Additional Design Procedures

Assessment of Steel Hatch Covers Using Finite Element Analysis

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<th>Document Date</th>
<th>Notes</th>
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<tr>
<td>July 2007</td>
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</tbody>
</table>

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Chapter 1: Introduction

Section 1: Application

1.1 This document provides a procedure, acceptable to Lloyd’s Register, for carrying out the structural assessment of steel hatch covers using three dimensional linear finite plate element analysis.

1.2 The assessment comprises two parts:
   - PART A: Assessment of hatch covers under container and other cargo loads or subjected to internal pressure.
   - PART B: Assessment of hatch covers under loadline weather loads.

1.3 Both PART A and PART B assessments are required to be carried out for hatch covers on main weather decks where it is intended that they support cargo or internal pressure. The PART B assessment is not required for tween deck hatch covers.

1.4 Requirements given in Lloyd’s Register’s Rules and Regulations for the Classification of Ships (hereinafter referred to as the Rules for Ships) and the IACS Common Structural Rules for Bulk Carriers (hereinafter referred to as CSR for Bulk Carriers) also apply, as applicable.

1.5 A detailed report of the analysis is to be submitted for the approval of the hatch cover and must include the information listed in Section 3. The report must show compliance with the specified structural design criteria given in the relevant PART(s) of this procedure.

1.6 If the computer programs employed for the analysis are not recognised by Lloyd’s Register, full particulars of the programs used will also require to be submitted, see Pt 3 Ch 1, 3.1 of the Rules for Ships.

1.7 Lloyd’s Register may, in certain circumstances, require the submission of computer input and output to further verify the adequacy of the calculations carried out.

1.8 Where alternative procedures are proposed, these are to be agreed with Lloyd’s Register before commencement.
Section 2: Symbols and units

2.1 The symbols used in this document are as follows:

\( c \) = edge restraint factor, see Pt 3, Ch 4,7 of the Rules for Ships

\( k \) = higher tensile steel factor, see Pt 3, Ch 2,1 of the Rules for Ships

\( L_o \) = unsupported span

\( t \) = plate thickness before reduction for corrosion

\( t_c \) = corrosion addition

\( X \) = longitudinal axis, positive forward

\( Y \) = transverse axis, positive to port

\( Z \) = vertical axis, positive upwards

\( \delta_x \) = displacement along X axis

\( \delta_y \) = displacement along Y axis

\( \delta_z \) = displacement along Z axis

\( \theta_x \) = rotation about X axis

\( \theta_y \) = rotation about Y axis

\( \theta_z \) = rotation about Z axis

\( \lambda \) = buckling factor of safety

\( \sigma_{cr} \) = critical buckling stress corrected for plasticity

\( \sigma_c \) = elastic critical buckling stress

\( \sigma_o \) = specified minimum yield stress of material

2.2 Consistent units are to be used throughout the analysis.

Section 3: Direct calculation procedures report

3.1 The report submitted to Lloyd's Register is to contain the following information:

- List of plans used, including dates and versions;
- Detailed description of structural modelling including modelling assumptions;
- Plots to demonstrate correct structural modelling and assigned properties;
- Details of material properties used;
- Details of boundary conditions applied;
- Details of applied loading and confirmation that individual and total applied loads are correct;
- Plots and results that demonstrate the correct behaviour of the structural model in response to the applied loads;
- Summaries and plots of deflections;
- Summaries and sufficient plots from output to demonstrate that design criteria are not exceeded in any member;
- Result of plate buckling analysis;
- Tabulated results showing compliance with the design criteria;
- Proposed amendments to structure, where necessary, including revised assessment of stresses and buckling properties.
Chapter 2:  
Finite Element Analysis

Section 1:  Finite element model
Section 2:  Boundary conditions
Section 3:  General load application
Section 4:  Assessment against acceptance criteria

■ Section 1: Finite element model

1.1 The three dimensional (3-D), finite element (FE) model is to represent the geometric shape of the single-skin or double-skin hatch cover as appropriate. The following structural members and attachments are to be represented in the model:

- Top plate and secondary stiffeners;
- Longitudinal and transverse girders;
- Bottom plate and secondary stiffeners, where applicable;
- Skirt plate and supporting brackets;
- Hinges in folding type hatch covers. These may be represented as rigid links which tie together displacements in the Z direction. Alternative modelling methods may also be used to achieve this objective.

