CONSIDERATIONS ON DIMENSIONING OF GARAGE DECKS

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SUMMARY

This work deals with the optimization of ro-ro/pax deck structures, focusing on the primary supporting beams in absence of pillars, as these decks have to be free, as far as possible, in order to facilitate the ship loading and unloading. Some typical ro-ro/pax grillage type decks have been analyzed, aiming at a numerical comparison between the primary supporting beam stress values obtained by the following techniques: Shade orthotropic plate bending theory, grillage analysis, finite-element method. As a result, it has been assessed the relative accuracy of such analysis techniques in deck transverse and girder dimensioning.

Considering the necessity to minimize the deck structural weight and the web height, especially to improve the ship stability, it has been investigated the influence of each grillage parameter on deck framing behaviour, particularly in relation to the structural weight. These results have been achieved by a dedicated program, developed in MATLAB, that thanks to nested iterative cycles, optimizes grillage parameters, the minimum structural weight being the objective. Finally, some general guidelines to obtain easily a grillage dimensioning quite close to the optimized one are suggested.

1. INTRODUCTION

Ro-ro ship decks are often free of pillars and bulkheads, in order to facilitate the manoeuvring of vehicles. In dimensioning deck primary supporting members, first of all, it is necessary to define a model for the wheeled loads and then choose an appropriate analysis technique. Together with these aspects, there is the problem of optimizing, in terms of weights and volumes, those structures varying, in appropriate ranges, the height of the beams, the distance between transverses and the number of longitudinal girders.

Besides, since it seems useful to have some criterions for the assessment of principal grillage parameters, some suggestions are given in order to obtain, already in the first project stages, a structural arrangement near to the optimized one.

2. LOAD MODEL

For primary supporting members subjected to wheeled loads, yielding checks have to be carried out considering an uniformly distributed pressure on decks, equivalent to the vertical, static and dynamic, applied force distribution.

To define the equivalent pressure, it is necessary to consider the most unfavourable case, i.e. that one where the maximum axle number is located on the primary supporting member.

The static equivalent pressure can be evaluated with the following relation, suggested by R.I.NA. Rules 2007:

\[ p_{eq,stat} = \frac{n_V Q_A}{l s} \left( 3 - \frac{X_1 + X_2}{s} \right) g \]  (1)

in which it is assumed:

- \( n_V \) = maximum number of vehicles located on the primary supporting member;
- \( Q_A \) = maximum axle load in t;
- \( X_1 \) = minimum distance, in m, between two consecutive axles;
- \( X_2 \) = minimum distance, in m, between axles of two consecutive vehicles;
- \( l \) = span, in m, of the primary supporting members;
- \( s \) = spacing, in m, of primary supporting members.

The total equivalent pressure is the sum of a static term and a dynamic one and can be expressed in kN/m² as follows:

\[ p_{eq} = (1 + a_z) p_{eq,stat} \]  (2)

where \( a_z \) is the ship vertical acceleration, as fraction of \( g \), in the upright or inclined conditions.

This vertical load is transmitted, according to an appropriate distribution criterion, to longitudinal and transverse primary supporting members. If the spacing between transverses is comparable with that one between longitudinal members, an empiric but sufficiently accurate relation for the load distribution is Faulkner’s equation.

In detail, considering a shell panel between adjacent transverse and longitudinal primary supporting members (see FIG. 1) and assuming that:

- \( a \) is the panel greater side in m;
- \( b \) is the panel smaller side in m;
- \( \alpha = \frac{a}{b} \) is the panel aspect ratio,

it is possible to use the following uniform load distributions, in kN/m:

\[
\begin{align*}
q_a &= p_{eq} b \left( 1 - \frac{1}{2\alpha} \right) \\
q_b &= \frac{p_{eq} b}{2}
\end{align*}
\]  (3)
respectively along the greater side (suffix \(a\)) and the smaller one (suffix \(b\)):

![Diagram](image)

**FIG. 1**

### 3. STRUCTURAL ANALYSIS MODELS

According to R.N.A. Rules 2007, Part. B, Chapter 7, Appendix 2, the stresses induced by vertical loads in ro-ro deck primary supporting members can be calculated by means of two-dimensional grillage models and the stresses so obtained, due to local load only, have to be superimposed to the primary ones, separately calculated. Primary supporting members can be considered as elements of a grillage, because they form two sets of orthogonal beams, regularly spaced and subjected to lateral loads.

