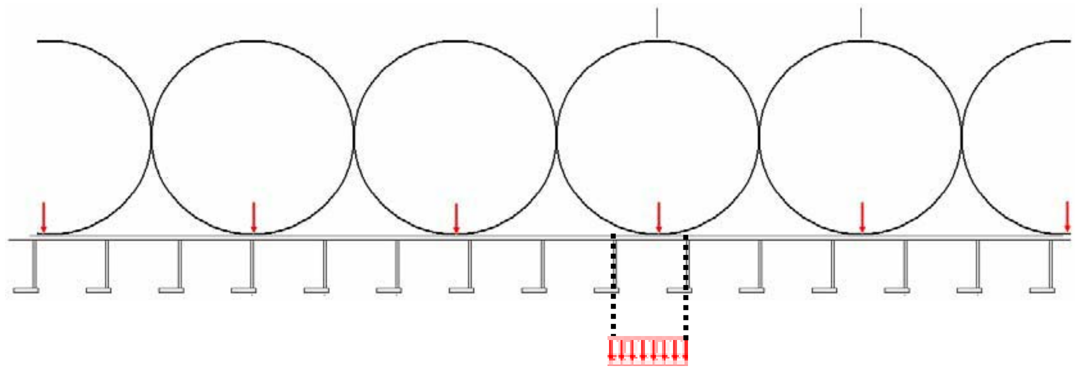
KC#609-1

RCP on evenly distributed load according to Ch. 6 Sec. 1 [2.7.1] and Sec. 2 [2.5.4] Steel coil loading

Load to be distributed over 1 elementary plate panel at per sketch below.



Uniform distributed load, when distributed to one elementary plate panel becomes:

$$P = (n_{tier} \text{ x } W_{coil} \text{ x } l_{stiff}/l_{coil}) / (l_{stiff} \text{ x } S_{stiff}) = (n_{tier} \text{ x } W_{coil}) / (l_{coil} \text{ x } S_{stiff})$$

Load on one EPP

Area of EPP

According to our understanding of Ch.6 Sec.1 Table 3 and Table 4, a 20% gap between steel coils is included in the calculations. The same gap could be included in the formulation for uniform load giving:

$$P = (n_{tier} \text{ x } W_{coil}) / (1.2 \text{ x } l_{coil} \text{ x } S_{stiff})$$

KC#609-2

Steel coil loading according to Ch. 6 Sec. 1 [2.7.1] and Sec. 2 [2.5.4]

Abstract

In the 3rd JBP October 2005 draft Ch. 6 Sec. 1 [2.7.4] and Sec. 2 [2.5.4] for steel coil loading, it is proposed to calculate the double bottom as uniformly loaded if steel coils are supported by a large number of dunnages. This pre assumes that the dunnages are very stiff and able to transfer the load efficiently to the nearest longitudinals. There are no requirements in the rules as to the scantlings or stiffness of dunnages. If dunnage stiffness are disregarded the load on stiffeners should be changed to a line load. Comparative calculations enclosed herein show the requirement in the Rules to be non conservative for this case. Increase of up to 78% is required depending on the longitudinal spacing. Even when calculating the full plastic utilisation of the panel, disregarding longitudinal stresses, the required sectional modulus of longitudinals was 3-10% higher than the Rule formulation.

The calculations show that significant permanent deflection should be expected for both the plating and the longitudinals of the inner bottom when the design load condition is applied to the net scantled structure. Significant permanent deflection governed by the membrane response is therefore anticipated.

Based on this assessment, we are of the opinion that the rule formulation for inner bottom plating and longitudinals should be changed to a line load formulation. It is our consideration that the introduction of explicit requirements to the scantling and stiffness of the dunnages is impractical.