1.2 The FE model is to be defined using a Right Handed Cartesian coordinate system (see Figure 2.1.1) with:

- the X-axis measured in the longitudinal direction, positive forward;
- the Y-axis measured in the transverse direction, positive to port from the centreline;
- the Z-axis measured in the vertical direction, positive upwards.

1.3 The idealisation may represent a quarter or half of the hatch cover providing the structure and the applied loads are symmetrical about the appropriate longitudinal and/or transverse centrelines. The properties of elements located on the boundaries representing lines of symmetry are to be halved and the symmetry boundary conditions specified in Section 2 of this Chapter are to be applied. Figure 2.1.1 shows a quarter hatch cover idealisation.

1.4 All plating, including webs and face plates of girders, is to be represented by linear shell elements of constant thickness with bi-axial in-plane stiffness and out-of-plane bending stiffness. Triangular elements are to be avoided where possible.

1.5 Secondary stiffeners, depending on their type and complexity, may be modelled using beam or plate elements. Where beam elements are used, these are to be positioned in the plane of the plating and are to have:

- Cross-sectional area representing the stiffener area, excluding the area of attached plating;
- Bending properties representing the combined attached plating and stiffener inertia.

1.6 The webs of the primary girders are to be represented by at least three elements in the depth. Asymmetrical face plates of primary girders are to be represented by at least three elements across the breadth. A uniform mesh following the stiffening arrangement is to be maintained where possible.

1.7 The aspect ratio of quadrilateral plate elements should not exceed 3:1. Triangular and distorted quadrilateral elements with corner angles less than 60 degrees and greater than 120 degrees are to be avoided.
1.8 Depend on the loading applied and the ship type being examined, the FE model may be based on net thickness or gross thickness. Specific details are given in Table 2.1.1. Where a net thickness FE model is used in the analysis, the required thickness of plating or stiffeners is the net thickness plus a corrosion addition given in Tables 2.1.2, 2.1.3 and 2.1.4.

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Ship Type</th>
<th>FE model</th>
<th>Corrosion addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part A</td>
<td>CSR Bulk Carriers</td>
<td>Net thickness</td>
<td>As given in Table 2.1.2.</td>
</tr>
<tr>
<td>Part A</td>
<td>Other ship types including non CSR bulk carriers</td>
<td>Gross thickness</td>
<td>NA</td>
</tr>
<tr>
<td>Part B</td>
<td>All ship types</td>
<td>Net thickness</td>
<td>As given in Tables 2.1.2, 2.1.3 and 2.1.4, as appropriate for the ship type and configuration</td>
</tr>
</tbody>
</table>

### Table 2.1.1 Plate thickness to be used in finite element models

#### Table 2.1.2 Corrosion allowance, $t_c$, for steel hatch covers on bulk carriers, ore carriers and combination carriers

<table>
<thead>
<tr>
<th>Hatch Cover Type</th>
<th>$t_c$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Single skin</td>
<td>2.0</td>
</tr>
<tr>
<td>(b) Double skin</td>
<td></td>
</tr>
<tr>
<td>(i) top and bottom plate</td>
<td>2.0</td>
</tr>
<tr>
<td>(ii) internal structures</td>
<td>1.5</td>
</tr>
</tbody>
</table>

#### Table 2.1.3 Corrosion allowance, $t_c$, for steel hatch covers on cellular cargo holds intended for the carriage of containers

<table>
<thead>
<tr>
<th>Hatch Cover Type</th>
<th>$t_c$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Single skin</td>
<td>1.0</td>
</tr>
<tr>
<td>(b) Double skin</td>
<td></td>
</tr>
<tr>
<td>(i) top and bottom plate</td>
<td>1.0</td>
</tr>
<tr>
<td>(ii) internal structures</td>
<td>1.0</td>
</tr>
</tbody>
</table>