According to the properties and arrangement of these elements, it is possible to define more or less accurate analysis models. First of all, if the primary supporting members are fitted along only one direction, or when the primary supporting members are fitted along two directions but the bending rigidity relative to one direction is at least three times the other one, it is sufficient to use the isolated beam model without any remarkable mistakes.

If, on the contrary, the bending rigidities of longitudinal and transverse primary supporting members are of the same order, it is necessary to adopt more refined techniques, particularly:

- Schade orthotropic plate bending theory;
- Beam grillage model with elastic restraints;
- Finite element analysis.

#### 3.1 CHARACTERIZATION OF RESTRAINT CONDITIONS

The Schade orthotropic plate bending theory and the beam grillage model with elastic restraints are based on two-dimensional structural models, where it isn’t possible to take fully account of side and fore/aft bulkheads primary supporting members, that is the rigidities of vertical frames. On the contrary, finite element methods allows to obtain a greater accuracy, modelling whole parts of ship or even the complete structure.

However, to consider the effect of the immediately upper and lower decks on the analyzed one, the contribution of bending compliances of side and bulkheads primary supporting members can be simulated by springs at their connections with horizontal beams. These support compliances produce on primary supporting members a decrease of the bending moment at the extremity sections and an increase in the mid section compared with the values obtained considering the supports as fully clamped.

However, as it isn’t simple to assess these compliances, but it is possible to evaluate their effects considering a three-dimensional structure in which also the upper and lower decks are schematized, as well as side and bulkheads primary supporting members, a ro-ro ship deck has been analyzed comparing the two following models:

1. 2D isolated deck: the supports at the extremities of the primary supporting members are treated as perfectly clamped;
2. Deck in a 3D model: the upper and lower decks, as well as side and bulkheads primary supporting members, are schematized in a 3D frame model; the members of the three considered decks are connected to side and bulkheads members, which in turn are clamped to the inner bottom.

The analyzed deck, as well as the immediately upper and lower ones, has the following characteristics:

- \(L_X=80\) m;
- \(L_Y=16\) m;
- \(s_X=2\) m;
- \(s_Y=2\) m;
- \(t=8\) mm;
- \(p_{eq}=6\) kN/m²;
- ’tween deck height=2.5m.

Transverse and longitudinal primary supporting members are 320x10+150x15 T sections, while side and bulkheads members are 300x8+100x12 T sections. In terms of bending moment the following results have been obtained:

<table>
<thead>
<tr>
<th></th>
<th>M( kNm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2D model</td>
</tr>
<tr>
<td>Clamped section</td>
<td></td>
</tr>
<tr>
<td>Transverse</td>
<td></td>
</tr>
<tr>
<td>Mid section</td>
<td>294,252</td>
</tr>
<tr>
<td>Longitudinal</td>
<td></td>
</tr>
<tr>
<td>Clamped section</td>
<td>151,859</td>
</tr>
<tr>
<td>Mid section</td>
<td>188,727</td>
</tr>
<tr>
<td></td>
<td>210,311</td>
</tr>
</tbody>
</table>

**TAB. 1**
From the results of TAB. 1, it is possible to appreciate the effect of the immediately upper and lower decks: as regards the transverses, the moment decreases at the extremity sections and increases at the mid section; as regards the deck girders, the moment decreases at the extremity clamped sections, while at the mid section it is almost unchanged.

As yielding checks have to be carried out, in both cases, at the extremity sections, i.e. where the deck is connected to side and bulkheads primary supporting members, the assumption of fixed ends leads to a low over-estimate of the moments at the extremity sections of 3-5%.

Then, in the following, the deck will be considered as clamped to side and bulkheads primary supporting members, neglecting the restraint compliances, on safety side.

