Geometric Stress Concentrations
Factors for Classified Details

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GEOMETRIC STRESS CONCENTRATION

FACTORS FOR CLASSIFIED DETAILS

by

OFFSHORE DIVISION
Lloyd's Register of Shipping
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1.0 INTRODUCTION

The primary purpose of this document is to provide information for the determination of geometric stress concentration factors for classified details. This report includes information relating to structural features commonly found in fatigue prone areas of both semi-submersible units and fixed platform installations.

The fatigue life aspect is a very important design consideration for offshore structures. With respect to semi-submersibles, fatigue cracking is relatively common, even in modern units. The cracks are generally found to have initiated at points of stress concentrations which may be due to design deficiencies and/or poor workmanship.

In general, any discontinuity in a stressed structure results in a local increase in stress at the discontinuity. The ratio of the peak stress at the discontinuity to the nominal average stress that would prevail in the absence of the discontinuity is commonly referred to as the stress concentration factor (SCF).

The peak stress (i.e. nominal stress x SCF) is normally used in conjunction with an appropriate S-N curve to derive the estimated fatigue life.

For jacket type structures, the most fatigue prone areas are the tubular brace to chord connections (i.e. nodal joints). For these joints a large amount of data exists for determining the SCFs (e.g. parametric equations). These connections have been excluded from this document as they are specifically addressed in references 28 and 27.

For semi-submersibles, experience has shown that the areas of minimum fatigue life are usually found at the joints, stiffener terminations, penetrations in primary bracings and also at their junctions with hulls, columns and decks. Some of these features also exist on jacket type structures and there is a general lack of information on the appropriate SCFs.

The design weld S-N curves for classified details are widely published and are included in the Department of Energy's "Offshore Installations: Guidance on design and construction" document for particular weld arrangements.

The guidance notes often recommend the inclusion of a geometric SCF, however, only very limited information on appropriate values for these are included.

The Department of Energy Review Panel on Fatigue Guidance has included a new S-N curve in the Guidance Notes to cover most classified details. The implications of this new 'P' S-N curve have been included in the relevant sections of this document.

Clearly there has been a need to collate the available information on stress concentration factors for the various classified details.

The contents of this document are tailored to encourage designers to adopt or generate local structural details which would lead to improved fatigue performance in service.
A review of published and Lloyd's Register data has been undertaken to obtain information on geometric stress concentration factors for certain common structural details which are considered to be important with respect to fatigue. The relevant information has been extracted to provide guidance on stress concentration factors for typical arrangements.

The guidance given is applicable for overall axial and bending loading only.

This document is intended to be used in conjunction with weld classifications contained in HSE Guidance, which is a revision of section A21.2.12(a) and A21.2.13 of the 4th edition D.En Guidance Notes. In addition the W curve is revised to W', and has a new factor with reference to the P curve, for weld throat failure.

A list of references has been included (see Section 18).

No new finite element work has been undertaken during this study, however the results from some previous acrylic model tests and finite element analysis carried out by Lloyd's Register has been included. This work includes a reinforced brace penetration, a brace to column connection and a stiffener termination.

Those fatigue sensitive structural details where additional information is required to adequately determine SCFs have been highlighted and some recommendations regarding further study made in Section 19.
2.0 SUMMARY OF DETAILS INCLUDED

This section highlights typical structural details which are considered to be of importance from a fatigue life point of view. These have generally been taken from the results of a previous Lloyd's Register study published as a Department of Energy Offshore Technology Report. (reference 22).

The various structural details considered include items which have been relatively free from problems in-service in addition to those features which have proven to be prone to defects in-service.

Listed in Table 2.1 (see over) are fourteen common structural details / arrangements found on semi-submersible vessels and fixed platform installations together with the section numbers of this report where information on SCFs may be found. These features are subject to regular inspection during survey cycles.

The list given in Table 2.1 is not exhaustive but should cover most commonly found details.
### Table 2.1
Summary of details and report/section numbers

<table>
<thead>
<tr>
<th>Detail</th>
<th>Description</th>
<th>Report section no.</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><strong>Transverse/circumferential butt weld:</strong> In flat plates and tubular members. Welds essentially transverse to the direction of the applied stress</td>
<td>4</td>
</tr>
<tr>
<td><img src="image2" alt="Diagram" /></td>
<td><strong>Longitudinal butt welds:</strong> In welds essentially parallel to the direction of the applied stress</td>
<td>5</td>
</tr>
<tr>
<td><img src="image3" alt="Diagram" /></td>
<td><strong>Axial stiffener welds</strong></td>
<td>6</td>
</tr>
<tr>
<td><img src="image4" alt="Diagram" /></td>
<td><strong>Cope holes:</strong> In members welded parallel to the direction of the applied stress</td>
<td>7</td>
</tr>
<tr>
<td><img src="image5" alt="Diagram" /></td>
<td><strong>Circumferential butt welds:</strong> Between tubular and conical sections. Weld essentially transverse to the direction of the applied stress</td>
<td>8</td>
</tr>
<tr>
<td><img src="image6" alt="Diagram" /></td>
<td><strong>Bracing diaphragm or ring stiffener welds</strong></td>
<td>9</td>
</tr>
<tr>
<td><img src="image7" alt="Diagram" /></td>
<td><strong>Welded attachments:</strong> On the surface of a stressed member</td>
<td>10</td>
</tr>
<tr>
<td>Detail</td>
<td>Description</td>
<td>Report section no.</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>-------------------</td>
</tr>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td>Ring reinforced penetration Through wall of bracing</td>
<td>11</td>
</tr>
<tr>
<td><img src="image2" alt="Diagram" /></td>
<td>Penetration in flat plate</td>
<td></td>
</tr>
<tr>
<td><img src="image3" alt="Diagram" /></td>
<td>Gusset stiffener end Smooth profile (weld toe ground). Abrupt profile.</td>
<td>12</td>
</tr>
<tr>
<td><img src="image4" alt="Diagram" /></td>
<td>Gusset stiffener: Terminating at a ring stiffener or diaphragm</td>
<td>13</td>
</tr>
<tr>
<td><img src="image5" alt="Diagram" /></td>
<td>Column to pontoon deck joint</td>
<td>14</td>
</tr>
<tr>
<td><img src="image6" alt="Diagram" /></td>
<td>Bracing to column joints: Full penetration welds</td>
<td>15</td>
</tr>
<tr>
<td><img src="image7" alt="Diagram" /></td>
<td>Bracing to bracing joints: Both with and without stiffening</td>
<td>16</td>
</tr>
<tr>
<td><img src="image8" alt="Diagram" /></td>
<td>Cruciform joint</td>
<td>17</td>
</tr>
</tbody>
</table>
3.0 S-N CURVE RELATIONSHIPS

3.1 FATIGUE LIFE RATIOS

From the equations and diagrams of the basic S-N curves as given in the Department of Energy Guidance Notes (Reference 1) fatigue life ratios have been derived for each S-N curve compared to the new reference 'P' curve. These are shown in Table 3.1.

Thus, for example, at a constant stress range (Sb) of 100 N/mm² the fatigue life obtained using the 'F' class S-N curve would be 0.414 times that obtained using the new 'P' S-N curve.

Note that factors for stress range account for the change in slope of the S-N curves at N = 10⁷ cycles

<table>
<thead>
<tr>
<th>S-N curve</th>
<th>Stress range (Sb) N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
</tr>
<tr>
<td>B</td>
<td>95.4</td>
</tr>
<tr>
<td>C</td>
<td>12.3</td>
</tr>
<tr>
<td>D</td>
<td>1.0</td>
</tr>
<tr>
<td>E</td>
<td>0.54</td>
</tr>
<tr>
<td>F</td>
<td>0.23</td>
</tr>
<tr>
<td>F2</td>
<td>0.12</td>
</tr>
<tr>
<td>G</td>
<td>0.049</td>
</tr>
<tr>
<td>W</td>
<td>0.024</td>
</tr>
</tbody>
</table>

3.2 ADDITIONAL FACTORS

Some other additional fatigue life ratios have been determined to illustrate the effect of using the different S-N curves and these are given in Table 3.2 below.

For example the fatigue life obtained using the 'E' class S-N curve would be 1.652 times that obtained using the 'F' S-N curve.

<table>
<thead>
<tr>
<th>S-N curve ratio</th>
<th>Fatigue life ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>F/F2</td>
<td>1.463</td>
</tr>
<tr>
<td>E/F</td>
<td>1.652</td>
</tr>
<tr>
<td>E/F2</td>
<td>2.417</td>
</tr>
</tbody>
</table>
3.3 USE OF THE SINGLE NEW 'P' S-N CURVE

This is only feasible where the slopes of all the existing S-N curves are the same. The 'B' and 'C' curves do not have a single conversion factor unlike the D to W curves. (See also Table 3.1).

However these curves have now been modified such that their slopes are the same as the new 'P' curve, thus conforming in slope with the D to W curves.

Two key points may be defined for the new 'P' S-N curve
(1) change of slope from 3.0 to 5.0 at endurance cycles (N) = 10^7
(2) stress range (at N = 10^7) = 53.36 N/mm^2

The stress range values (S_0) for each S-N curve, at N = 10^7 cycles, given in the Guidance Notes (reference 1) are approximate. The actual (S_0) values are given for information in Table 3.3.

<table>
<thead>
<tr>
<th>S-N curve</th>
<th>Actual</th>
<th>G. Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>53.36</td>
<td>53</td>
</tr>
<tr>
<td>E</td>
<td>47.03</td>
<td>47</td>
</tr>
<tr>
<td>F</td>
<td>39.78</td>
<td>40</td>
</tr>
<tr>
<td>F2</td>
<td>35.03</td>
<td>35</td>
</tr>
<tr>
<td>G</td>
<td>29.23</td>
<td>29</td>
</tr>
<tr>
<td>W</td>
<td>25.19</td>
<td>25</td>
</tr>
</tbody>
</table>

Values of stress range factors for all existing S-N curves with reference to the new 'P' S-N curve are given in Table 3.4.