#### Table 2.1.4 Corrosion allowance, $t_c$, for steel hatch covers on other ship types

<table>
<thead>
<tr>
<th>Hatch Cover Type</th>
<th>$t_c$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Single skin</td>
<td>2.0</td>
</tr>
<tr>
<td>(b) Double skin</td>
<td></td>
</tr>
<tr>
<td>(i) top and bottom plate</td>
<td>1.5</td>
</tr>
<tr>
<td>(ii) internal structures</td>
<td>1.0</td>
</tr>
<tr>
<td>(c) Tween Deck Hatch Covers</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Section 2: Boundary conditions

2.1 The boundary conditions to be applied for the PART A and PART B assessments are to be in accordance with this Section (see also Figure 2.2.1).

2.2 Boundary nodes in way of bearing pads on the hatch coamings are to be fixed against displacement in the vertical direction (i.e. $\delta_z = 0$).
2.3 At boundary nodes in way of lifting stoppers and wedges, predetermined Z direction displacements are to be imposed to reflect anticipated maximum clearances between the cover and the stoppers.

2.4 Ground springs are to be used to represent cleats which are designed to secure a hatch cover under internal pressure. The spring constant should be provided by the manufacturers for the type and arrangement of the cleat considered.

2.5 On model boundaries representing lines of symmetry, the following conditions are to be applied:

- For symmetry of the hatch cover about the centreline in the Y direction, rotations about the Y and Z axes and the displacement along the X axis are to be constrained (i.e. $\theta_y = \theta_z = 0$ and $\delta_x = 0$);
- For symmetry of the hatch cover about the centreline in the X direction, rotations about the X and Z axes and displacement along the Y axis are to be constrained (i.e. $\theta_x = \theta_z = 0$ and $\delta_y = 0$).

![Figure 2.2.1 Typical boundary conditions on a quarter finite element model of a hatch cover](image)

**Note:** At grid points in way of bearing pads: $\delta_z = 0$

### Section 3: General load application

3.1 The application of loads to the finite element model is to be in accordance with Ch 3 for the PART A assessment and Ch 4 for the PART B assessment.

3.2 The weight of the hatch cover structure is to be included in the analysis.
Section 4: Assessment against acceptance criteria

4.1 Results from the finite element analysis are to be assessed against the permissible deflection, membrane stress and buckling criteria specified in Ch 3 for the PART A assessment and in Ch 4 for the PART B assessment.

4.2 Membrane stresses are to be determined at the centroid and at the middle plane of shell elements.

4.3 The procedure to be used for assessing the buckling capability of panels depends on the ship type under consideration. Details are given in Table 2.4.1.

4.4 Buckling strength assessment of plate panel is to be based on net thickness; the appropriate corrosion addition, \( t_c \), is identified in Table 2.4.2. In addition, For cases where the finite element model is based on gross scantlings as specified in Table 2.1.1, the applied stresses are to be factored by the ratio \( t/(t-t_c) \) for the buckling check.

4.5 The buckling factor of safety, \( \lambda \), is defined as the ratio of the critical buckling stress to the applied stress.

4.6 When the elastic critical buckling stress, \( \sigma_c \), exceeds 50% of the specified minimum yield stress, \( \sigma_o \), the buckling stress is to be adjusted for effects of plasticity using the Johnson-Ostenfeld correction formula given below:

\[
\sigma_{cr} = \sigma_c \left( 1 - \frac{\sigma_c}{4\sigma_o} \right)
\]

where:

\( \sigma_{cr} \) = critical buckling stress corrected for plasticity effects
\( \sigma_c \) = elastic critical buckling stress
\( \sigma_o \) = specified minimum yield stress of material