3.2 SCHADE ORTHOTROPIC PLATE BENDING THEORY

It is well-known that some materials exhibit anisotropic mechanical characteristics; their behaviour, however, often has three planes of symmetry. Materials having this behaviour are known as orthotropic, because they have different elastic constants along their symmetry axes.

In the case of orthotropic plate, with respect to a reference frame with $x$ and $y$ axes laying on the mid plate plane and $z$ axis consequently oriented in order to obtain a counter clock-wise frame, the equation governing the vertical displacement field, in the hypothesis of small elastic strains is, as well-known, the following:

$$\nabla^4 w = \frac{p}{D}$$

being $D$ the plate bending rigidity:

$$D = \frac{Et^3}{12(1-v^2)}$$

and $t$ the plate thickness, $E$ the Young modulus and $v$ the Poisson modulus of material.

It is possible to obtain the orthotropic plate bending equation, neglecting the distortion induced by vertical shear as:

$$D_x \frac{\partial^4 w}{\partial x^4} + 2H \frac{\partial^4 w}{\partial x^2 \partial y^2} + D_y \frac{\partial^4 w}{\partial y^4} = p$$

In equation (6) $H$ is a function of the bending rigidities $D_x$ and $D_y$ and of the torsional rigidity $D_{xy}$ according to equation (7):

$$H = D_{xy} + \frac{v}{2}(D_x + D_y)$$

indicating with $i_x$ and $i_y$ the moments of inertia, per unit length, of primary supporting members with associated plate of effective breadth $b_z$ in order to consider the shear–lag:

$$\begin{align*}
    i_x &= \frac{I_x}{s_x} \\
    i_y &= \frac{I_y}{s_x}
\end{align*}$$

Schade orthotropic plate bending theory allows to define the displacement and stress fields in stiffened panels, whose behaviour can be considered similar to the orthotropic plate one.

If, indeed, the stiffened panels have mutually orthogonal and uniformly spaced supporting members along the two directions, these members can be “spread” on the panel, obtaining an equivalent plate with different bending rigidities along $x$ and $y$ axes.

Referring to the system in FIG.2 and denoting with:

- $L_x =$ the deck length;
- $L_y =$ the deck breadth;
- $s_x =$ the spacing between longitudinal primary supporting members;
- $s_y =$ the spacing between transverse primary supporting members,
- suffix $X$ the quantities relative to longitudinal elements;
- suffix $Y$ the ones relative to transverse elements,
Schade didn’t define the torsional rigidity in terms of structural variables, but developed a numerical approximated expression for \( H \) parameter to be substituted in equation (6).

It could be expected that the accuracy reachable in assessment of stresses in grillage elements is good if stiffened panels are close to orthotropic plate theoretical model. Therefore, for closely spaced grillages, as ro-ro decks, the accuracy of the theory can be supposed acceptable.

Schade suggested, for various boundary conditions, some numerical solutions to assess the stresses generated in grillage elements, so expressed for transverse (10) and longitudinal (11) elements:

\[
\sigma_y = k_y \frac{p_{xy} L_y^2 r_y}{l_y} \\
\sigma_x = k_x \frac{p_{yx} L_x^2 r_x}{\sqrt{l_x l_y}}
\]  

(10)  

(11)

In equations (10) and (11) \( r_x \) and \( r_y \) are the distances from their neutral axes to extreme fibres of longitudinal and transverse members respectively, including a plate of effective breadth \( b_e \).

Parameters \( k_x \) and \( k_y \) are given by diagrams, as function of panel boundary conditions, virtual aspect ratio \( \eta \) and torsional rigidity parameter \( h \) so defined:

\[
\rho = \frac{L_y}{L} \sqrt{\frac{l_y}{l_x}} \\
\eta = \frac{i_{px} \cdot i_{py}}{i_{px} \cdot i_{pc}}
\]  

(12)  

(13)

In equation (13) \( i_{px} \) and \( i_{py} \) are the unit moments of inertia, about the section neutral axes, of plates associated to longitudinal and transverse elements.

In diagram of FIG.3 the curves proposed by Schade in 1941 for all clamped edges are shown, in order to assess relevant coefficients.