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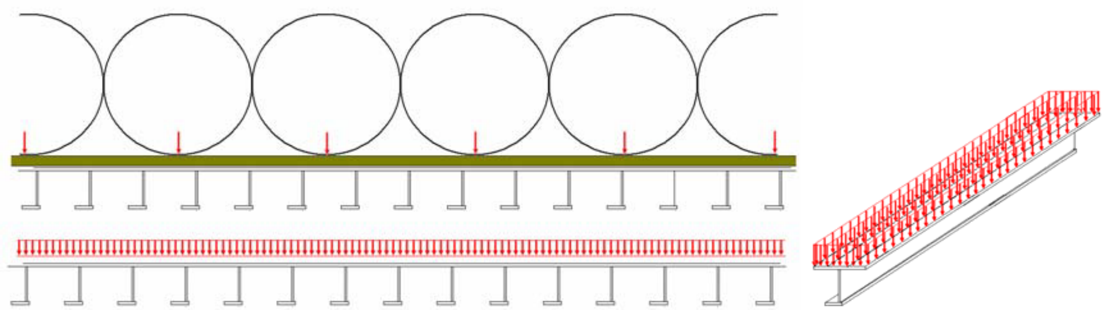
Introduction

JBP 3rd draft, Ch.6 Sec.2 [2.5.4]:

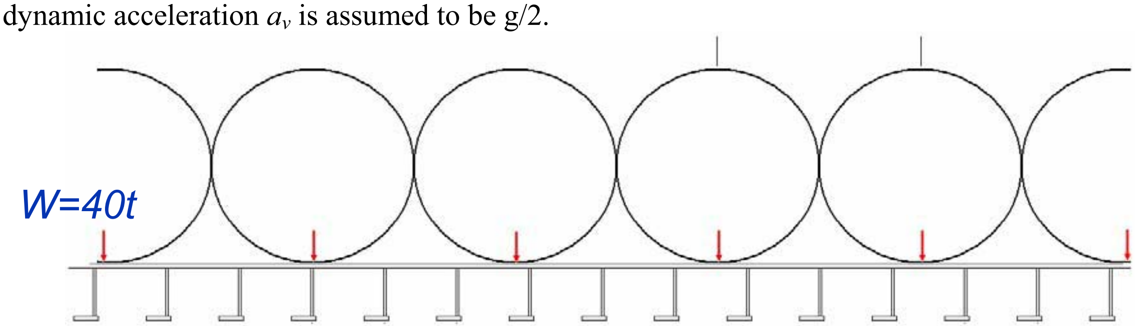
"Where the number of load points per elementary plate panel n_2 is greater than 10/or the number of dunnages n_3 is greater then 5, the inner bottom may be considered as loaded by a uniform distributed load. In such a case, the scantling of the inner bottom ordinary stiffeners is to be obtained according to [3.2.3]"

DNV interpretation of the text is: If the bottom coil is supported by 6 or more dunnages going transversally, the load from the coil on the inner bottom can be simplified to a uniform pressure. See below figure.



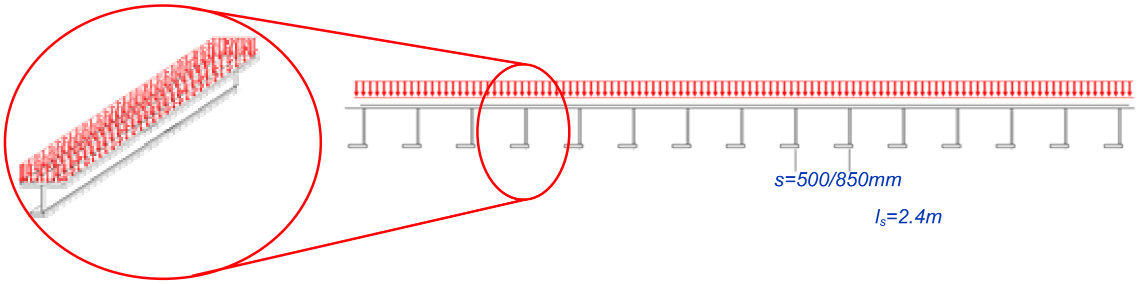
The load is then transferred between the longitudinals by the wooden dunnages. This requires the dunnages to be extremely stiff. It is our opinion that this assumption is wrong and that the pressure load should be changed to a line load on the stiffener. We have performed a small comparison case below in order to elaborate our understanding of the problem.

