CI-T 1 (Mar. 2008)

# Buckling assessment of corrugated bulkheads

**Rule Section**

| | |
|---|---|
| 9/2.2.5 | Acceptance Criteria |
| Table 9.2.2 | Maximum Permissible Utilisation Factor against Buckling |
| 10/3.2 | Buckling of plates |
| Table 10.3.1 | Buckling Factor and Reduction Factor for Plane Plate Panels |
| 10/3.5.1 | Struts, pillars and cross ties |
| 10/3.5.2 | Corrugated bulkheads |
| B/2.7.3.7 | Buckling assessment |

**Description**

Procedure and specific instructions for the buckling assessment of corrugated bulkheads in cargo tank FE analysis.

**Common Procedure**

**1. General**

In the absence of suitable advanced buckling method, the following two buckling modes are to be assessed on vertically or horizontally corrugated longitudinal or transverse bulkheads in accordance with 9/2.2.5 (Table 9.2.2) and 10/3.5.2:

**A. Corrugation flange panel buckling (refer to 9/2.2.5, 10/3.5.2.1, B/2.7.3.7):**

Local buckling of flange panel of corrugated bulkheads is to be checked for uni-axial plate buckling using Case 1 in Table 10.3.1 with applying stress ratio $\psi = 1.0$ (i.e. constant applied stress) and the criteria given in 9/2.2.5 (Table 9.2.2).

**B. Corrugation overall column buckling (refer to 9/2.2.5 and 10/3.5.2.2):**

Corrugated bulkheads subjected to axial compression is to be checked for overall column buckling failure mode in accordance with 10/3.5.1 and the criteria given in 9/2.2.5 (Table 9.2.2).

Application of buckling assessment to corrugated bulkheads:

<table>
<tr><th rowspan="2"></th><th colspan="2">Corrugation orientation</th></tr>
<tr><th>Horizontal</th><th>Vertical</th></tr>
<tr><td>Longitudinal bulkhead</td><td>Required</td><td rowspan="2">Required, only if subject to localised vertical forces</td></tr>
<tr><td>Transverse bulkhead</td><td>Required</td></tr>
</table>