3.3 GRILLAGE ANALYSIS METHOD

In grillage models, the structure is schematized by pure bending beams, connected in the nodes, with plates of effective breadth \( b_e \) to consider the shear-lag. This breadth is function of the distance between the points of zero bending moment \( L_0 \) that for uniformly loaded beams clamped at the ends is \( L_0 = \frac{\sqrt{3}}{3} L \), where \( L \) is the element span.

Concerning loads, as it is necessary to define the load per unit length, it is possible to use the load distribution criteria proposed by Faulkner (see Par. 2).

By using a generic structural frame analysis program, it’s possible to calculate rapidly the maxima of vertical bending moment stresses, which are at the extremity clamped sections.

It’s useful to remark that neglecting the torsional rigidity doesn’t produce, in this case, great errors because that rigidity is very little for thin walled beams with open sections, as longitudinal and transverse primary supporting members are.

In terms of stresses, by applying a pure bending beam model, the yielding check to carry out is the following:

\[
\sigma = \frac{M_{\text{max}}}{W_{\text{min}}} \leq \sigma_{\text{all.}}
\]  

(14)

3.4 FINITE ELEMENTS ANALYSIS

Finite elements analysis is, obviously, the most accurate and versatile technique as it permits to take precisely into account the contribution of plating and carry out local analysis as the ones near the intersections of beams with side and bulkheads primary supporting members.

Defining for each shell element a local coordinates system as in FIG. 4 and denoting by \( \sigma_{ij} \) the stress along \( j \) axis acting on the face having the normal parallel to \( i \) axis, it is possible to define the Von Mises stress \( \sigma_{VM} \) as follows:

\[
\sigma_{VM} = \sqrt{\sigma_{11}^2 + \sigma_{22}^2 + \sigma_{33}^2 - \sigma_{12} \sigma_{21} - \sigma_{13} \sigma_{31} - \sigma_{23} \sigma_{32}}
\]  

(15)

FIG. 4

This stress, that considers only the deviatory part of the stress tensor, is an index of material yielding and has to be less than the allowable stress.
In such structural analysis, it is suitable to use 4 nodes shell elements: care must be paid in mesh definition, so that all the panels have an aspect ratio less than 2, anyway less than 4.

4. ANALYSIS OF SOME TYPICAL RO-RO DECK STRUCTURES

To carry out a numerical comparison between the stresses calculated by applying the previously described techniques, two ro-ro ship decks have been analyzed. Particularly, the first deck is relative to a fast ferry, used to carry only cars, while the second one is relative to a traditional ro-ro ship, used to carry heavy vehicles, including fork-lifts and trailer trucks. In finite element analysis, carried out with SAP, the structural model is a coarse mesh type and the primary supporting members are modelled with 4 nodes shells. The aspect ratio of all shell elements are never higher than 4 and for the greater part of them it is less than 2. The webs of all primary supporting members have been schematized with two lines of shells, in order to subdivide the web into two parts. Likewise, the plates have been schematized with two symmetric lines of elements.

4.1 ANALYSIS OF A RO-RO FAST FERRY DECK PRIMARY SUPPORTING MEMBERS

It has been carried out the evaluation of the highest stresses acting on the primary supporting members of a fast ferry used to carry vehicles; the ship main dimensions are: \( L_{bp} = 97,61 \text{ m} \); \( B = 17,10 \text{ m} \); \( D = 10,40 \text{ m} \); \( \Delta = 1420 \text{ t} \). The project data assumed in the analysis are the following (see FIG. 5):

- \( L_X = 80 \text{ m} \);
- \( L_Y = 16 \text{ m} \);
- \( s_X = 2 \text{ m} \);
- \( s_Y = 2 \text{ m} \);
- \( t = 8 \text{ mm} \);
- \( p_{eq} = 6 \text{ kN/m}^2 \).

The numerical comparison has been carried out, supposing that all transverse and longitudinal primary supporting members have a \( 320 \times 10 + 150 \times 15 \) T section in high-strength steel with \( \sigma_y = 355 \text{ N/mm}^2 \).