The following is pre-assumed. Coil, (or bottom coil), weight is 40t ≈ 400kN. Coil length is, including spacing, l_c = 1.2 meters and diameter D =1.5 meters. The allowable stress is assumed to be $\lambda_s R_Y$=0.9x235/0.78=271N/mm^2, which is maximum allowable stress for AH32 steel if longitudinal stresses are disregarded. Two stiffener spacings are calculated s_1=500mm and s_2=850mm. The length of stiffeners between floors is assumed to be l_s=2.4m. The dynamic acceleration a_v is assumed to be g/2.



Rule calculation

The rule calculation assumes that the double bottom is uniformly loaded.



Pressure from coil is:

$$P = W(g + a_v)/(Dl_c) = 40(9.81 \times 1.5)/(1.5 \times 1.2) = 327kN/m^2$$

Required plate thickness according to Sec. 1[2.7.4](C_a=C_r=1)

$$t_{req,s_1=500} = 15.8 C_a C_r s \sqrt{\frac{P}{\sigma_{all}}} = 8.68mm + t_k$$

$$t_{req,s_2=850} = 15.8 C_a C_r s \sqrt{\frac{P}{\sigma_{all}}} = 14.75mm + t_k$$

Typical t_k for inner bottom adjacent to ballast tank is 5.4 mm.

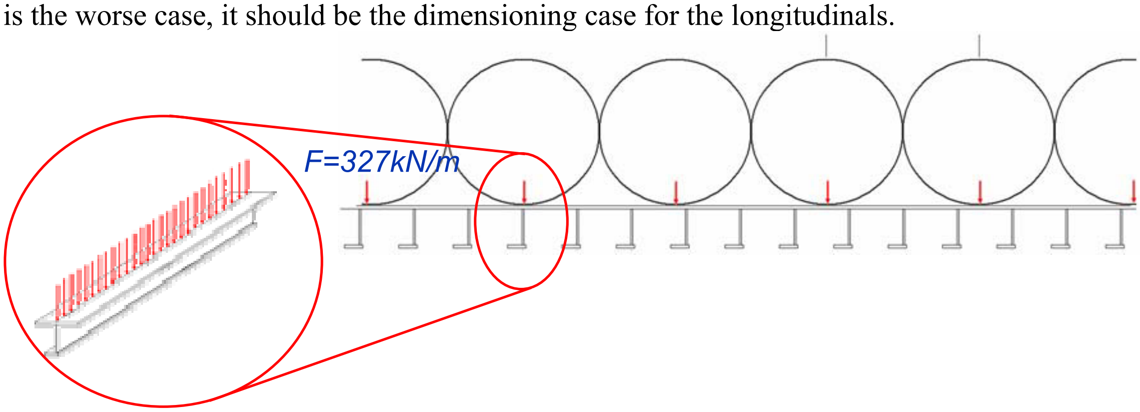
Required section modulus on stiffener is:

$$w_{req,s_1=500} = 10^3 \frac{Psl_s^{\ 2}}{12\sigma} = 290cm^3$$

$$w_{req,s_2=850} = 10^3 \frac{Psl_s^{\ 2}}{12\sigma} = 492cm^3$$

DNV alternative calculation

We assume that the load from the coils are transferred as a line load to the nearest longitudinal(s). As the coils diameter does not match the stiffener spacing exactly, there will always be one or more coils within the double bottom that will meet one longitudinal. As this is the worse case, it should be the dimensioning case for the longitudinals.



Line load on the most severe loaded longitudinal is:
$q_l = W(g + a_v)/l_c = 40(9.81 \times 1.5)/1.2 = 491 kN/m$

Corresponding end moment on stiffener is:
$$M = \frac{q_l l_s^{\ 2}}{12} = 235 kNm$$

The required section modulus is:
$$w_{req} = \frac{M}{\sigma} = \frac{160}{271} \times 10^3 = 869 cm^3$$
The section modulus is independent of the stiffener spacing.

The required section modulus for the DNV calculation is three times the section modulus required by the Rules when the stiffener spacing is $s_1=500$mm. In order to calculate the longitudinals according to the Rules, the dunnages have to be extremely stiff in order to transfer the load efficiently between longitudinals.