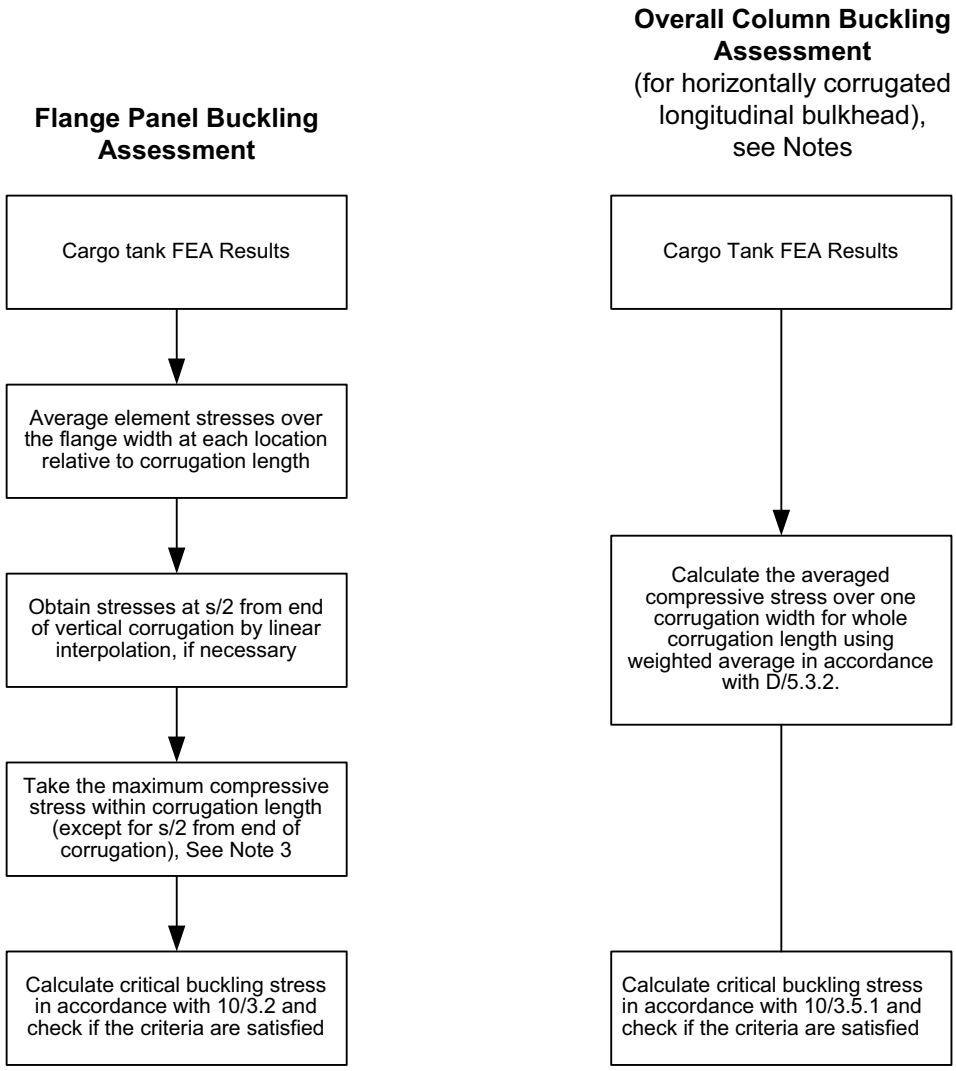
## 2. Procedure

- Overall procedure of each buckling assessment is indicated in Figure PR1.
- Details of each buckling assessment are summarized in Table PR1.
- Example procedure of averaging and interpolation of element stresses for flange panel buckling on vertically corrugated bulkhead is indicated in Figure PR2.

The buckling assessments are to be done for all corrugation units subjected to compressive forces and for all applicable load cases.

**Figure PR1**

Flow Chart of Buckling Assessment of Corrugated Bulkheads




Notes:

1. Column buckling assessment is not necessarily required for vertically corrugated bulkheads not subjected to localised vertical forces.
2. For vertically corrugated bulkheads subjected to localised vertical forces (e.g. crane loads), working compressive forces may be obtained by hand calculation and need not be based on FE analysis.
3. Where more than one panel thicknesses are used, each panel thickness is to be checked with the maximum stress within each thickness range.

**Table PR1** Summary Details of Buckling Assessments for Corrugated Bulkheads

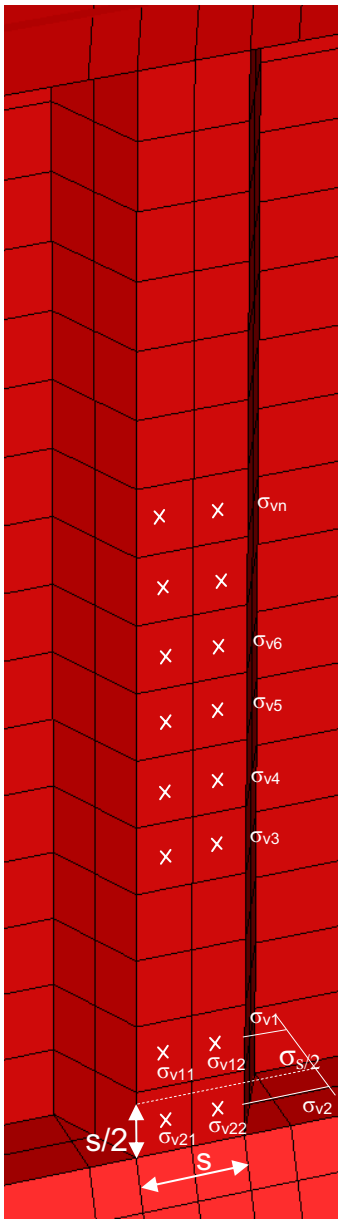
| | **Failure mode** | **Flange Panel Buckling** | **Overall Column Buckling, see Note 1** |
|---|---|---|---|
| **1** | **Application** | Applicable to all corrugation flanges | See page 1 item B. |
| **2** | **Structural model to be assessed** | Each corrugation flange panel.<br>Where more than one plate thicknesses are used for flange panel, maximum stress is to be obtained for each thickness range and to be checked with the buckling criteria for each thickness. | Each corrugation unit (one corrugation space), i.e.<br>half flange + web + half flange |
| **3** | **Stress Type** | Membrane stress at element centroid | Membrane stress at element centroid |
| **4** | **Direction of stresses** | Stress component parallel to corrugation knuckles<br>Buckling mode for stresses perpendicular to corrugation knuckles is not considered critical, and is not required. | Stress component parallel to corrugation knuckles |
| **5** | **Location of stresses to be used** | For corrugation flange inside or at s/2 (s=breadth of the flange) from ends of corrugation, stresses obtained from FE analysis are to be used.<br>For corrugation flange within s/2 from each end of corrugation span, stress can be taken as equal to values at s/2.<br>See Figure PR2 | Stresses within one corrugation space:<br>half flange + web + half flange<br>for whole corrugation span (including locations withins/2 from the ends). |
| **6** | **Averaging stresses - perpendicular to corrugation knuckles** | Averaging may be done over the flange width.<br>See Figure PR2. | Averaging is to be done over one corrugation space, i.e.,<br>half flange + web + half flange<br>for whole corrugation span including for s/2 from the ends (this is a simplification of the process assuming that impact of possible high stresses at ends after the averaging over whole corrugation is negligible)<br>Use weighted average in accordance with D/5.3.2 where element sizes are different and subjected to compressive and tensile stresses. |
| **7** | **Averaging stresses - parallel to corrugation knuckles** | Averaging is NOT to be done.<br>See Figure PR2. | |