<table>
<thead>
<tr>
<th>Highest stresses (N/mm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schade theory</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Longitudinal primary supporting members</td>
</tr>
<tr>
<td>Transverse primary supporting members</td>
</tr>
</tbody>
</table>

**TAB. 2**

Tabulated stresses have been calculated in accordance to paragraphs 3 and 4. The per cent changes respect to the finite element model are shown in **TAB.3**:

<table>
<thead>
<tr>
<th>( \Delta (%) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schade theory</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Longitudinal primary supporting members</td>
</tr>
<tr>
<td>Transverse primary supporting members</td>
</tr>
</tbody>
</table>

**TAB. 3**

This analysis shows that stress values, obtained by applying Schade orthotropic plate bending theory or grillage method, are a little less than the stresses obtained by the finite element model. However this little underestimate is balanced by the considerable reduction of computing effort compared to the one occurring for the finite element analysis.

4.2 ANALYSIS OF A RO-RO PANAMAX DECK PRIMARY SUPPORTING MEMBERS

It has been carried out the evaluation of the highest stresses acting on the primary supporting members of a ro-ro PANAMAX ship used to carry heavy vehicles; the ship main dimensions are: \( L_{bp} = 195,00 \text{ m} \); \( B = 32,25 \text{ m} \); \( D = 25,92 \text{ m} \); \( \Delta = 44200 \text{ t} \). The project data assumed in the analysis are the following (see FIG. 6):

- \( L_X = 160 \text{ m} \);
- \( L_Y = 24 \text{ m} \);
- \( s_X = 4 \text{ m} \);
- \( s_Y = 2,463 \text{ m} \);
- \( t = 14 \text{ mm} \);
The numerical comparison has been carried out supposing that all transverse and longitudinal primary supporting members are, respectively, a 970x11+320x30 and 970x12+280x30 T sections, in high-strength steel with $\sigma_y = 355$ N/mm². The results are shown in TAB. 4:

<table>
<thead>
<tr>
<th></th>
<th>Schade theory</th>
<th>Grillage method</th>
<th>FEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal primary</td>
<td>310</td>
<td>287</td>
<td>325</td>
</tr>
<tr>
<td>supporting members</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse primary</td>
<td>348</td>
<td>342</td>
<td>361</td>
</tr>
<tr>
<td>supporting members</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TAB. 4

The per cent changes, respect to the finite element model, are shown in TAB.5:

<table>
<thead>
<tr>
<th></th>
<th>Schade theory</th>
<th>Grillage method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal primary</td>
<td>-4,83</td>
<td>-11,69</td>
</tr>
<tr>
<td>supporting members</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transverse primary</td>
<td>-3,60</td>
<td>-5,26</td>
</tr>
<tr>
<td>supporting members</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TAB. 5

4.3 SOME CONSIDERATIONS ON THE ABOVE RESULTS

The previously tabulated results show that per cent variations of Schade theory and grillage analysis are little.

However, as the calculus effort in applying Schade theory is very little if compared to finite element model, in the following paragraph a scheme is shown for dimensioning the deck primary supporting members, obtaining, since from first project stages, an optimized grillage configuration in terms of weight.

5. A TECHNIQUE FOR PRELIMINARY DESIGN OF RO-RO DECK PRIMARY SUPPORTING MEMBERS

5.1 PRELIMINARY CONSIDERATIONS

In first structural analysis stages it’s certainly useful to have some general guidelines, allowing to obtain a structural configuration near to the minimum weight optimized one. Scantlings of ro-ro deck primary supporting members are substantially influenced by the following parameters:

- primary supporting members height;
- equivalent pressure, as function of carried vehicles;
- spacing between transverses;
- number of longitudinal primary supporting members.

The height of supporting members influences in a significant way the deck structural weight, because, when it increases, it’s possible to reach high moment of inertia values, with relatively small section areas; then large weight decreases can be obtained.

On the other side, increasing this height implies to increase the ship depth, under the same conditions. Then it’s important, already in the first project stages, to know which are the values of deck member height that lead the grillage arrangement to be near to the optimized one.

Longitudinal primary supporting members’ number and the distance between transverses strongly influence the stresses generated in grillage elements. So, in the same way, it could be useful to know preliminarily the transverse spacing and the longitudinal members’ number that minimize the deck structural weight.