Example: if the 'P' class S-N curve is going to be used where previously the 'F' class S-N curve would have been used then an additional factor on the stress range (S_0) of 1.342 must be applied.

i.e. stress range ('P' curve) = nominal stress range x SCF x 1.341

<table>
<thead>
<tr>
<th>S-N curve</th>
<th>Stress range factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0.64</td>
</tr>
<tr>
<td>C</td>
<td>0.76</td>
</tr>
<tr>
<td>D</td>
<td>1.0</td>
</tr>
<tr>
<td>E</td>
<td>1.135</td>
</tr>
<tr>
<td>F</td>
<td>1.341</td>
</tr>
<tr>
<td>F2</td>
<td>1.523</td>
</tr>
<tr>
<td>G</td>
<td>1.826</td>
</tr>
<tr>
<td>W</td>
<td>2.118</td>
</tr>
</tbody>
</table>
4.0 TRANSVERSE / CIRCUMFERENTIAL BUTT WELD

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Sketch" /></td>
<td><img src="image" alt="Failure locations" /></td>
</tr>
</tbody>
</table>

4.1 S-N CURVES

The applicable S-N curve will depend on the type of weld used (see reference 1, Appendix A21).

For semi-submersible units in general only weld types corresponding to S-N curves 'C' to 'E' would normally be considered suitable for primary members. Welds made from one side, corresponding to S-N curves 'F' and 'P2', are not normal practice.

For fixed platform installations however, the applicable S-N curve may lie between 'C' and 'P2'. For a constant stress range of 100 N/mm² the fatigue lives determined using these S-N curves vary by a factor of around 10. This illustrates the importance of correct identification of the relevant S-N curve.

4.2 JOINT GEOMETRY

Four types of arrangement could normally be expected to define the range of joint geometries.

4.2.1 Equal plate thickness connection, no chamfer on parent metal. Joint may include allowable fabrication misalignment.
4.2.2 Unequal plate thickness connection, no chamfer on parent metal. Joint may include allowable fabrication misalignment.

\[ t_1 < t_2 \leq 1.15 \times t_1 \]

4.2.3 Unequal plate thickness connection, chamfer on thicker plate not to exceed slope of 1:3. Joint may include allowable fabrication misalignment.

\[ t_2 > 1.15 \times t_1 \]

4.2.4 Angular misalignment between flat plates

4.3 MISALIGNMENT

For tubular members the maximum fabrication axial misalignment for fatigue prone locations would normally be limited to the smaller of 0.1 x t or 3mm

where t = thickness of thinner plate.

The maximum angular misalignment would be limited to the smaller of .001 x length of member or 3mm.

(Taken from reference 24).
Table 4.1
Allowable misalignment for tubular member

<table>
<thead>
<tr>
<th>Thinner plate thickness (mm)</th>
<th>Allowable misalignment (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>&gt;40</td>
<td>3</td>
</tr>
</tbody>
</table>

In references 1 and 11 it is stated that nominal misalignments are included within the given S-N classifications, provided certain conditions are met. For initial design, however, it is recommended that, in the absence of specific data confirming this, the SCF should account for allowable fabrication misalignments.

4.4 STRESS CONCENTRATION FACTORS (FLAT PLATES ONLY)

Data has been obtained from references 3, 5, 6, 17, 28, 29, 30

These relate to failure location 1, see section 4.0. A general expression for axial misalignment is given in 4.4.1 for a specific set of boundary conditions. This has then been modified appropriate to the arrangements given in 4.2. Also given is an expression for angular misalignment between flat plates.

Figures 4.1 to 4.4 are given to illustrate the variation of SCF for each arrangement and figure 4.5 shows an effect of modifying the assumed boundary conditions.

It should be noted that for combined misalignments (e.g. axial and angular) that:

\[ \text{SCF (total)} = \text{SCF (axial)} + \text{SCF (angular)} - 1 \]

4.4.1 General expression (axial type loading)

\[ M = P \cdot e \]
\[ M = M_1 + M_2 \text{ (where } M_1 + M_2 \text{ are the moments in the plate at the weld.)} \]
\[ \text{Unit stress } = \sigma_{m1}, P = \sigma_{m1} \cdot t_1 \]
\[ M = (\sigma_{m1} \cdot t_1) \cdot e \]
The moment ratio at the connection depends on assumed boundary conditions, stiffness and length.

\[ M_1 = \frac{\left( \frac{I_1}{L_1} \right)}{\left( \frac{I_1}{L_1} + \frac{I_2}{L_2} \right)} \cdot M \]

setting \( L_1 = L_2 \)
and \( I_1 = t_1^3 \), \( I_2 = t_2^3 \) gives

\[ M_1 = \frac{t_1^3}{\left( t_1^3 + t_2^3 \right)} \cdot \sigma_{m1} \cdot t_1 \cdot e \]

Bending stress

\[ \sigma_{bl} = \frac{M_1 \cdot 6}{t_1^2} \]

dependence

\[ \sigma_{bl} = \frac{6 \cdot e}{t_1} \left( \frac{t_1^3}{t_1^3 + t_2^3} \right) \]

and

\[ SCF = 1 + \frac{6 \cdot e}{t_1} \left( \frac{t_1^3}{t_1^3 + t_2^3} \right) \]

4.4.2 Equal thickness with misalignment

For this case \( t_1 = t_2 = t \)
Substituting for \( t_1 \) and \( t_2 \) in SCF equation 4.4.1 gives,

\[ SCF = 1 + \frac{3 \cdot e}{t} \]
4.4.3 Unequal Thickness; No Misalignment

For this case \( e = (t_2 - t_1) / 2 \)
Substituting for 'e' in SCF equation 4.4.1 gives,

\[
SCF = 1 + \frac{3 \left( \frac{t_2}{t_1} - 1 \right)}{1 + \left( \frac{t_2}{t_1} \right)^3}
\]

4.4.4 Angular Misalignment

Assuming boundary conditions equivalent to:

**fixed ends**

\[
SCF = 1 + \frac{3y}{t} \left( \frac{\tanh \beta/2}{\beta/2} \right)
\]

**pinned ends**

\[
SCF = 1 + \frac{6y}{t} \left( \frac{\tanh \beta}{\beta} \right)
\]

where

\[
\beta = \frac{2L}{t} \sqrt{\frac{3\sigma}{E}}
\]

\( \sigma = \) nominal axial stress

\( E = \) Young's modulus
The tanh correction (in brackets) allows for reduction in angular misalignment due to straightening of joint under tensile loading. It is always \( \leq 1 \) and therefore usually conservative to ignore it. The exception is if when combined with axial misalignment the angular component has the effect of reducing the overall stress. Its effect is negligible for \( 2L/t < 10 \) and it is independent of the assumed end fixing condition for \( 2L/t > 100 \).

### 4.4.5 SCF Diagrams

The expressions in 4.4.1 to 4.4.3 above are in agreement with those given in reference 6. However the Welding Institute have suggested that the power index (\( n \)) of 3.0 is non-conservative and recommend replacing this by 1.5. (Welding Institute private communication).

In the absence of data justifying the use of an alternative value a power index of 1.5 should be used. The SCF diagrams given in the following figures, 4.2, 4.3 and 4.5, are based on an index of 1.5.

Four basic SCF plots are illustrated in the following figures.

- **Figure 4.1** Applies to axial misalignment of butt joints of equal thickness plates including a fabrication misalignment.

- **Figure 4.2** Applies to axial misalignment of butt joints of unequal plate thickness without misalignment.

- **Figure 4.3** Applies to axial misalignment of butt joints of unequal plate thickness including a fabrication misalignment.

- **Figure 4.4** Applies to angular misalignment of butt joints of equal thickness.

- **Figure 4.5** Illustrates effect of varying length ratio.
SCF = 1 + \frac{3e}{t}

e = \text{lessor of } 0.1 \times t \text{ or } 3\text{mm}

Figure 4.1
SCF for butt joint of equal plate thickness including fabrication misalignment
\[ SCF = 1 + \frac{3\left(\frac{t_2}{t_1} - 1\right)}{\left[1 + \left(\frac{t_2}{t_1}\right)^{1.5}\right]} \]

**Figure 4.2**

SCF for butt joints of unequal plate thickness without misalignment.
4.4.6 Effect of Length Ratio ($l_1/l_2$)

The cases illustrated in Figures 4.1 to 4.3 do not include any modifying effects due to varying length ratio, support conditions or tapering effects of thicker plate.

The basic SCF equation given in 4.4.3 is modified to

\[
SCF = 1 + 3 \left( \frac{t_2}{t_1} - 1 \right) f \left( 1 + \frac{t_2^{1.5}}{t_1^{1.5}} \right)
\]

where $f$ is a variable factor to account for length ratio and support conditions.

The example shown in figure 4.5 relates to a butt weld where the thicker plate has a 1:4 taper and is close to a fixed support. Based on a fixed beam study for $l_1/l_2 = 9$ a value of $f = 0.64$ is included. Note that 'n' has again been given a value of 1.5.
Figure 4.5
S.C.F for butt joints of unequal plate thickness without misalignment with varying length ratio.
4.5 STRESS CONCENTRATION FACTORS (TUBULAR MEMBERS)

Additional data has been obtained from references 11 and 23.

These relate to failure location 1, see section 4.0.

The expressions and SCFs developed for flat plates have been used previously for tubular members. As stated earlier it has been recommended that the power index 'n', see section 4.4.4, should be reduced from 3.0 to 1.5.

Data has been made available (Reference 23) giving thickness transition SCFs, for a range of D/t ratios, based on results from a series of 'BOSOR' analyses. These are given in Figure 4.6, for D/t ratios up to 60.

The following equation was stated by Earl & Wright to be conservatively fitted to the BOSOR results:

\[
St = 1.07 \left[ 1.0 + 0.1 \left( 3 + \frac{R}{10t_1} \right) \tanh \left( \left( \frac{t_2}{t_1} - 1 \right) \left( 3 + \frac{R}{10t_1} \right)^0.3 \right) \right]
\]

where \( St = \) SCF for thickness transition
\( t_1 = \) brace thickness
\( t_2 = \) stub thickness
\( R = \) brace radius

The total SCF should be obtained from the following expression:

\[ SCF = St \times Sm \]

Where \( St \) is given above

and

\[
Sm = 1.0 + \frac{6e}{t_1} \frac{1}{1 + \left( \frac{t_2}{t_1} \right)^{2.5}}
\]

\( e = \) mismatch

The value of \( n = 2.5 \) derived by Earl & Wright is consistent with that given in Ref.11 for tubular connections.