Plastic coil response calculation

For reference, we have calculated the ultimate capacity of the inner bottom subjected to steel coil loading (plastic capacity). The calculation procedure used is originally derived for evaluation of ice loads on longitudinally stiffened panels.

Calculation procedure outline

Load model

It is assumed that the diameter of the coils is larger than two primary frame spaces, $D>2s$. The steel coil is loaded on a wooden support, which is soft compared to the steel coil. The coil will deform in to the wood and spread the load over a small distance b of the inner bottom plating, see Figure 1.

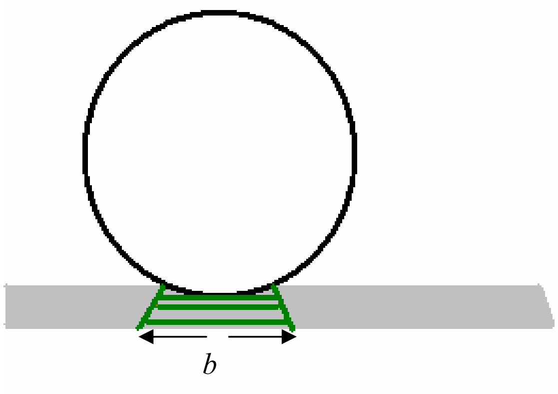


Figure 1 Steel coil deforming in to the wooden support

As described earlier, the coils will be loaded randomly within the double bottom. The diameter, D, of the coils do not match the primary longitudinal spacing. Consequently, there will always be coils meeting a longitudinal and coils at the middle of a plate field. The first will be the governing condition for the stiffeners scantlings, whereas the latter will be the governing condition for the plate scantlings.

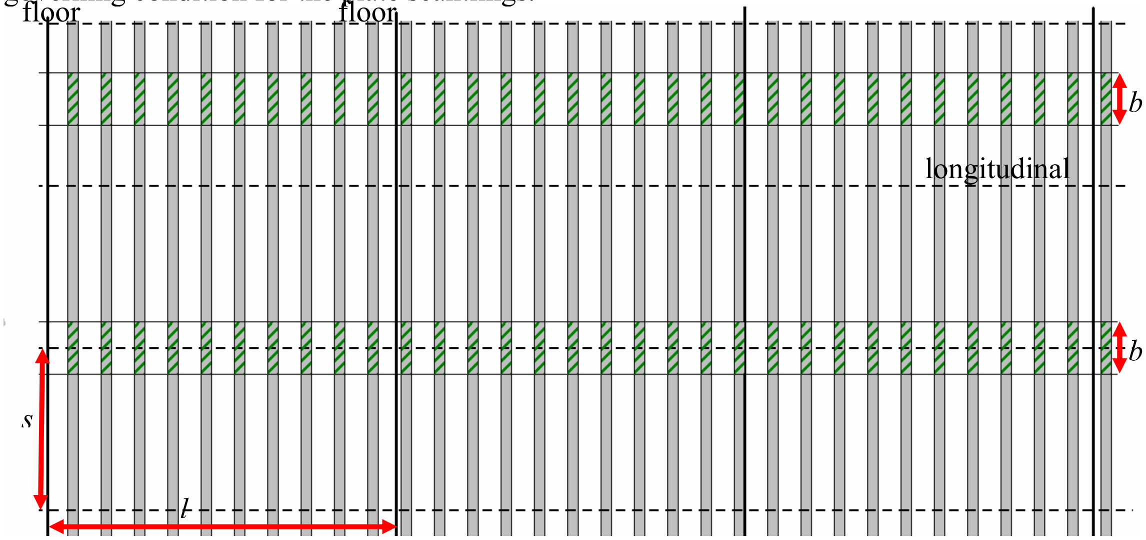


Figure 2 Load model plates and longitudinals

When the number of dunnages is large, the pressure from the steel coils on the wooden support will converge towards a uniform pressure within the breadth *b*, see Figure 2.

Longitudinals

We further assume plastic response of the plate and longitudinals.