Table 2.4.1 Applicable panel buckling assessment procedures for ship types

<table>
<thead>
<tr>
<th></th>
<th>Uniaxial buckling (see Note 1)</th>
<th>Shear buckling</th>
<th>Biaxial buckling</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSR bulk carriers</td>
<td>Chapter 9, Section 5, 5.2.3 of CSR for Bulk Carriers</td>
<td>Chapter 9, Section 5, 5.4.6 of CSR for Bulk Carriers</td>
<td>Chapter 6, Section 3.2 of CSR for Bulk Carriers</td>
</tr>
<tr>
<td>Other ship type including non CSR bulk carriers</td>
<td>Pt 3, Ch 11, Table 11.2.1 and Pt 3, Ch 4, Table 4.7.2 of the Rules for Ships</td>
<td>Pt 3, Ch 4, Table 4.7.2 of the Rules for Ships</td>
<td>See Notes 1, 2 and 3</td>
</tr>
</tbody>
</table>

Notes:

1. For calculating the elastic critical buckling stress of plate panels loaded in compression on the longer edge, the edge restraint factor, \( (\nu) \), defined in Pt 3, Ch 4.7 of the Rules for Ships may be taken into account. This factor may not be used in the calculation of critical buckling stress for compression applied on the shorter edge.

2. Biaxial buckling assessment of plate panels is to include the effects of bi-axial compressive stress, shear stress and 'in-plane' bending stress. In general, the average stresses acting within the plate panel are to be used for the buckling calculation.

3. It is recommended that Lloyd’s Register’s software be used for the calculation of the buckling factor of safety. This computer program incorporates the correction factor identified above.
Table 2.4.2 Corrosion addition thickness to be applied in buckling strength assessment

<table>
<thead>
<tr>
<th>Hatch cover type</th>
<th>( t_c ) mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hatch covers on bulk carriers, ore carriers and combination carriers</td>
<td>See Table 2.1.2</td>
</tr>
<tr>
<td>Hatch covers on cellular cargo holds intended for the carriage of containers</td>
<td>See Table 2.1.3</td>
</tr>
<tr>
<td>Hatch covers on other ship types</td>
<td>See Table 2.1.4</td>
</tr>
</tbody>
</table>
Chapter 3:  
PART A Assessment: Hatch Covers supporting Containers and other Cargo Loads

Section 1: Objectives
1.1 Assessment of the strength capability of steel hatch covers under container and other cargo loads, including internal pressure loads, is to be in accordance with the requirements in this Chapter.

1.2 The assessment is to verify compliance with the acceptance criteria given in Section 5 for the loading specified in Section 3.

Section 2: Finite element model
2.1 The finite element model is to be developed in accordance with the requirements given in Chapter 2, Section 1.

Section 3: Loads
3.1 In addition to the requirements in Chapter 2, Section 3, the loads described in this Section are to be applied.

3.2 Container stack loads are to be derived based on standard 20ft and/or 40ft containers as appropriate to the design requirements. The following load cases are to be analysed, depending on the hatch cover type (see Pt 4, Ch 8, Tables 8.11.1, 8.11.2 and Fig.8.11.1 of the Rules for Ships):
- Container static upright load normal to the hatch cover top plating;
- Container static heeled load normal to the hatch cover top plating at a 30 degrees roll angle.

3.3 Container stack loads are to be applied at the container foundations in accordance with Pt 4, Ch 8, Fig. 8.11.1 and Table 8.11.2 of the Rules for Ships. These loads are to be applied as point loads at appropriately located grid points in the finite element model.

3.4 The magnitudes of container stack loads for the container static heeled load case are to be derived based on the most onerous stack weight combination, see Pt 4, Ch 8, Table 8.11.2 of the Rules for Ships.

3.5 Internal pressure resulting from ballast in holds and from other cargo loads on hatch covers are to be defined as point or uniformly distributed loads as appropriate, in accordance with the Rules for Ships.