Note: Earl and Wright have assumed that the effect of mismatches resulting from normal fabrication practice are included in the S-N curves which are based on experimental test results from welded specimens.

However as given in 4.3 it is recommended that, for design, the SCF should account for allowable fabrication misalignment.

For \( D/t_1 \) ratios greater than 100 the SCF diagrams for flat plates (figures 4.1 to 4.4) may also be referred to.
$SCF = 1 + \frac{6 \epsilon}{t_1} \left( \frac{t_1^{1.5}}{t_1^{1.5} + t_2^{1.5}} \right)$

Ratio of plate thickness $t_2/t_1$

(e includes the lesser of $0.1 \times t_1$ or $3\text{mm}$)

Figure 4.3
SCF for Butt Joints of unequal plate thickness including fabrication misalignment
Figure 4.4
SCF for butt joints of equal thickness including angular misalignment
Figure 4.6
SCF in tubulars due to wall thickness transition
5.0 LONGITUDINAL BUTT WELD

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Sketch Diagram]</td>
<td>![Failure Locations Diagram]</td>
</tr>
</tbody>
</table>

5.1 S-N CURVES

The applicable S-N curve will depend on the type of weld used (See reference 1, Appendix A21).

For semi-submersible units in general only weld types corresponding to S-N curves 'B' to 'D' would normally be considered suitable for this location. Welds made from one side are not normal practice.

For fixed platform installations however the applicable S-N curve may lie between 'B' and 'E'. It is thus clearly important to identify correctly the relevant S-N curve (see also section 4.1).

5.2 STRESS CONCENTRATION FACTORS

In this case the stress distributions inherent in this type of welded joint are included in the classification assigned to the joint.

In general no additional geometric stress concentration factor would be required for this detail and the applied SCF may be taken to be 1.0.

If a gross geometric discontinuity exists in the region of the weld, e.g. a penetration or structural attachment, then an appropriate SCF should be determined to account for this. (See other sections).
6.0 AXIAL STIFFENER WELD

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Sketch" /></td>
<td><img src="image" alt="Failure Locations" /></td>
</tr>
</tbody>
</table>

6.1 S-N CURVES

The applicable S-N curve will depend on the type of weld used (See reference 1, Appendix A21). For normal fabrication when the weld may contain stop/start positions within the length the 'D' S-N curve is to be used. The S-N curve should be downgraded to 'E' for intermittent welding.

6.2 STRESS CONCENTRATION FACTORS

The stress distribution inherent in this type of welded joint are included in the classification assigned to the joint. In general no additional geometric stress concentration factor would be required for this detail and the applied SCF may be taken to be 1.0.

If a gross discontinuity exists in the region of the plate close to the weld, e.g. a penetration or structural attachment, then an appropriate SCF should be determined to account for this.

Discontinuities such as cope holes and stiffener terminations are specifically dealt with in later sections.
7.0 COPE HOLE

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure Locations</th>
</tr>
</thead>
</table>

7.1 S-N CURVES

For normal fabrication the 'F' class S-N curve is to be used (See reference 1, Appendix A21).

7.2 STRESS CONCENTRATION FACTORS

Data has been obtained from references 1, 3 and 30.

The presence of a standard small radius cope hole is allowed for in the joint classification given above.

Reference 1 recommends that in general no additional geometric stress concentration factor would be required for this detail and the applied S C F may be taken to be 1.0.

If a gross geometric discontinuity exists in the region of the weld, e.g. a penetration or structural attachment, then an appropriate S C F should be determined to account for this. (See other sections).

7.3 VARIATIONS

Several alternative arrangements are possible for this type of structural detail leading to various S-N curve - S.C.F. combinations.

7.3.1 Continuous welding containing stop/start positions:

Normal applicable S-N curve = 'D'
Nominal S C F = 1.0
7.3.2 Intermittent welding:

Normal applicable S-N curve = 'E'
Nominal SCF = 1.0

7.3.3 Continuous welding containing stop/start positions and small radius cope hole:

Normal applicable S-N curve = 'F'
Nominal SCF = 1.0

7.3.4 The implications of the above are:

(1) The effect of discontinuous welding is to downgrade the applicable S-N curve from 'D' to 'E'. Implied SCF = 1.135 (on the 'D' S-N curve).

(2) The effect of a small radiused cope hole with discontinuous welding is to downgrade the applicable S-N curve from 'E' to 'F'. Implied SCF = 1.18 (on the 'E' S-N curve).

(3) The effect of a small radiused cope hole with continuous welding is to downgrade the applicable S-N curve from 'D' to 'F'. Implied SCF = 1.341 (on the 'D' S-N curve).

7.4 POTENTIAL IMPROVEMENTS

7.4.1 Base Case: small radius cope hole, continuous welding

S-N curve = 'F'
SCF = 1.0
7.4.2 One method of improving the detail designation would be to grind flush the plate butt weld and eliminate the cope hole.

\[ \text{S-N curve} = 'D' \]
\[ \text{SCF} = 1.0 \]

7.4.3 An alternative improvement would be to profile the cope hole. It is possible to reduce the applicable S.C.F by a factor of around 1.5 from that used for the radius cope hole. The effect of this is greater than the difference between the 'F' and 'D' class S-N curves. This detail could thus be adequately covered by using

\[ \text{S-N curve} = 'D'. \]
\[ \text{SCF} = 1.0 \]

(The overall dimensions of the profiled cope hole would be approximately 170 mm length x 75 mm height. The weld should be full penetration and toe ground in way of the profiled cope hole to avoid possible failure through the weld throat.)

7.4.4 The modifications given above would improve the calculated fatigue life by a factor of 2.4 from the base case in 7.4.1.
8.0 CONICAL/TUBULAR INTERSECTION WELD

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Sketch" /></td>
<td><img src="image2" alt="Failure locations" /></td>
</tr>
</tbody>
</table>

8.1 S-N CURVES

The applicable S-N curve will depend on the type of weld used (See reference 1, Appendix A21) and whether junction stiffening is fitted.

For semi-submersible units in general only butt weld types corresponding to S-N curves 'C' or 'E' would normally be considered suitable for this location. Butt welds made from one side, corresponding to S-N curves 'F' and 'F2', are not normal practice.

For fixed platform installations however the applicable S-N curve may lie between 'C' and 'F2'. It is thus clearly important to identify correctly the relevant S-N curve (see also section 4.1).

Circumferential stiffening welds should be assessed using the 'F' class S-N curve.

8.2 JOINT GEOMETRY

Five types of basic arrangements are examined below. In all cases plating/ring stiffener centre lines are taken to occur at a single point. (i.e. the effects of any misalignment are not included).

8.2.1 Unstiffened connection, equal thickness

\[
t_1 = \text{cylinder thickness}
\]
\[
t_2 = \text{cone thickness}
\]
\[
t_1 = t_2
\]
8.2.2 Unstiffened connection, unequal thickness

\[ t_1 = \text{cylinder thickness} \]
\[ t_2 = \text{cone thickness} \]

Generally \( t_2 > t_1 \)

8.2.3 Connection stiffened by internal ring stiffener

\[ t_1 = \text{cylinder thickness} \]
\[ t_2 = \text{cone thickness} \]
\[ t_2 \geq t_1 \]

Ring stiffener

8.2.4 Connection stiffened by internal bulkhead

\[ t_1 = \text{cylinder thickness} \]
\[ t_2 = \text{cone thickness} \]
\[ t_3 = \text{bulkhead thickness} \]

Generally \( t_2 \geq t_1 \)

Bulkhead

8.2.5 Connection stiffened by internal bulkhead/ring and axial stiffener

\[ t_1 = \text{cylinder thickness} \]
\[ t_2 = \text{cone thickness} \]

Generally \( t_2 \geq t_1 \)

Bulkhead / Ring stiffener
8.3 RANGE OF PARAMETERS

Typical range of parameters is given in table 8.1 below:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder diameter (D)</td>
<td>1500mm</td>
<td>2500mm</td>
</tr>
<tr>
<td>Cylinder thickness (t₁)</td>
<td>15mm</td>
<td>60mm</td>
</tr>
<tr>
<td>Cone thickness (t₂)</td>
<td>15mm</td>
<td>60mm</td>
</tr>
<tr>
<td>Bulkhead thickness (t₃)</td>
<td>15mm</td>
<td>30mm</td>
</tr>
<tr>
<td>Angle α</td>
<td>0</td>
<td>20deg</td>
</tr>
</tbody>
</table>

8.4 STRESS CONCENTRATION FACTORS

Data has been obtained from references 2, 11 and 19.

These are given below for failure location 1. For the tubular connection weld, for the arrangements given, the maximum SCF would be expected to occur on the outer surface. Where available the value of the SCF for the inner surface, which is applicable for assessment of the bulkhead/ring stiffener weld toe, is also given.

Diagrams illustrating the SCF variation for the arrangements given in 8.2 are shown in figures 8.1.1 to 8.4.2.

It is clear there are differences in values of SCFs determined for a particular arrangement from the various figures given. In the absence of data supporting the use of an alternative value it is recommended that the higher SCF values be used.

8.4.1 Arrangement 1; Unstiffened connection, equal thickness

\[
\alpha \quad t_1 = t_2 = t
\]

(\(\alpha\) in radians)

8.4.1.1 From reference 2:

\[
SCF = 1 + 0.6 \sqrt{\frac{2D}{t}} \tan \alpha
\]

rearranging this gives

\[
SCF = 1 + 0.85 \sqrt{\frac{D}{t}} \tan \alpha \quad \text{(see figure 8.1.1)}
\]
8.4.1.2 From reference 11:

\[ \text{SCF} = 1 + 2.0 \times \tan \left( \frac{\alpha}{2} \right) \times \sqrt{\frac{R}{t}} \]

this may be rearranged to give

\[ \text{SCF} = 1 + 0.71 \sqrt{\frac{D}{t}} \tan \alpha \] (see figure 8.1.2)

8.4.1.3 Lloyd's Register has a general computer program available for this type of detail. For comparison results from this are also illustrated on figure 8.1.2 and show general agreement with the equation in 8.4.1.2 above.