The pressure within *b* is:

$$P = \frac{q_l}{b} = \frac{W(g + a_v)}{l_c b}$$

The required shear area is defined as:

$$A_{s,req} = 10\frac{P \times 0.5 \times b_1 l}{\sigma_y / \sqrt{3}}$$

Where b_1/b is the portion of the load transferred in to the longitudinal and $(b - b1)/b$ is the portion transferred through plate bending in to the adjacent longitudinals. See Figure 3.

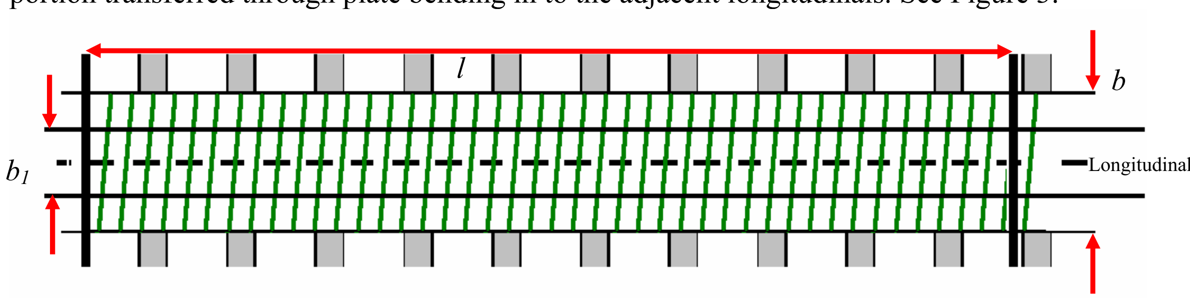


Figure 3 Relationship between b_1 and *b*

b_1 is given by:

$$b_1 = \max[k_0 b, b/3]$$

$$k_0 = 1 - \frac{2}{b}\left\{\sqrt{(s-b/2)^2 + \frac{10^{-3}t^2\sigma_y}{P}} - (s-b/2)\right\}$$

The plastic sectional modulus of longitudinal is given by:

$$z_{req} = 10^3 \frac{Pb_1 l^2 \alpha_{Plastc}}{8\sigma_y}$$

Where $\alpha_{plastic}$ is the relation between the plastic capacity of the longitudinal at the boundary to the plastic capacity at mid span.

$$\alpha_{Plastic} = \frac{1}{2 + k_{wl}\left[\sqrt{1-\alpha_{shear}{}^2} - 1\right]}$$

$\alpha_{shear} = A_{s,req} / A_{s,act}$ without being larger than 1. $A_{s,req}$ is the required shear area of longitudinal, whereas $A_{s,act}$ is the actual fitted shear area. α_s=1 will give the maximum required sectional modulus for the longitudinal.

$k_{wl} = \frac{1}{1 + 2 A_{fl,act} / A_{s,act}}$ where $A_{fl,act}$ is the fitted flange area of the stiffener.

Plates

Based on plastic response of the plate the required thickness is:

$$t_{req} = 15.8s\sqrt{2\frac{b}{s} - \left(\frac{b}{s}\right)^2}\sqrt{\frac{P}{\sigma_y}}$$

Plastic calculation

The plastic calculation have been done for the case with longitudinal spacing, s=850mm.

If we assume b=0.15 m, the required scantling for the above condition will be:

$$q_l = \frac{W(g+a_v)}{bl_c} = \frac{40(9.81\times 1.5)}{0.15\times 1.2} = 3270 kN/m^2$$

The fraction of the pressure carried by the stiffener:

$$k_{0,s_2=850} = 1 - \frac{2}{b}\left\{\sqrt{(s-b/2)^2 + \frac{10^{-3}t^2\sigma_y}{P}} - (s-b/2)\right\} = 0.8326$$

$$b_1 = \max[k_0 b, b/3] = \max[0.1249, 0.05] = 0.1249m$$

That is, the fraction of the load transferred to the adjacent stiffener is 16.7%.