| | Failure mode | Flange Panel Buckling | Overall Column Buckling, see Note 1 |
|---|---|---|---|
| 8 | **Final stresses to be used for buckling criteria** | Maximum average compressive stress (average stress calculated as per above 6) except within s/2 from each end of corrugation span (s = breadth of the flange)<br>Where stress at s/2 cannot be obtained directly from a plate element, the stress at s/2 is to be obtained by linear interpolation of centroid stress from neighbour elements. Stress at a location within s/2 is to be taken as the average compressive stress at s/2.<br>Where more than one panel thicknesses are used within a flange panel, maximum stress within each thickness range is to be used. | Averaged compressive stress as per above 6 and 7 |
| 9 | **Critical buckling stress** | Table 10.3.1, Case 1 with applying stress ratio ψ = 1.0 is to be used (uni-axial compression).<br>Where more than one panel thicknesses are used, each panel thickness is to be checked with the maximum stress within each thickness range. | Column buckling in accordance with 10/3.5.1.3 is to be assessed.<br>Torsional buckling as per 10/3.5.1.4 and 10/3.5.1.5 need not be assessed.<br>Effect of bending due to lateral pressure may be ignored.<br>Where web or flange thickness varies along the corrugation length, the section of the least buckling strength is to be used. |
| 10 | **Utilisation factors** | Section 9/2.2.5 (Table 9.2.2) “flange buckling”, i.e.<br>S+D: 0.9, S: 0.72 | Section 9/2.2.5 (Table 9.2.2) “column buckling”, i.e.<br>S+D: 0.9, S: 0.72 |

**Note**

Working compressive force of localised vertical forces (e.g. crane loads) for overall column buckling assessment of vertically corrugated bulkheads may be obtained by hand calculation and need not be based on FE analysis. For such case, end constraint factor corresponding to pinned end is to be applied except that fixed end may be applied where stool with width exceeding 2 times the depth of corrugation is fitted or where corrugation is directly connected to the inner bottom without lower stool.

**Figure PR2**
Averaging and Linear Interpolation of Element Stresses for
Flange Panel Buckling of Vertically Corrugated Bulkhead




- Averaging element stresses in direction perpendicular to corrugation knuckles is to be done first over the flange width.
- Averaging element stresses in direction parallel to corrugation knuckles is NOT to be done.
- The "interpolation" is to be applied where the stress value at s/2 from lower end cannot be obtained directly from an element.
- After averaging the stresses over the flange width, and after obtaining the stress at s/2 from lower end, the maximum stress is to be used for compliance with the buckling criteria.
- Where more than one plate thicknesses are used for flange panel, maximum stress is to be obtained for each thickness range and to be checked with the buckling criteria for each thickness.

$\sigma_{V11}$, $\sigma_{V12}$, $\sigma_{V21}$, $\sigma_{V22}$: vertical membrane stress evaluated at element centroid;

$\sigma_{V1}$ : average stress from $\sigma_{V11}$ and $\sigma_{V12}$

$\sigma_{V2}$ : average stress from $\sigma_{V21}$ and $\sigma_{V22}$

$\sigma_{s/2}$ : stress at s/2 obtained by linear interpolation between $\sigma_{V1}$ and $\sigma_{V2}$

$\sigma_{V3}$, $\sigma_{V4}$, $\sigma_{V5}$, $\sigma_{V6}$,… , $\sigma_{Vn}$: average vertical flange stresses

$\sigma_{final} = \max(\sigma_{s/2}, \sigma_{V3}, \sigma_{V4}, \sigma_{V5}, \sigma_{V6}, \ldots, \sigma_{Vn})$

**Implementation date**

This CI is effective from 1 April 2008.

**Background**

The requirements of the buckling assessments for corrugated bulkheads in cargo tank FE analysis are particularly given in 10/3.5.2 and B/2.7.3.7 with the additional explanations in the corresponding background documents. However, the information contained in the rules and the background document does not fully address the detailed procedure of the buckling assessment particularly with regard to the location to be taken and the averaging procedure of the element stresses from the results of the FE analysis for each buckling mode. This procedure is prepared to summarize the procedures and to provide more clarifications of the buckling assessments of corrugated bulkheads.