8.4.1.4 In view of the above it is recommended that figure 8.1.2 (equation 8.4.1.2) is used.

8.4.2 Arrangement 2; Unstiffened connection, unequal thickness

![Diagram]

\( \alpha \) in radians)

generally \( t_2 > t_1 \)

8.4.2.1 From reference 2:

\[ \text{SCF} = 1 + \frac{0.6 \frac{t_1}{t_2} \sqrt{D(t_1 + t_2)}}{te^2} \tan \alpha \]

where \( te = t_1 \) for cylinder
\( te = t_2 \) for cone

For normal case where \( t_2 > t_1 \) then \( te = t_1 \) gives highest value and

\[ \text{SCF} = 1 + \frac{0.6 \frac{t_1}{t_2} \sqrt{D(t_1 + t_2)}}{t_1} \tan \alpha \]

This may be rearranged to give

\[ \text{SCF} = 1 + 0.6 \sqrt{\frac{D}{t_1}} \left( 1 + \frac{t_2}{t_1} \right) \tan \alpha \] (see figure 8.2.1)

8.4.2.2 From reference 11:

\[ \text{SCF} = 1 + 2.0 \times \tan \left( \frac{\alpha}{2} \right) \times \sqrt{\frac{R}{t}} \]

this may be rearranged to give

\[ \text{SCF} = 1 + 0.71 \sqrt{\frac{D}{t}} \tan \alpha \] (see figure 8.2.2)

this will give the largest value setting \( t = t_1 \)
8.4.2.3 Results from L.R. general program for this type of detail are also illustrated on figure 8.2.2 and show good agreement with equation 8.4.2.2 above.

8.4.2.4 In view of the above it is recommended that figure 8.2.2 is used.

8.4.3 Arrangement 3; Connection stiffened by internal ring stiffener,

\[ \alpha \text{ in radians} \]

generally \( t_2 \geq t_1 \)

8.4.3.1 From reference 11:

\[
\text{SCF} = 1 + 1.75 \tan \left( \frac{\alpha}{2} \right) \sqrt{\frac{R}{t}} \quad \text{outer surface}
\]

\[
\text{SCF} = 1 - 1.75 \tan \left( \frac{\alpha}{2} \right) \sqrt{\frac{R}{t}} \quad \text{inner surface}
\]

These may be rearranged to give:

\[
\text{SCF} = 1 + 0.62 \sqrt{\frac{D}{t}} \tan \alpha \quad \text{outer surface}
\]

\[
\text{SCF} = 1 - 0.62 \sqrt{\frac{D}{t}} \tan \alpha \quad \text{inner surface}
\]

for the tubular connection weld:

\[
\text{SCF} = 1 + 0.62 \sqrt{\frac{D}{t}} \tan \alpha \quad \text{(see figure 8.3.1)}
\]

setting \( t = t_1 \) will give the highest value.

8.4.3.2 For comparison purposes L.R. has used a general computer program developed for this type of detail to consider the effects of variations in the different parameters involved. The range of parameters included are given in Section 8.3 and additionally, for the ring stiffeners, in table 8.2 below.

Typical ring stiffener parameters

\[
tw
\]

\[
dw
\]

\[
bf
\]

\[
tf
\]
Table 8.2

<table>
<thead>
<tr>
<th>Section</th>
<th>dw (cm)</th>
<th>tw (cm)</th>
<th>bf (cm)</th>
<th>tf (cm)</th>
<th>A (cm²)</th>
<th>I (cm⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>1.3</td>
<td>15</td>
<td>2.0</td>
<td>55</td>
<td>600</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>1.4</td>
<td>18</td>
<td>2.0</td>
<td>70</td>
<td>1000</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>1.5</td>
<td>20</td>
<td>2.0</td>
<td>85</td>
<td>1400</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>1.7</td>
<td>24</td>
<td>2.0</td>
<td>108</td>
<td>2330</td>
</tr>
<tr>
<td>5</td>
<td>38</td>
<td>1.8</td>
<td>25</td>
<td>2.5</td>
<td>130</td>
<td>3270</td>
</tr>
</tbody>
</table>

A = area of section
I = second moment of area of section

From the results of the program it was seen that both the ratio \( t_2/t_1 \) and ring stiffener section had a relatively small effect on the SCF.

The maximum values obtained are given in figure 8.3.2.

8.4.3.3 There are significant differences in the values of the SCFs given above. For fatigue critical areas it is recommended that the higher values of SCF, given in figure 8.3.1, are adopted for design unless additional data supporting the use of a lower value is obtained (e.g. F.E. analysis).

8.4.4 Arrangement 4; Connection stiffened by internal bulkhead,

8.4.4.1 From reference 11:

\[
SCF = 1 + 1.50 \tan \left(\frac{\alpha}{2}\right) \sqrt{\frac{R}{t}} \quad \text{outer surface}
\]

\[
SCF = 1 - 1.50 \tan \left(\frac{\alpha}{2}\right) \sqrt{\frac{R}{t}} \quad \text{inner surface}
\]

These may be rearranged to give:

\[
SCF = 1 + 0.53 \sqrt{\frac{D}{t}} \tan \alpha \quad \text{outer surface}
\]

\[
SCF = 1 - 0.53 \sqrt{\frac{D}{t}} \tan \alpha \quad \text{inner surface}
\]

for the tubular connection weld:

\[
SCF = 1 + 0.53 \sqrt{\frac{D}{t}} \tan \alpha \quad \text{(see figure 8.4.1)}
\]

Setting \( t = t_1 \) will give the highest value..
8.4.4.2 For comparison purposes L.R. has used a general computer program developed for this type of detail to consider the effects of variations in the different parameters involved. The range of parameters included are given in table 8.1. From the results of the program it was seen that both the ratio $t_2/t_1$ and bulkhead thickness had a relatively small effect on the SCF. The maximum values obtained are given in figure 8.4.2.

8.4.4.3 There are significant differences in the values of the SCF's given above. For fatigue critical areas it is recommended that the higher values of SCF, given in figure 8.4.1, are adopted for design unless additional data supporting the use of a lower value is obtained (e.g., F.E. analysis).

8.4.5 Arrangement 5: Connection stiffened by internal bulkhead/ring stiffener and axial stiffeners

![Diagram showing connection with axial stiffening, cylinder thickness $t_1$, cone thickness $t_2$, bulkhead/ring stiffener $t_3$.]

The effect of closely spaced axial stiffeners (eight or more) will be to reduce the value of the SCF's. In the absence of alternative data this may be estimated by using the formulations given in 8.4.1 to 8.4.4 above and substituting an effective thickness ($t_e$) for $t$, where $t_e$ gives the same local bending stiffness as the plate/axial stiffener combination.

For widely spaced stiffeners (seven or less) the SCF will only be reduced in way of the stiffener positions. At intermediate positions, in the absence of alternative data, their effect should be neglected.

8.4.6 SCF diagrams

Eight basic SCF plots are illustrated in the figures given below.

Figures 8.1.1 and 8.1.2 Apply to unstiffened conical/tubular intersections of equal thickness.

Figures 8.2.1 and 8.2.2 Apply to unstiffened conical/tubular intersections of unequal thickness.

Figures 8.3.1 and 8.3.2 Apply to ring stiffened conical/tubular intersection butt welds.

Figures 8.4.1 and 8.4.2 Apply to bulkhead stiffened conical/tubular intersection butt welds.
SCF = 1 + 0.85√ \frac{D}{t} \tan \alpha

(Note: \alpha is in radians)

Figure 8.1.1
SCF for conical/tubular intersection unstiffened, equal thickness
(t_1 = t_2 = t)
SCF = 1 + 0.71 \sqrt{\frac{D}{t}} \tan \alpha

(Note: \alpha is in radians)

Figure 8.1.2
SCF for conical/tubular intersection unstiffened, equal thickness
\( t_1 = t_2 = t \)
SCF = 1 + 0.6 \frac{D}{t_1} \left(1 + \frac{t_2}{t_1}\right) \tan \alpha

(Note: $\alpha$ is in radians)

Figure 8.2.1
SCF for conical/tubular intersection unstiffened, unequal thickness
SCF = 1 + 0.71 \sqrt{\frac{D}{t_1}} \tan \alpha

(Note: \alpha is in radians)

---

**Figure 8.2.2**
SCF for conical/tubular intersection unstiffened, unequal thickness
\[ SCF = 1 + 0.62 \sqrt{\frac{D}{t}} \cdot \tan \alpha \]

(Note: \( \alpha \) is in radians)

**Figure 8.3.1**

SCF for ring stiffened conical/tubular intersection butt welds
from LR Program

Figure 8.3.2
SCF for ring stiffened conical / tubular intersection butt welds
SCF = 1 + 0.53 \sqrt{\frac{D}{t}} \tan \alpha

(Note: \alpha is in radians)

Figure 8.4.1
SCF for bulkhead stiffened conical/tubular intersection butt welds
Figure 8.4.2
SCF for bulkhead stiffened conical/tubular intersection butt welds
9.0 RING STIFFENER WELD

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
</table>

9.1 S-N CURVES

For normal fabrication the 'F' class S-N curve is to be used (see reference 1, Appendix A21).

9.2 JOINT GEOMETRY

Two types of basic arrangement are examined below
1. Tubular member with ring stiffener only.
2. Tubular member with ring stiffener and axial stiffeners.

9.3 RANGE OF PARAMETERS

Typical range of parameters is given in table 9.1 below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder diameter (D)</td>
<td>1500mm</td>
<td>2500mm</td>
</tr>
<tr>
<td>Cylinder thickness (t)</td>
<td>15mm</td>
<td>60mm</td>
</tr>
<tr>
<td>Ring area (Ar)</td>
<td>5500mm²</td>
<td>13000mm²</td>
</tr>
</tbody>
</table>
9.4 **STRESS CONCENTRATION FACTORS**

Data has been obtained from reference 11.

These are given below for failure location 1. Diagrams illustrating the SCF variations are given in figures 9.1.1 and 9.1.2. It should be noted that there will be differences in SCFs determined using the figures given. In the absence of data supporting the use of an alternative value it is recommended that the higher SCF be used (fig 9.1.1, equation 9.4.1.1).