The required shear area:

$$A_{s,req} = 10\frac{P\times 0.5\times b_1 l}{\sigma_y / \sqrt{3}} = 10\frac{3270\times 0.5\times 0.1249x2.4}{301/\sqrt{3}} = 28.22cm^3$$

Required section modulus assuming α_{shear} =1.

$$k_{wl} = \frac{1}{1+2\,{}^{A_{fl,act}}\!\big/_{A_{s,act}}} = \frac{1}{1+2\,{}^{(90\times 13.1)}\!\big/_{19.91}} = 0.4581$$

$$\alpha_{Plastic} = \frac{1}{2+k_{wl}\left[\sqrt{1-\alpha_{shear}{}^{2}}-1\right]} = \frac{1}{2+0.4581\left[\sqrt{1-1^{2}}-1\right]} = 0.6486$$

$$z_{req} = 10^{3}\,\frac{Pb_{1}l^{2}\alpha_{Plastc}}{8\sigma_{y}} = 10^{3}\,\frac{3270\times 0.1249\times 2.4^{2}\times 0.6486}{8\times 301} = 634cm^{3}$$

It should be noted that this is the required net plastic sectional modulus for the longitudinal. The elastic sectional modulus is typically ≈15-20% smaller. Hence, the equivalent net elastic section modulus is about 507-540cm^3.

Plates

$$t_{req} = 15.8s\sqrt{2\frac{b}{s}-\left(\frac{b}{s}\right)^{2}}\sqrt{\frac{P}{\sigma_{y}}} = 15.8\times 0.85\sqrt{2\frac{0.15}{0.85}-\left(\frac{0.15}{0.85}\right)^{2}}\sqrt{\frac{3270}{301}} = 25.11mm$$

It should be noted that b=0.15 is assumed to be slightly conservative at the middle of the plate span. If b=0.3m is used the requirement would decrease to 23.86mm.

It should be noted that the global, axial, stresses are disregarded in above calculation. The design condition is plastic, with allowable stress equal to yield. Fatigue is not evaluated.
If actual section modulus is smaller than the above calculated, the longitudinal will deform plastically. The shortage will be carried by the plate to the nearest longitudinals by membrane response. (i.e. significant permanent deformations)

Summary

In the 3rd JBP draft October 2005 Ch. 6 Sec. 1 [2.7.4] and Sec. 2 [2.5.4] for steel coil loading, it is proposed to calculate the double bottom as uniformly loaded if steel coils are supported by a large number of dunnages. This is pre assuming that the dunnages are very stiff and able to transfer the load efficiently to the nearest longitudinals.

Three calculations procedures are calculated above. All with the following coil particulars: W=40 tonnes, length 1.2 meters, diameter 1.5 meters and number of dunnages per coil >6.

(s=850mm)	**Dunnage assumption**	$\boldsymbol{W_{req,net}}$ **[cm^3]**	$\boldsymbol{t_{req,net}}$ **[mm]**
Rule calculation	Very stiff	490	14.75
DNV alternative	No stiffness	870	(not calc)
Plastic capacity disregarding longitudinal stress	No stiffness	540*	25.11**

*Estimated elastic sectional modulus
** based on an assumed load breadth b=0.15 meters, see above calculation for details.

There is no requirement in the Rules as to the dimensions of dunnages. It is therefore unreasonable to assume a uniform pressure according to the Rule formulation. If dunnages are assumed to be without stiffness, the load should be applied as a line load on the longitudinals. In our calculation this corresponds to an increase of longitudinal section modulus of up to 78%, depending on the spacing of the longitudinals.
For reference, a plastic calculation was conducted for the latter case. The calculation was made without global stresses, allowing full plastic utilization of the longitudinals, σ_y=300. The calculation showed a required sectional modulus, compared to the Rule formulation, of +3-10% depending on the $w_{plastic}/w_{elastic}$ ratio of the longitudinals.

The calculations show that significant permanent deflection should be expected for both the plating and the longitudinals of the inner bottom when the design load condition is applied to the net scantled structure. Significant permanent deflection governed by the membrane response is therefore anticipated.

Based on this assessment, we are of the opinion that the rule formulation for inner bottom plating and longitudinals should be changed to a line load formulation. It is our consideration that the introduction of explicit requirements to the scantling and stiffness of the dunnages is impractical.