3.6 For CSR bulk carriers, the internal pressure resulting from ballast in holds and pressure due to uniform cargoes (e.g. timber) is to be determined in accordance with Chapter 9, Section 5,
4.1.3 and 4.1.4 of the CSR for Bulk Carriers. Special consideration will be given to hatch covers intended to support containers and special cargoes (e.g. pipes etc.) which may temporarily retain water during navigation.

■ **Section 4: Boundary conditions**

4.1 The application of boundary conditions to the finite element model is to be in accordance with Chapter 2, Section 2.

■ **Section 5: Acceptance criteria**

5.1 Stress levels, buckling factors of safety and primary girder deflections are to comply with the acceptance criteria given in Tables 3.5.1 and 3.5.2.

5.2 Deflections are to be evaluated in way of longitudinal and transverse girders.

5.3 Evaluation of membrane stresses is to be in accordance with requirements given in Chapter 2, Section 4.

5.4 The approaches to be used for assessing the buckling capability of plate panels and for determining the buckling factors of safety are to be in accordance with Chapter 2, Section 4 and Tables 3.5.1 and 3.5.2.
Table 3.5.1 Acceptance criteria for PART A assessment: (hatch covers under container and other cargo loads) for all ship types other than CSR bulk carriers

<table>
<thead>
<tr>
<th>Load case</th>
<th>Permissible membrane stresses</th>
<th>Permissible deflection (mm)</th>
<th>Buckling factor of safety $(\lambda)$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct stress $(N/mm^2)$</td>
<td>Shear stress $(N/mm^2)$</td>
<td>$0.0035 l_o$ Note 1</td>
</tr>
<tr>
<td>Container Load – Static Upright</td>
<td>0.50 $\sigma_o$</td>
<td>0.29 $\sigma_o$</td>
<td>0.0035 $l_o$ Note 1</td>
</tr>
<tr>
<td>Container Load – Static Heeled</td>
<td>0.70 $\sigma_o$</td>
<td>0.42 $\sigma_o$</td>
<td>Note 2</td>
</tr>
<tr>
<td>Timber cargo</td>
<td>0.50 $\sigma_o$</td>
<td>0.29 $\sigma_o$</td>
<td>$0.0035 l_o$ Note 1</td>
</tr>
<tr>
<td>Internal pressure load</td>
<td>0.50 $\sigma_o$</td>
<td>0.29 $\sigma_o$</td>
<td>0.0020 $l_o$</td>
</tr>
</tbody>
</table>

Symbols

$l_o$ = unsupported span in (mm)

$\sigma_o$ = specified minimum yield stress of material but not to be taken greater than 355N/mm², see Pt 3, Ch 2, 1.2.3 of the Rules for Ships

Notes

1. For hatch covers of container ships of which the particulars are in compliance with Pt 3, Ch 11, 2.2.5 of the Rules for Ships, a relaxation in deflection criterion may be considered on a case-by-case basis.
2. When the deflection exceeds 0.0045 $l_o$, the ultimate strength of the hatch cover is to be specially considered.
3. No allowance is to be given for the effect of cargo securing loads.
4. Container load-static heeled load case is not required for Type I hatch covers, see Pt 4, Ch 8, 11 of the Rules for Ships.
5. Direct and shear stresses are to be taken as element axial and shear stresses in accordance with the X, Y and Z axes specified in Chapter 2, 1.2.
### Table 3.5.2 Acceptance criteria for PART A assessment:
(hatch covers under containers and other cargo loads) for CSR bulk carriers

<table>
<thead>
<tr>
<th>Load case</th>
<th>Permissible membrane stresses</th>
<th>Buckling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct stress</td>
<td>Uniaxial and shear buckling</td>
</tr>
<tr>
<td></td>
<td>Shear stress</td>
<td>Bi-axial buckling</td>
</tr>
<tr>
<td>Internal ballast pressure and pressure due to uniform cargoes, see Note 1.</td>
<td>See Note 2</td>
<td>See Note 3</td>
</tr>
</tbody>
</table>