In addition the SCFs given are generally only applicable for overall axial / bending stresses in the tubular member. (see also Section 1.13)

9.4.1 Arrangement 1; tubular member with ring stiffener

![Diagram of tubular member with ring stiffener]

9.4.1.1 From reference 11

\[ SCF = 1 - \frac{0.5}{1 + \frac{1.2 t^2}{A_r \sqrt{t}}} \]  
(See figure 9.1.1)

Typical value of SCF: 0.65 to 0.90

9.4.1.2 For comparison results from L.R.s general program for this type of detail are given in figure 9.1.2 and show good agreement with 9.4.1.1 above. Typical value of SCF: 0.60 to 0.85

9.4.2 Arrangement 2; tubular member with ring stiffener and axial stiffeners

![Diagram of tubular member with ring and axial stiffeners]

The effect of closely spaced axial stiffeners (eight or more) is to increase the cylinder stiffness with a resultant increase in the SCF. This may be estimated by using the formulations given in 9.4.1 and substituting an effective thickness \( t_e \) for \( t \), where \( t_e \) gives the same local bending stiffness as the plate/axial stiffener combination.

Alternatively the SCF may be conservatively taken as 1.0.
Figure 9.1.1
SCF for weld toes of ring stiffened tubular members

Figure 9.1.2
SCF for weld toes of ring stiffened tubular members (LR Program)
10.0 SURFACE ATTACHMENT WELD

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Sketch" /></td>
<td><img src="image" alt="Failure locations" /></td>
</tr>
</tbody>
</table>

10.1 S-N CURVES

For normal fabrication the 'F' class S-N curve is to be used. (See reference 1, Appendix A21)

10.2 TYPICAL GEOMETRIES

It is recommended that the attachment length is kept below 150 mm whenever possible.

Two forms of small attachments are considered below.

It should be noted that these do not cover main stiffening members which are dealt with in sections 12 and 13.

10.2.1 Plate attachment (used for pipe brackets, access platforms etc).
10.2.2 Pad attachment (used for handrails, anodes etc).

10.3 STRESS CONCENTRATION FACTORS

Data has been obtained from references 3, 5, 8, 15, 20 and 25.

These are considered below for failure location 1, the significant parameters being the attachment length (l) and shape at end.

10.3.1 Attachment length \( l < 150 \text{ mm} \)

For this case the recommended value of the SCF is 1.0 with the 'F' S-N curve. Some studies into geometric effects (references 15, 20 and 25) would appear to indicate that the actual SCF may be up to 1.5, however it appears that this effect is included in the choice of the 'F' curve S-N classification. See figures 10.1 and 10.2.

10.3.2 Attachment length \( l \geq 150 \text{ mm} \)

For this case the value of the SCF may increase with increasing length. Limited information available at the present time suggests that the SCF is likely to be between 1.14 and 1.36 (with the 'F' curve) for attachment lengths greater than 150mm depending on the form of the attachment.

For long attachments a specific analysis may be required.

It is recommended that the 'F' curve is used with an appropriate SCF. Account may be taken where appropriate of the implied SCF inherent in the 'F' curve.
Figure 10.1
Example of SCF for attachment pad
Figure 10.2
Example of SCF for plate attachment
11.0 RING REINFORCED PENETRATION WELD

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Sketch" /></td>
<td><img src="image" alt="Failure locations" /></td>
</tr>
</tbody>
</table>

11.1 S-N CURVES

The applicable S-N curve will depend on the type of weld used (see reference 1, Appendix A21).

For fatigue prone locations full penetration welding would normally be required and for this case the 'D' S-N curve is generally applicable.

Where partial penetration or fillet welds are used, weld stresses are to be assessed using the appropriate curve for failure in the weld throat.

For most practical applications, for location 1, the 'D' S-N curve is appropriate and the design SCFs given below may be used for the loading cases specified. However for complex geometry arrangements and loading systems the 'F' S-N curve may be relevant at certain locations. The SCF would require to be specially considered. Further data may be derived from references 8, 9 and 10.

11.2 JOINT GEOMETRY

Four types of basic arrangement are examined below. The first three relate to typical openings found in tubular members and the fourth relates specifically to openings found in bulkheads and decks of plated structures.

Location 1 is at the weld toe, location 2 is through the weld throat.

11.2.1 Ring reinforced circular penetrations (used for pipe fittings drainholes etc)

![Diagram](image)

bracing thickness = t

Ring/flange depth = f
11.2.2 Ring reinforced elliptical penetrations (used for flooding ports, access manholes etc)

![Diagram of an elliptical penetration with labels L, B, tr, and bracing thickness = t, Ring/flange depth = f]

11.2.3 Ring reinforced rectangular penetrations with full radius corners (used for flooding ports, access manholes etc)

![Diagram of a rectangular penetration with labels L, B, tr, and bracing thickness = t, Ring/flange depth = f]

(Note that this may also be regarded as a particular case of 11.2.4).

11.2.4 Rectangular penetrations with/without ring reinforcement with rounded corners (used for doors and misc. openings in plated structures)

![Diagram of a rectangular penetration with labels L, B, tr, R, and plate thickness = t, Ring/flange depth = f]
11.3 RANGE OF PARAMETERS

Typical range of parameters (for 11.2.1 to 11.2.3) are given in table 11.1 below

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bracing thickness (t) mm</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td>Hole diameter (D) mm</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td>Hole length (L) mm</td>
<td>400</td>
<td>800</td>
</tr>
<tr>
<td>Hole breadth (B) mm</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>Ring thickness (tr) mm</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>Flange depth (f) mm</td>
<td>50</td>
<td>200</td>
</tr>
</tbody>
</table>

11.4 STRESS CONCENTRATION FACTORS

Data has been obtained from references 3, 5, 8, 9, 10, 12 and 16.

These are given below for failure locations 1 and 2. When the ring stiffener is connected by a full penetration weld, only location 1 needs to be considered. When the ring stiffener is connected by a partial penetration or fillet weld, location 1 and 2 should be considered. Diagrams illustrating the SCF variation for the arrangements given in 11.2 are shown in figures 11.1.6 to 11.4.6.

11.4.1 Arrangement 1; Ring stiffened circular penetrations

\[
\text{bracing thickness} = t \\
\text{Ring depth} = f
\]

11.4.1.1 Location 1

A great deal of data is available for these penetrations and a large number and variety of parameters catered for.

For tubular members under axial/bending loads figure 11.1.6 is given as a curve for general use although it is acknowledged that variations may be suggested from alternative sources.
The values given in the figure are broadly consistent with those obtained from a number of sources for the range of parameters given in section 11.3 and are based on reference 9. Typical values of SCF for the parameters given may be expected to be between 1.5 to 1.8. Although figure 11.1.6 does not strictly take into account the weld radius effect, from references 8 and 12, for typical values of weld radius/t between 0.3 and 0.5, the resultant SCFs appear consistent with those given in the figure.

The SCF depends on the value of the equivalent cross sectional area A, where

\[ \bar{A} = \zeta A \text{ and } A = \text{cross sectional area of reinforcement} \]
\[ \zeta = \text{efficiency factor determined from figures 11.1.1 to 11.1.5} \]

**Symmetric reinforcement**

\[ \bar{A} = \zeta \times (2htr) \]
\[ \zeta \text{ from figure 11.1.1} \]
\[ R = \text{radius} \]

**Unsymmetric reinforcement**

\[ \bar{A} = \zeta \times htr \]
\[ \zeta \text{ from figure 11.1.1 to 11.2.5} \]
\[ (\text{for } h/\text{tr from 3 to 10}) \]
\[ R = \text{radius} \]

For symmetric compact reinforcement \( \bar{A} = \text{tr.f} \)

11.4.1.2 Location 2

For partial penetration and fillet welds the SCF should be based on the shear stress in the weld throat.
Figure 11.1.7 gives values for SCF to be used in the formula below. These have been based on data given in reference 10 and results from a number of finite element analyses carried out by L.R.

Typical values of maximum shear stress for fatigue would be expected to lie between 0.6 and 1.0 times the nominal applied axial/bending stress.

Fatigue shear stress:

\[
\tau_{w} = \frac{(SCF_{\tau}) \times t}{2 \times t_{w}} \times \sigma
\]

where \( t_{w} \) = weld throat thickness
and \( \sigma \) = nominal axial/bending stress

(Note: Also refer to Section 12.3.1.2).

11.4.2 Arrangement 2; Ring stiffened elliptical penetrations

![Diagram of elliptical penetration with dimensions L, B, tr, and bracing thickness t.]

bracing thickness = t
Ring depth = f

11.4.2.1 Location 1

In general the major axis of the ellipse should be aligned parallel with the axial/bending stress and therefore 'L' will be greater than 'B'. SCFs obtained for \( L > B \) will generally be smaller than those for an equivalent circular reinforced opening.

The SCFs given in figure 11.2.1 are based on those given in reference 9. (A to be determined from 11.4.1.1). Typical values for the parameters given in section 11.3 would be expected to lie between 1.3 and 1.7.

11.4.2.2 Location 2

No specific data is available, however the SCF may be estimated from figure 11.1.7 using \( D = B \).

(Note: Also refer to Section 12.3.1.2).
11.4.3 Arrangement 3: Ring reinforced rectangular penetrations with full radius corners

\[ \text{bracing thickness} = t \]
\[ \text{Ring depth} = f \]

11.4.3.1 Location 1

Equivalent data for this arrangement does not appear to be readily available at the present time.
A comparison has been made for unreinforced elliptical and rectangular openings, reinforced elliptical openings, square openings and data from L.R. model tests.

On the basis of this, and in the absence of alternative data, the SCF should be taken as the highest value obtained from figure 11.2.1 or figure 11.1.6, setting B = D.

11.4.3.2 Location 2

No specific data is available, however the SCF may be estimated from figure 11.1.7 using D = B.

(Note: Also refer to Section 12.3.1.2).

11.4.4 Arrangement 4: Rectangular penetrations with/without ring reinforcement with rounded corners (in plating)

\[ \text{plate thickness} = t \]
\[ \text{Ring depth} = f \]

Six cases have been addressed, these include two for an unreinforced opening and four for a reinforced opening.

For the unreinforced opening SCFs are considered for axial and shear loads.

For the ring reinforced opening SCFs are considered for axial and shear loads for both location 1 and 2.
11.4.4.1 Unreinforced opening under axial loading.

SCFs are given in figure 11.4.1, these are based on data from reference 9.

11.4.4.2 Unreinforced opening under shear loading.

SCF values are given in figure 11.4.2, these are based on data from reference 9.