It’s clear, however, that both these parameters will be chosen also in function of other restraint conditions. In fact, as the spacing of transverses is equal to the web frame distance, this parameter influences the side and bottom scantlings too.

Similarly, longitudinal supporting members’ number can be influenced both by the necessity of reaching the required values of the section modulus and by the number of extremity bulkhead vertical webs.

What will be said in the following allows to carry out an optimized arrangement for ro-ro deck supporting members, without considering other restraints conditions that should be evaluated only case by case. Such results have been obtained by a purposely developed program in MATLAB, that, by nested iterative cycles, permits to assess the minimum weight structural arrangement, varying in appropriate ranges all the grillage parameters.
The distance between transverses has been varied in the range 2.00 ÷ 3.60 m. Instead, for longitudinal members, it has been varied the number of elements rather than their distance. Structural arrangements with 1, 3, 5, and 7 primary longitudinal supporting members have been analyzed, considering, weight being the same, the arrangement with three elements better than the others and the one with five elements better than the one with seven elements.

As, for primary supporting members, it is necessary to add secondary local stresses to the primary ones induced by vertical bending moment, it has been assumed, for longitudinal members, a secondary allowable stress $\sigma_{all.long.} = 315$ N/mm$^2$, supposing a primary allowable stress of 40 N/mm$^2$. This value is on the safety side, because the maxima of secondary stresses induced by wheeled loads are located at the extremity clamped sections where the primary stresses induced by vertical bending moment are very low. For transverses, instead, it has been assumed an allowable secondary stress $\sigma_{all.tr.} = 355$ N/mm$^2$.

The plating thickness depends on spacing between ordinary stiffeners and on wheeled loads. As in structural weight optimization the equivalent pressure has been varied between 6 and 30 kN/m$^2$, a corresponding variation in plating thickness to be associated to primary supporting members has been assumed as follows:

<table>
<thead>
<tr>
<th>$p_{eq.}$ (kN/m$^2$)</th>
<th>thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-9</td>
<td>6</td>
</tr>
<tr>
<td>10-14</td>
<td>8</td>
</tr>
<tr>
<td>15-20</td>
<td>10</td>
</tr>
<tr>
<td>21-26</td>
<td>12</td>
</tr>
<tr>
<td>27-30</td>
<td>14</td>
</tr>
</tbody>
</table>

**TAB. 6**

5.2 OPTIMUM SPACING BETWEEN DECK TRANSVERSES

The results of the numerical analysis show that the optimum spacing between transverses $s_Y$, with reference to FIG.2, is substantially independent of both applied load and deck length, but is a function only of the deck breadth. With $L_Y$ and $s_Y$ in m, the following relation has been obtained, in order to assess the optimum distance between transverses:

$$s_Y = \frac{L_Y}{n+1}$$  \hspace{1cm} (17)

5.3 OPTIMUM NUMBER OF PRIMARY LONGITUDINAL SUPPORTING MEMBERS

Concerning the spacing between primary longitudinal supporting members, it’s more useful to assess the number of evenly spaced elements which optimize the grillage. It has been found that this parameter depends on deck breadth, equivalent pressure and height of the girders.

Considering a range of thicknesses between 8 and 30 mm for webs and face-plates, it has been found that the best arrangements are the ones with 3 and 5 evenly spaced girders. The arrangement with 7 elements gives mostly weights quite greater than the ones obtained for 5 members elements. When both such arrangements give almost the same structural weight, the one with 5 has to be preferred because of fabrication simplicity.

The number of primary supporting members that optimize the deck structural weight is shown in the following diagrams, each one relative to a web height value. Therefore, from such diagrams, the optimum number of girders is immediately obtained as function of web height Indicating as $n$ this number, with notation of FIG. 2, the optimum distance between deck girders is:
5.4 SCANTLINGS OF PRIMARY SUPPORTING MEMBERS

As previously said, it seems possible to use in the initial stages of structural analysis Schade orthotropic plate bending results, because these ones lead to little errors in evaluating the stresses respect to the ones achievable with finite element method.