**Notes**

1. Refer to Chapter 9, Section 5, 4.1 of **CSR for Bulk Carriers**. Special consideration will be given to hatch covers intended to support containers and special cargoes (e.g. pipes etc.) which may temporarily retain water during navigation, see 3.6.
2. Refer to Chapter 9, Section 5, 1.5 of **CSR for Bulk Carriers**.
3. Refer to Chapter 9, Section 5, 5.2.3 of **CSR for Bulk Carriers**.
4. Refer to Chapter 6, Section 3, 3.2 of **CSR for Bulk Carriers**.
5. No allowance is to be given for the effect of cargo securing loads.
6. Direct and shear stresses are to be taken as element axial and shear stresses in accordance with the X, Y and Z axes specified in Chapter 2, 1.2.
Chapter 4:  
Part B Assessment: Hatch Covers supporting Loadline Weather Loads

**Section 1: Objectives**

1.1 Assessment of the capability of steel hatch covers under weather loads is to be in accordance with the requirements in this Chapter.

1.2 The assessment is to verify compliance with the acceptance criteria given in Section 5 for the loading specified in Section 3.

**Section 2: Finite element model**

2.1 The finite element model is to be developed in accordance with the requirements given in Chapter 2, Section 1.

**Section 3: Loads**

3.1 In addition to the requirements of Chapter 2, Section 3, the loads described in this Section are to be applied.

3.2 Loadline weather loads are given in Pt 3, Ch 11, 1.2.1 and 2.2.5 of the Rules for Ships and in Chapter 9, Section 5, 4.1.2 and Chapter 4, Section 5, 2.2 of CSR for Bulk Carriers.

3.3 The weather load is to be applied to the top plate of the hatch cover as a uniform pressure. The pressure is to be calculated at the longitudinal position of the hatch cover mid-length.

**Section 4: Boundary conditions**

4.1 The application of boundary conditions to the finite element model is to be in accordance with Chapter 2, Section 2.

**Section 5: Acceptance criteria**

5.1 Stress levels, buckling factors of safety and primary girder deflections are to comply with the acceptance criteria specified in Table 4.5.1.

5.2 Deflections are to be evaluated in way of longitudinal and transverse girders.

5.3 The evaluation of membrane stresses is to be in accordance with requirements given in Chapter 2, Section 4.
5.4 The approaches to be used for assessing the buckling capability of panels and for determining the buckling factors of safety are to be in accordance with Chapter 2, Section 4 and Table 4.5.1.

Table 4.5.1 Acceptance criteria for PART B assessment: hatch covers under loadline weather loads

<table>
<thead>
<tr>
<th>Hatch cover type</th>
<th>Permissible membrane stresses</th>
<th>Permissible deflection (mm)</th>
<th>Buckling factor of safety ($\lambda$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct stress (N/mm²)</td>
<td>Shear stress (N/mm²)</td>
<td>Uniaxial and shear buckling</td>
</tr>
<tr>
<td>Steel weathertight covers</td>
<td>0.8 $\sigma_o$</td>
<td>0.46 $\sigma_o$</td>
<td>1.25 (See Note 2 for CSR bulk carriers)</td>
</tr>
</tbody>
</table>

Symbols

$l_o = \text{unsupported span in (mm)}$

$\sigma_o = \text{specified minimum yield stress of material but not to be taken greater than } 355\text{N/mm}^2$, see Pt 3, Ch 2, 1.2.3 of the *Rules for Ships*. For CSR bulk carriers, see Chapter 3, Section 1, 2.1.1, Table 1 of *CSR for Bulk Carriers*.

Notes

1. Direct and shear stresses are to be taken as element axial and shear stresses in accordance with the X, Y and Z axes specified in Chapter 2, 1.2.
2. For CSR bulk carriers, refer to Chapter 9, Section 5 and Chapter 6, Section 3 of *CSR for Bulk Carriers*. ($\lambda = 1.25$ is not applied in the context of these Rules).
3. For CSR bulk carriers, refer to Chapter 6, Section 3, 3.2.4 of *CSR for Bulk Carriers*. ($\lambda = 1.1$ is not applied in the context of these Rules).