11.4.4.3 Ring reinforced opening under axial loading (location 1).

Data covering a range of aspect ratios does not appear to be readily available at the present time. In the absence of alternative data the SCF may be estimated as the highest value obtained from figure 11.2.1 or figure 11.4.3.

(A is determined from 11.4.1.1).

11.4.4.4 Ring reinforced opening under axial loading (location 2).

For partial penetration and fillet welds the SCF should be based on the shear stress in the weld throat. Equivalent data for this location does not appear to be readily available at the present time. In the absence of alternative data the SCF may be estimated from figure 11.1.7 using D = 2R.

(Note: Also refer to Section 12.3.1.2).

11.4.4.5 Ring reinforced opening under shear loading (location 1) Data covering a range of aspect ratios does not appear to be readily available at the present time. In the absence of alternative data the SCF may be estimated as the highest value obtained from figure 11.4.4 or 11.4.5.

(A is determined from 11.4.1.1)

This data has been based on reference 9.

11.4.4.6 Ring reinforced opening under shear loading (location 2).

For partial penetration and fillet welds the SCF should be based on the shear stress in the weld throat.

Equivalent data for this location does not appear to be readily available at the present time. In the absence of alternative data the SCF may be estimated from figure 11.4.6 using D = 2R. This data has been based on reference 10.

(Note: Also refer to Section 12.3.1.2).
Figure 11.1.1
ζ for symmetric flange reinforcement (Ref 9)
Figure 11.1.2
ζ for unsymmetric flange reinforcement  b/tr = 3 (Ref 9)
Figure 11.1.3
ζ for unsymmetric flange reinforcement  h/tr = 4 (Ref 9)
Figure 11.1.4
\( \zeta \) for unsymmetric flange reinforcement  \( h/tr = 5 \) (Ref 9)
Figure 11.1.5
$\zeta$ for unsymmetric flange reinforcement  $h/tr = 10$ (Ref 9)
For symmetric compact reinforcement $\bar{A} = tr.f$

$\sigma_{\text{max}} = SCF \times \sigma$

**Figure 11.1.6**
SCF for ring stiffened circular penetration in tubular member under axial/bending loads (Location 1) (Ref 9)
Fatigue shear stress \[ tw = \frac{(SCF \tau) \times t}{2 \times tw} \times \sigma \]

where \( tw = \) weld throat thickness
and \( \sigma = \) nominal axial/bending stress

Figure 11.1.7
SCF for ring stiffened circular penetration in tubular member under axial/bending loads (Location 2) (Ref 10)
For symmetric compact reinforcement  $\bar{A} = \text{tr.f}$

**Figure 11.2.1**
SCF for ring stiffened elliptical penetration in tubular member under axial/bending loads (location 1) (Ref 9)
Figure 11.4.1.
S.C.F for unreinforced rectangular opening in plate under axial load
(Ref 9)
Figure 11.4.2
SCF for unreinforced rectangular opening in plate under shear load (Ref 9)
For symmetric compact reinforcement, \( A = \text{tr} \cdot f \)

Figure 11.4.3
SCF for ring reinforced square opening with rounded corners in plate under axial loading (location 1) (Ref 9)
For symmetric compact reinforcement $\bar{A} = tr.f$

$\sigma_{max} = SCF \times t$

$L = B$

$\frac{2A}{B.t}$

Figure 11.4.4.
SCF for ring reinforced square opening with rounded corners in plate under shear load (location 1) (Ref 9)
Figure 11.4.5.
SCF for ring stiffened elliptical opening in plate under shear load
(Ref 9)
Fatigue shear stress \( tw = \frac{(SCF \tau) \times t}{2 \times tw} \times q \)

where

\( tw = \) weld throat thickness

and

\( q = \) nominal shear stress

**Figure 11.4.6**

SCF for ring stiffened circular penetration in plate under shear load (Location 2) (Ref 10)
12.0 GUSSET STIFFENER END

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Sketch" /></td>
<td><img src="image" alt="Failure locations" /></td>
</tr>
</tbody>
</table>

12.1 S-N CURVES

The applicable S-N curve will depend on the type of weld used (see reference 1, Appendix A21).

For fatigue prone locations full penetration welding would normally be required and for this case the T" S-N curve is to be used.

Where partial penetration or fillet welds are used, weld stresses are to be assessed using the appropriate curve for failure in the weld throat.

12.2 JOINT GEOMETRY

Three types of arrangement are examined below. Type 1 is not recommended for fatigue sensitive locations.
1. Abrupt stiffener termination.
2. Soft profile stiffener termination.
3. Internal/external stiffener combination.

12.3 STRESS CONCENTRATION FACTORS

Data has been obtained from references 3, 5, 8, 9, 13 and 14.

These are considered below for failure locations 1 and 2. When the gusset stiffener weld adjacent to the termination is full penetration, only location 1 needs to be considered. When the gusset stiffener weld adjacent to the termination is partial penetration or fillet, locations 1 and 2 need to be considered.

Diagrams illustrating the SCF variation for the arrangements given are shown in figures 12.1 to 12.3.
12.3.1 Type 1; Abrupt stiffener termination

D = bracing diameter
As = nominal stiffener area
θ = nose angle (30° - 90°)
t = bracing thickness

12.3.1.1 Location 1

The SCFs shown in figure 12.1 have been based on results from model tests and stiffness considerations. (reference 14). Typical values may be expected to be between 1.4 and 1.8.

12.3.1.2 Location 2

For partial penetration and fillet welds the SCF should be based on the shear stress in the weld throat.

No specific data is available for this location. From reference 3 the reference stress for fatigue of a weld throat should be the vector sum of the shear stresses in the weld metal based on an effective throat dimension (see below) and on the assumption that none of the load is carried in bearing between parent metals.

This is illustrated below. When calculating the stress range, the vector difference of the greatest and the least vector sum stress may be used instead of the algebraic difference.

\[ \sigma_N = \frac{P_N + (P_{Ne} + M)}{lt} \]

\[ \sigma_P = (\sigma_N^2 + \sigma_T^2)^{0.5} \]

\[ \sigma_T = \frac{P_T}{lt} \]

\[ t = \text{combined size of effective weld throats} \]

\[ P_N \]

\[ M \]

\[ P_T \]

\[ E_0 \]

\[ l \]

\[ e \]
The value of the SCF will depend on the actual arrangement and the attachment welds. For typical arrangements it has been estimated that the value of the SCF is likely to be less than 3.0.

From reference 5 some useful data with respect to the critical weld size of transverse load carrying fillet welds are shown in figure 12.4.

12.3.2 Type 2; Soft profile stiffener termination

\[ g = \text{effective throat of the weld} \]

\[ t = \text{bracing thickness} \]

\[ D = \text{bracing diameter} \]

\[ A_s = \text{nominal stiffener area} \]

\[ \theta = \text{nose angle (< 20°)} \]

12.3.2.1 Location 1

The SCFs shown in figure 12.2 have been based on results from model tests (reference 14) and stiffness considerations. Typical values may be expected to be between 1.0 and 1.2.

12.3.2.2 Location 2

For this arrangement full penetration welding is recommended in way of the toe of the gusset. Therefore only location 1 needs to be considered.
12.3.3 Type 3; Internal/external stiffener combination

12.3.3.1 Location 1

SCF data has been based on results from model tests (reference 14) and stiffness considerations and may be determined as follows:

\[
SCF \ (c) = SCF \ (a) \times K_c
\]

Where:

- \( SCF \ (c) \) = stress concentration factor for stiffener combination (not to be taken as less than 1.0)
- \( SCF \ (a) \) = stress concentration factor from figure 12.1 or figure 12.2 as applicable
- \( K_c \) = factor allowing for overlap of stiffeners (see figure 12.3).

12.3.3.2 Location 2

For partial penetration and fillet welds the SCF should be based on the shear stress in the weld throat.

No specific data is available for this location. (see 12.3.1.2)
Figure 12.1
SCF for abrupt stiffener termination under axial/bending loads (location 1)

\[ \sigma_{\text{max}} = \text{SCF} \times \sigma \]
Figure 12.2
SCF for soft profile stiffener termination under axial / bending loads (location 1)

\[ \sigma_{\text{max}} = \text{SCF} \times \sigma \]
Figure 12.3
SCF $k_c$ factor for internal/external stiffener combination under axial/bending loads (location 1)
Figure 12.4
Critical weld sizes of transverse load-carrying fillet welds (Ref 5)
13.0 GUSSET STIFFENER TERMINATING AT A RING STIFFENER

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Sketch" /></td>
<td><img src="image" alt="Failure locations" /></td>
</tr>
</tbody>
</table>

13.1 S-N CURVE

The applicable S-N curve will depend on the type of weld used (see reference 1, Appendix A21).

For fatigue prone locations full penetration welding would normally be required and for this case the 'T' S-N curve is to be used.

Where partial penetration or fillet welds are used, weld stresses are to be assessed using the 'W' S-N curve.

13.2 STRESS CONCENTRATION FACTORS

Data has been obtained from references 3, 5, 8, 9, 13 and 14.

These are considered below for failure locations 1 and 2. When the gusset stiffener weld adjacent to the ring is full penetration, only location 1 needs to be considered. When the gusset stiffener weld adjacent to the ring is partial penetration or fillet, locations 1 and 2 need to be considered.
13.2.1 Stiffener Arrangement

![Diagram of stiffener arrangement]

Typical arrangement

\[
t = \text{bracing thickness} \\
D = \text{bracing diameter} \\
As = \text{nominal stiffener area} \\
Is = \text{nominal stiffener inertia about axis x x} \\
Ar = \text{ring stiffener area} \\
Ir = \text{ring inertia about x x} \\
\theta = \text{nose angle (30°–90°)}
\]

For typical arrangements \( Ar \) would be between 1.0 \( As \) to 3.0 \( As \) and \( Ir \) would be between 3.0 \( Is \) and 6.0 \( Is \).

13.2.2 Location 1

Values given are based on L.R. model tests. (Reference 13 and 14).

\[ \text{SCF}(r) = \text{SCF}(a) \times 0.75 \]

where \( \text{SCF}(r) = \text{stress concentration factor including effect of ring stiffener} \)

(\text{not to be taken as less than 1.0})

\[ \text{SCF}(a) = \text{stress concentration factor determined from 12.3.1.} \]

The above SCF may be used irrespective of whether a rat hole is present at the stiffener to ring intersection or not.