The easiness of this approach is outlined in the following. Given the equivalent pressure by equations (1) and (2), it is possible to assess, thanks to eq. (16) and diagrams of FIG. 7, the optimum distance between transverses and the optimum number of deck girders. The following plating effective breadth \( b_e \) will be associated to longitudinal and transverse primary supporting members respectively:

\[
b_{eX} = 0.23 \cdot s_X \quad (18)
\]

\[
b_{eY} = 0.23 \cdot s_Y \quad (19)
\]

In Schade theory application, as for garage decks the aspect ratio \( \beta \) is much greater than 1, it is allowable to consider that coefficients in equations (10) and (11) assume the values \( k_Y = 0.0916 \) and \( k_X = 0.0627 \).

Indicating with \( \sigma_{all.tr.} \) and \( \sigma_{all.long.} \) the allowable stresses for transverses and girders respectively, it’s possible to calculate the minimum section modulus for transverses by the following relation:

\[
W_{YM} (cm^3) = \frac{0.0916 \cdot p_{eq} \cdot L_Y^2 \cdot s_X}{\sigma_{all.tr.}} \quad (20)
\]

The transverse section scantlings have to be chosen taking into account the plating of effective breadth \( b_{eY} \), such as to satisfy the condition:

\[
W_{YM} (cm^3) \geq W_{YM} (cm^3) \quad (21)
\]

The condition valid for longitudinal members is:

\[
\frac{W_{el}}{I_{el}} (cm^3) \geq \frac{0.0039 \cdot p_{eq} \cdot L_Y^2 \cdot s_X \cdot s_Y}{I_{el} (cm^4) \cdot \sigma_{all.long.}} \quad (22)
\]

In the last relation \( I_{el} \) is the moment of inertia of transverse section with plating of effective breadth \( b_{eY} \).

5.5 WEIGHT OF PRIMARY SUPPORTING MEMBERS

To assess the weight of primary supporting members, it’s possible to consider that these elements are “spread”
along the deck length. Then, in function of member height, equivalent pressure and deck breadth \( L_Y \), it's possible to assess, from diagrams shown in FIG. 8, the weight per unit length, of transverse and longitudinal supporting members.

<table>
<thead>
<tr>
<th>Primary supporting members weight/length - Web height = 400 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_Y = 16 ) m</td>
</tr>
<tr>
<td>0.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary supporting members weight/length - Web height = 500 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_Y = 16 ) m</td>
</tr>
<tr>
<td>0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Primary supporting members weight/length - Web height = 600 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_Y = 16 ) m</td>
</tr>
<tr>
<td>0.8</td>
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<table>
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<tr>
<th>Primary supporting members weight/length - Web height = 700 mm</th>
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<tbody>
<tr>
<td>( L_Y = 16 ) m</td>
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<th>Primary supporting members weight/length - Web height = 800 mm</th>
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<tr>
<td>( L_Y = 16 ) m</td>
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<th>Primary supporting members weight/length - Web height = 900 mm</th>
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<td>( L_Y = 16 ) m</td>
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<th>Primary supporting members weight/length - Web height = 1000 mm</th>
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<tr>
<td>( L_Y = 16 ) m</td>
</tr>
<tr>
<td>1.6</td>
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</table>

**FIG. 8**

The total structural weight of longitudinal and transverse supporting members, in \( t \), without plating, will be obtained by multiplying the value \( w \) of previously diagrams by deck length:

\[
TotalWeight = w \cdot L_X
\]  

6. CONCLUSIONS

Stresses acting on garage decks of two typical ro-ro ships have been evaluated by means of different structural models: it has been concluded that Schade orthotropic plate bending theory gives sufficiently accurate results, at least in the first stages of the dimensioning procedure. Then, a systematic numerical evaluation of the weight of deck primary supporting beams has been carried out and
the optimum values of the grillage parameters have been derived.
At last, a simple procedure, based on Schade theory, for the early dimensioning of deck transverses and girders has been obtained.
It is intended to extend this procedure to decks with one or more lines of pillars, drawing out the results now obtained for single span decks.

7. REFERENCES