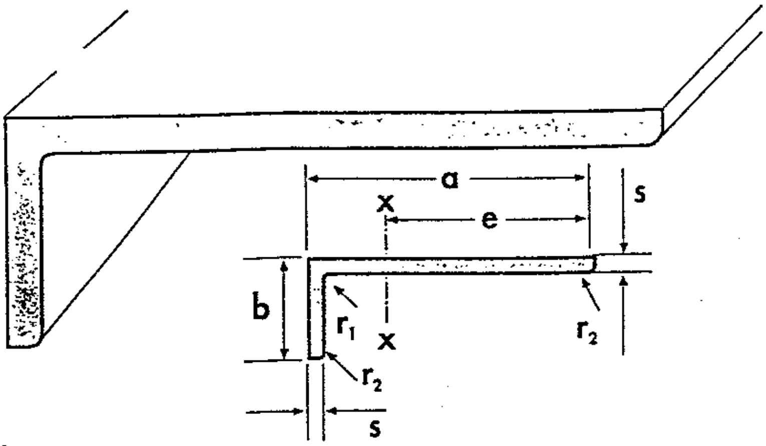
Rolled Angles

SMOOTH CORNERS



Dimension range, weight/m and static values

Width a mm	Height b mm	Thickness s mm	r_1 mm	r_2 mm	Area cm^2	Weight kg/m	e cm	I_x cm^4	W_x* cm^3
180	90	10	14	7	26.2	20.6	11.72	880	244
180	90	12	14	7	31.2	24.5	11.63	1040	283
180	90	14	14	7	36.1	28.3	11.54	1190	319

Plate cross sectional area 60 cm^2

* Inclusive plate as noted

Standard lengths

8 – 18 m.
Other lengths by special agreement.

Orders

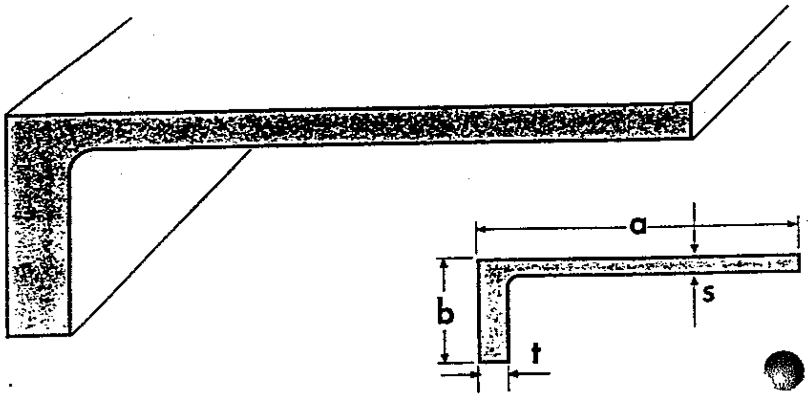
must include the following measurements:
a x b x s.

Welded Angles to NJA Standard

Butt/Fillet welded

Full penetration welds by special agreement.

SMOOTH CORNERS



Standard lengths

8 –18 m.
Other lengths by special agreement.

Orders

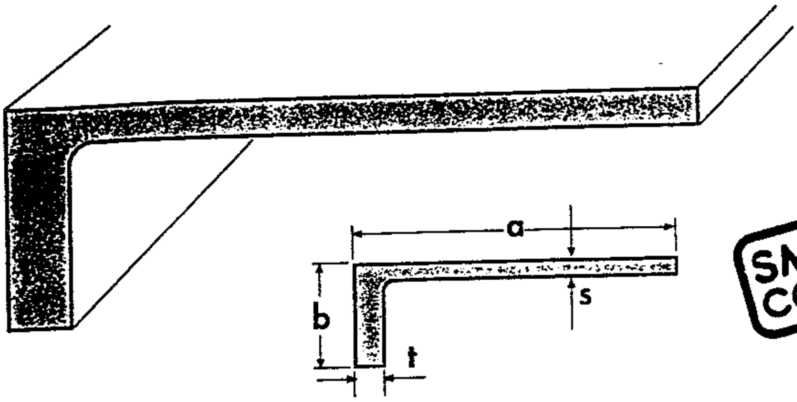
must include the following measurements:
a x b x s x t.