13.2.3 Location 2

For partial penetration and fillet welds the SCF should be based on the shear stress in the weld throat.

No specific data is available for this location. (see 12.3.1.2).
14.0 COLUMN TO PONTOON JOINT

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Column" /></td>
<td><img src="image" alt="Pontoon" /></td>
</tr>
</tbody>
</table>

14.1 S-N CURVES

The applicable S-N curves will depend on the exact structural arrangement of these complex joints. In way of critical locations it is unlikely that use of a class higher than T6 could normally be justified.

To determine the minimum fatigue life it would generally be necessary to examine several locations in way of the joint.

14.2 STRESS CONCENTRATION FACTORS

Very little suitable data is available. In general SCFs for various locations within the joint should be obtained by an appropriate method (e.g. F.E. analysis, model testing) for each joint configuration.

The occurrence of fatigue cracking at these joints may in general be expected to be comparatively infrequent and is usually of a relatively minor nature.

The most likely key problem areas would be in the region of the column shell to pontoon deck connection at the main transverse and longitudinal bulkheads (critical areas are indicated in Figure 14.1). Particular attention to structural details and welding should be given in these areas.

14.3 EXAMPLE CASE STUDY

14.3.1 A fatigue analysis has been carried out using Lloyd's Register's computer package for structural analysis of semi-submersibles. Two finite element models were produced for the analysis.

The first being a global F.E.M. of the complete vessel to determine overall load paths and the second a detailed F.E.M. of a typical pontoon to column joint connection to determine local stress distributions (see figure 14.1).

The object of these analyses was to obtain and compare fatigue life predictions in way of the joint.
14.3.2 The loadings applied to the detailed joint F.E.M. were in the form of applied displacement sets taken from appropriate nodal points of the global F.E.M.

14.3.3 Minimum fatigue lives obtained from the detailed F.E. analysis are, as expected, of a very localized nature.

Stress results from typical loading cases were examined to observe the concentration characteristics in way of the joint.

This showed that the local stress patterns were highly dependent on the applied loading case. It was thus very difficult to determine a unique value for the stress concentration factor.

In order to obtain similar values of minimum fatigue lives for both models an equivalent nominal reference SCF of about 2.0 (using the 'F' S-N curve) had to be introduced for use in the global F.E.M. fatigue analysis.

14.3.4 Data from a number of strain gauges placed on the vessel at locations in way of the critical corner of the pontoon to column joint was made available. This was compared to detailed stress range data output from the fatigue analysis for appropriate elements of the finite element model. A reasonable level of agreement was noted however more information would be required in order to draw any conclusions from this.
Figure 14.1
Example pontoon to column joint F.E. model in way of critical areas
15.0 BRACING TO COLUMN JOINT

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Sketch" /></td>
<td>Refer to Figure 15.1 and Table 15.1</td>
</tr>
</tbody>
</table>

15.1 S-N CURVES

The applicable S-N curves will depend on the particular detail being assessed and the type of weld used (see reference 1, Appendix A21).

It will normally be necessary to consider a number of different locations to determine the overall minimum fatigue life of the joint.

A summary of typical details found at these joints together with associated S-N curves is given in Figure 15.1 and Table 15.1.
| Location number | Description of detail at brace to column connection | S-N curve *
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Parent metal adjacent to toe of full penetration weld:</td>
<td>D</td>
</tr>
<tr>
<td>2</td>
<td>Bracing</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>Column</td>
<td>D</td>
</tr>
<tr>
<td>4</td>
<td>Parent metal adjacent to toe of cope hole:</td>
<td>D</td>
</tr>
<tr>
<td>5</td>
<td>Bracing weld</td>
<td>F</td>
</tr>
<tr>
<td>6</td>
<td>Column weld</td>
<td>F</td>
</tr>
<tr>
<td>7</td>
<td>Parent metal adjacent to toe of profiled cope hole:</td>
<td>F</td>
</tr>
<tr>
<td>8</td>
<td>Bracing clear of column</td>
<td>B/C</td>
</tr>
<tr>
<td>9</td>
<td>Column clear of bracing</td>
<td>B/C</td>
</tr>
<tr>
<td>10</td>
<td>Bracing inside column</td>
<td>B/C</td>
</tr>
<tr>
<td>11</td>
<td>Parent metal adjacent to toe of welded stiffener attachments to bracing</td>
<td>B/C</td>
</tr>
<tr>
<td>12</td>
<td>Parent metal adjacent to weld toe of external bracket at bracing</td>
<td>B/C</td>
</tr>
<tr>
<td>13</td>
<td>Parent metal, bracket edge:</td>
<td>C</td>
</tr>
<tr>
<td>14</td>
<td>edge machined - no face flat</td>
<td>D</td>
</tr>
<tr>
<td>15</td>
<td>at toe of weld for face flat</td>
<td>D</td>
</tr>
<tr>
<td>16</td>
<td>Parent metal adjacent to continuous weld (for bracket) essentially parallel to direction of applied stress</td>
<td>D</td>
</tr>
<tr>
<td>17</td>
<td>Parent metal adjacent to continuous weld (for bracket) essentially perpendicular to direction of applied stress</td>
<td>F</td>
</tr>
</tbody>
</table>

*Note: The SCF examples given in table 15.3 and used in combination with these S-N curves were obtained from finite element analyses.
15.2 JOINT GEOMETRY

Two types of basic arrangement are examined below. It should be noted that deviations from the basic arrangements are possible due to the large number of brace to column joint configurations.

15.2.1 Circular bracing entering circular/flat sided column

15.2.2 Rectangular bracing entering circular/flat sided column
15.3 Parameters

Typical parameters for these joints are defined below.

15.3.1 Geometry - circular bracing, circular/flat sided column

15.3.2 Geometry - rectangular bracing, circular/flat sided column
### 15.3.3 Table 15.2 below illustrates typical parameter values for the geometries given in 15.3.1 and 15.3.2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal brace diameter (mm)</td>
<td>Dn</td>
<td>1200</td>
<td>2500</td>
</tr>
<tr>
<td>Nominal brace thickness (mm)</td>
<td>tn</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>Bracing diameter / depth at column (mm)</td>
<td>Db</td>
<td>1200</td>
<td>2500</td>
</tr>
<tr>
<td>Bracing breadth at column (mm)</td>
<td>Bb</td>
<td>1200</td>
<td>4000</td>
</tr>
<tr>
<td>Bracing thickness at column (mm)</td>
<td>tb</td>
<td>25</td>
<td>80</td>
</tr>
<tr>
<td>Bracing cross plate thickness (mm)</td>
<td>tp</td>
<td>12</td>
<td>45</td>
</tr>
<tr>
<td>Column diameter / depth (mm)</td>
<td>Dc</td>
<td>5000</td>
<td>14000</td>
</tr>
<tr>
<td>Column breadth (mm)</td>
<td>Be</td>
<td>7000</td>
<td>14000</td>
</tr>
<tr>
<td>Column thickness at bracing (mm)</td>
<td>tc</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Mousehole radius (mm)</td>
<td>rm</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Profile radius (mm)</td>
<td>rp</td>
<td>150</td>
<td>800</td>
</tr>
<tr>
<td>Inclined angle (degrees)</td>
<td>θ</td>
<td>90</td>
<td>140</td>
</tr>
<tr>
<td>Ring web depth (mm)</td>
<td>Wd</td>
<td>300</td>
<td>600</td>
</tr>
<tr>
<td>Ring web thickness (mm)</td>
<td>Wt</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Ring flange width (mm)</td>
<td>Fd</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Ring flange thickness (mm)</td>
<td>Ft</td>
<td>15</td>
<td>35</td>
</tr>
</tbody>
</table>

### 15.4 STRESS CONCENTRATION FACTORS

It is important to note that a large variety of joint configurations and structural arrangements are possible within this joint type and have in fact been constructed in the past.

SCFs for most of the details requiring assessment are arrangement dependent. It has not therefore been practical to develop a simple method to determine these at this time.

SCF values for any proposed joint design would have to be determined by appropriate methods (e.g. finite element analysis, model testing).
15.4.1 Case Studies

L.R. has carried out a review of data from around 20 different joint arrangements. SCFs have been obtained for each appropriate reference location given in Figure 15.1. The values are summarised in Table 15.3.

A further study has been carried out to quantify a ‘design’ SCF, independent of location, related to use of the ‘P’ S-N curve for each joint arrangement.

From this the following observations have been made:
(i) Equivalent SCFs, related to use of the ‘P’ S-N curve, for the various joint designs were between 2.0 and 5.0.
(ii) Most of the joints had equivalent SCFs of between 2.0 and 3.5.
(iii) Joint geometries indicating equivalent SCFs in excess of 4.0 are not recommended.

### Table 15.3
Summary of examples

<table>
<thead>
<tr>
<th>Location (see Figure 15.1)</th>
<th>SCF</th>
<th>S-N Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>1</td>
<td>1.1</td>
<td>4.5</td>
</tr>
<tr>
<td>2</td>
<td>1.1</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>7</td>
<td>2.5</td>
<td>5.0</td>
</tr>
<tr>
<td>8</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>9</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>11</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>12</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>13</td>
<td>2.0</td>
<td>3.3</td>
</tr>
<tr>
<td>14</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>15</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>
16.0 BRACING TO BRACING JOINT

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Sketch Image]</td>
<td>Refer to Figure 16.1 and Table 16.1</td>
</tr>
</tbody>
</table>

16.1 S-N CURVES

The applicable S-N curves will depend on the particular detail being assessed and the type of weld used (see reference 1, Appendix A21).

It will normally be necessary to consider a number of different locations to determine the overall minimum fatigue life of the joint.

A summary of typical details found at multi-stiffened tubular joints together with associated S-N curves is given in Figure 16.1 and Table 16.1.