Dimension range, weight/m and static values

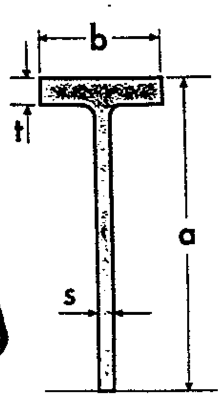
Width a mm	Height b mm	Thickness s mm	Thickness t mm	Area A cm^2	Weight kg/m	e cm	I_x cm^4	W_x* cm^3	
200	90	9	12	27.7	21.8	13.3	1159	308	Plate cross sectional area 100 cm^2
250	90	9	13	33.0	25.9	16.3	2181	437	
250	90	10.5	15	38.2	30.0	16.2	2502	495	
250	90	11.5	16	41.3	32.4	16.1	2697	527	
300	100	10.5	15	44.9	35.3	19.3	4276	681	
300	100	11.5	16	48.7	38.2	19.1	4615	725	
325	120	10.5	14	49.5	38.8	21.1	5564	820	
325	120	11.5	15	53.7	42.1	21.0	6017	876	
350	120	10.5	16	54.3	42.6	22.9	7064	975	
350	120	11.5	18	59.8	46.9	22.9	7738	1068	
375	120	10.5	18	59.1	46.4	24.7	8805	1142	
375	120	11.5	20	64.8	50.9	24.7	9609	1242	
400	120	11.5	23	71.0	55.7	26.6	11893	1516	Plate cross sectional area 150 cm^2

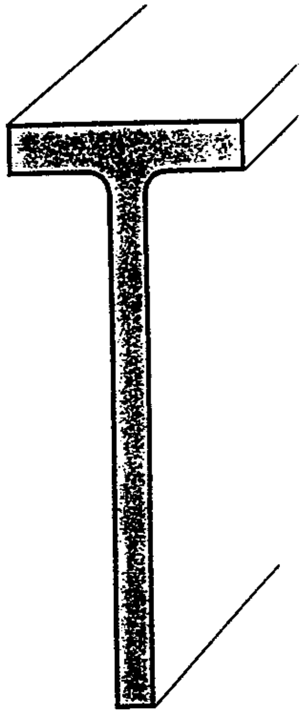
* Inclusive plate as noted

Welded Angles and T-Sections



SMOOTH CORNERS





Dimension range, weight/m and static values

	Width a mm	Height b mm	Thickness s mm	Thickness t mm	Area A cm²	Weight kg/m	e cm	I_x cm⁴	W* cm³	
T-Sections	315	100	12	15	51.0	40.8	19.6	5329	764	Plate cross sectional area 100 cm²
	340	120	12	15	57.0	45.6	21.6	6995	946	
	370	120	12	20	66.0	52.8	24.2	9523	1235	
	395	120	12	20	69.0	55.2	25.6	11387	1350	
	425	120	12	25	78.0	62.4	28.2	14750	1682	
Angles and T-Sections	450	120	12	25	81.0	64.8	29.6	17250	1885	Plate cross sectional area 150 cm²
	455	120	12	30	87.0	69.6	30.7	18630	2118	
	460	120	12	35	93.0	74.4	31.6	19900	2350	
	475	120	12	25	84.0	67.2	31.0	20010	2030	
	525	120	12	25	90.0	72.0	33.8	26300	2330	
	525	150	12	25	97.5	78.0	35.1	28420	2685	
	530	150	12	30	105.0	84.0	36.4	30590	3026	
	535	150	12	35	112.5	90.0	37.5	32590	3364	
	575	150	12	25	103.5	82.8	37.9	36420	3033	
	585	150	12	35	118.5	94.8	40.5	41710	3775	
	625	150	12	25	109.5	87.6	40.7	45700	3395	
	630	150	12	30	117.0	93.6	42.1	49110	3799	
	635	150	12	35	124.5	99.6	43.4	52260	4200	
	625	200	12	25	122.0	97.6	42.8	50440	4096	
	630	200	12	30	132.0	105.6	44.3	54120	4636	
	635	200	12	35	142.0	113.6	45.7	57450	5172	
	675	200	12	25	128.0	102.4	45.7	62190	4602	Plate cross sectional area 175 cm²
	685	200	12	35	148.0	118.4	48.7	70810	5782	
	725	200	12	25	134.0	107.2	48.5	75510	5054	
	735	200	12	35	154.0	123.2	51.7	85940	6319	
	775	200	12	25	140.0	112.0	51.3	90480	5520	
	780	200	12	30	150.0	120.0	53.1	96990	6197	
	785	200	12	35	160.0	128.0	54.7	102920	6870	
	830	200	14	30	172.0	137.6	54.5	127070	7003	
	835	200	14	35	182.0	145.6	56.1	134890	7707	
	880	200	14	30	179.0	143.2	57.2	148920	7572	
	885	200	14	35	189.0	151.2	58.9	158020	8317	
	930	200	15	30	195.0	156.0	59.3	180990	8331	
	935	200	15	35	205.0	164.0	61.0	191950	9110	
	985	200	15	35	212.5	170.0	63.7	221100	9768	
	1035	200	15	35	220.0	176.0	66.5	252890	10440	

* Inclusive plate as noted

Butt /Fillet welded

Full penetration welds by special agreement.

Orders

must include the following measurements: a x b x s x t.

Standard lengths

8 – 18 m,

Other lengths by special agreement.

By special agreement other dimensions and combinations can be offered to satisfy required area and/or strength.

Heights up to 1500 mm can be offered.

Static values for required combination can be given.

Welded I-Sections are also available in heights from 350 – 1500 mm

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