Table 16.1
Details at multi-stiffened tubular joint

<table>
<thead>
<tr>
<th>Location number</th>
<th>Description</th>
<th>S-N Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Parent metal adjacent to toe of weld for typical ring or stiffening frame</td>
<td>F</td>
</tr>
<tr>
<td>2</td>
<td>Parent metal adjacent to toe of weld for typical longitudinal stiffener: continuous weld</td>
<td>D</td>
</tr>
<tr>
<td>3</td>
<td>adjacent to cope holes</td>
<td>F</td>
</tr>
<tr>
<td>4</td>
<td>Parent metal at bracket or radiused plate: Edge of plate</td>
<td>B/C</td>
</tr>
<tr>
<td>5</td>
<td>Toe of bracket</td>
<td>F</td>
</tr>
<tr>
<td>6</td>
<td>Parent metal adjacent to toe of full penetration intersection welds: parallel to applied stress</td>
<td>D</td>
</tr>
<tr>
<td>7</td>
<td>perpendicular to applied stress</td>
<td>D</td>
</tr>
</tbody>
</table>
Figure 16.1
Details at multi-stiffened tubular joint
16.2 JOINT GEOMETRY

Seven types of basic arrangements are illustrated in Table 16.2 below: three unstiffened joint configurations; three ring stiffened configurations and a multi-stiffened configuration.

Table 16.2

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Sketch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Unstiffened 'T' joint</td>
<td>![Sketch of unstiffened 'T' joint]</td>
</tr>
<tr>
<td>2</td>
<td>Unstiffened 'K' joint</td>
<td>![Sketch of unstiffened 'K' joint]</td>
</tr>
<tr>
<td>3</td>
<td>Unstiffened 'KT' joint</td>
<td>![Sketch of unstiffened 'KT' joint]</td>
</tr>
<tr>
<td>4</td>
<td>Ring stiffened 'T' joint</td>
<td>![Sketch of ring stiffened 'T' joint]</td>
</tr>
<tr>
<td>5</td>
<td>Ring stiffened 'K' joint</td>
<td>![Sketch of ring stiffened 'K' joint]</td>
</tr>
<tr>
<td>6</td>
<td>Ring stiffened 'KT' joint</td>
<td>![Sketch of ring stiffened 'KT' joint]</td>
</tr>
<tr>
<td>7</td>
<td>Multi-stiffened 'K' and 'KT' joints</td>
<td>![Sketch of multi-stiffened 'K' and 'KT' joints]</td>
</tr>
</tbody>
</table>

The first six types generally relate to fixed platform structures and are dealt with in some detail in References 26 and 27.

The last type is the one most commonly found on semi-submersible structures. Members in way of the joint intersection may be rectangular or circular cross section.
16.3 RANGE OF PARAMETERS

Very limited data on joint type 7 was available. From that which was available the main joint parameters lay within the range given in table 16.3 below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chord diameter (D) mm</td>
<td>1200 - 2500</td>
</tr>
<tr>
<td>Chord thickness (T) mm</td>
<td>25 - 60</td>
</tr>
<tr>
<td>Brace diameter (d) mm</td>
<td>1200 - 2000</td>
</tr>
<tr>
<td>Brace thickness (t) mm</td>
<td>25 - 50</td>
</tr>
<tr>
<td>Brace to chord angle (θ) deg</td>
<td>30 - 90</td>
</tr>
</tbody>
</table>

16.4 STRESS CONCENTRATION FACTORS

SCF's for fixed platform structural joints (joint types 1 to 6 in table 16.2) should be determined from References 26 and 27.

It is important to note that a large variety of joint arrangements are possible within joint type 7 and SCF's are arrangement dependent.

SCF values for any proposed joint design would have to be determined by appropriate methods (e.g. finite element analysis, model testing).

L.R. has reviewed data from several joint arrangements of joint type 7, see table 16.2. Only limited data was available.

The SCF's obtained for each appropriate reference location given in figure 16.1 are summarised in Table 16.4.
<table>
<thead>
<tr>
<th>Location</th>
<th>Member</th>
<th>Axial SCF</th>
<th>Bending SCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chord</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Brace</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>Chord</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Brace</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>Chord</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Brace</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>Chord</td>
<td>1.8 to 3.5</td>
<td>1.8 to 3.5</td>
</tr>
<tr>
<td></td>
<td>Brace</td>
<td>1.8 to 3.5</td>
<td>1.8 to 3.5</td>
</tr>
<tr>
<td>5</td>
<td>Chord</td>
<td>1.0 to 1.5</td>
<td>1.0 to 1.5</td>
</tr>
<tr>
<td></td>
<td>Brace</td>
<td>1.0 to 1.5</td>
<td>1.0 to 1.5</td>
</tr>
<tr>
<td>6</td>
<td>Chord</td>
<td>1.5 to 2.5</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td></td>
<td>Brace</td>
<td>1.5 to 2.5</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td>7</td>
<td>Chord</td>
<td>1.5 to 2.5</td>
<td>1.5 to 2.5</td>
</tr>
<tr>
<td></td>
<td>Brace</td>
<td>1.5 to 2.5</td>
<td>1.5 to 2.5</td>
</tr>
</tbody>
</table>
17.0  CRUCIFORM JOINT

<table>
<thead>
<tr>
<th>Sketch</th>
<th>Failure locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Sketch" /></td>
<td><img src="image" alt="Failure locations" /></td>
</tr>
</tbody>
</table>

17.1  S-N CURVES

The applicable S-N curve will depend on the type of weld used (see reference 1, Appendix A21).

For fatigue prone locations full penetration welding would normally be required and for this case the 'F' S-N curve is to be used.

Parent metal adjacent to the toe of a fillet welded cruciform or 'T' joint is to be assessed using the 'F2' S-N curve.

Where partial penetration or fillet welds are used, weld stresses are to be assessed using the appropriate curve for failure in the weld throat.

17.2  JOINT GEOMETRY

From reference 11 and 28 the general joint geometry may be illustrated as given in Figure 17.1 below.

![Figure 17.1](image)
Member stiffness parameter

\[ k_i = \frac{E(t_i)^3}{3 \cdot L_i} \]

where
- \( E \) = Young's modulus
- \( t_i \) = member thickness
- \( L_i \) = member unsupported length
- \( e \) = misalignment

17.3 STRESS CONCENTRATION FACTORS

These are given below for failure locations 1 and 2. Stress concentration factors will depend on misalignment at the joint and support conditions / equivalent stiffness of each plate.

When full penetration welds are used only location 1 needs to be considered. Where partial penetration or fillet welds are used locations 1 and 2 should be considered.

SCF data has been obtained from three sources (references 11, 21 and 28). Results are broadly consistent for the specific cases given.

17.3.1 Axial misalignment (location 1)

General expression for SCF (see Figure 17.1)

\[ SCF (member \ i) = 1 + 6 \frac{e}{t_i} \frac{k_i}{(k_1 + k_2 + k_3 + k_4)} \]

Where an element is unrestrained then \( k_i \) should be set to zero for that member.

17.3.2 Axial misalignment (location 2)

For partial penetration and fillet welds the SCF should be based on the applied stress range in the weld throat, see also Section 12.3.1.2.

\[ SCF = 1 + \left( \frac{e}{t + h} \right) \]

17.3.3 Angular misalignment (location 1)

An expression for angular misalignment is given in reference 28 however the factors given are at present under discussion.
18.0 REFERENCES


10. Gurney C. 'An analysis of the stresses in a flat plate with a reinforced circular hole under edge forces', ARC R&M 1834, 1938.


13. 'Strain concentrations at tube longitudinal stiffener ends with ring termination', Lloyd's Register internal report, 1981.


28. PD 6493


19.0 CONCLUDING REMARKS

19.1 It has been noted that for some of the details examined various sources suggested different SCFs for similar arrangements. In addition it is clear that more data is required for some details. These points are discussed for each detail in the following sections.

19.2 Transverse/Circumferential Butt Weld (see also section 4)

The following anomalies have been identified and require resolution.

19.2.1 Some sources suggest that normal fabrication misalignment is included within the S-N curves and only misalignment beyond this needs to be accounted for when calculating the SCF.

Other sources consider that all misalignment must be included in the determination of the SCF.

19.2.2 The general form of the expression for the SCF includes a power index (n) with a nominal value of 3 (see section 4.4.1).

This has been stated to be non-conservative and a value of 1.5 recommended. The effect of this, which is clearly significant, is illustrated in figures 19.2.1 to 19.2.3. In addition some data for tubulars is compared with flat plate SCFs, using a power index of 1.5, in figure 19.2.4.

At large values of D/t ratios the SCF for tubular members would be expected to be similar to those for flat plates.

An appropriate value for the power index requires further investigation as does SCF variation for D/t ratios greater than 60.

19.3 Cope Hole (see also section 7)

It is suggested that additional data should be obtained taking into account both the size and shape of the hole.

19.4 Conical/Tubular Intersection Weld (see also section 8)

Significant differences exist in the suggested SCFs from various sources for each arrangement considered. Examples of these are illustrated in figure 19.4.1 for unstiffened connections and figure 19.4.2 for bulkhead stiffened connections.

For unstiffened intersections, figure 19.4.1, there appears to be good agreement between the LR program results and reference 11 results and it is recommended that these should be adopted.

However for ring and bulkhead stiffened intersections, figure 19.4.2, this is clearly not the case. For these details it is recommended that the higher values are used unless data supporting the use of a lower value is obtained.
$\text{SCF} = 1 + \frac{3\left(\frac{t_2}{t_1} - 1\right)}{\left[1 + \left(\frac{t_2}{t_1}\right)^n\right]}$

**Figure 19.2.1**

SCF for butt joints of unequal plate thickness without misalignment
SCF = 1 + \frac{6e}{t_1} \left( \frac{t_1^n}{t_1^n + t_2^n} \right) 

Fig. 19.2.2
SCF for Butt Joints of unequal plate thickness including fabrication misalignment
Effect of Length Ratio ($l_1/l_2$)

The example shown below relates to a butt weld where the thicker plate has a 1:4 taper and is close to a fixed support and illustrates the effect of varying length ratio ($l_1/l_2$) and index 'n'.

![Graph showing SCF vs Ratio of plate thickness ($t_2/t_1$) for varying ratios $l_1/l_2$ and indices 'n'.]

Figure 19.2.3
SCF for butt joints of unequal plate thickness without misalignment with varying length ratio
Figure 19.2.4
Comparison of SCF for flat plate and tubular
1. SCF = 1 + 0.85 \sqrt{\frac{D}{t}} \tan \alpha \\
2. SCF = 1 + 0.71 \sqrt{\frac{D}{t}} \tan \alpha \\

* Results from L.R. program

Figure 19.4.1
Comparison of SCF for conical/tubular intersection unstiffened, equal thickness (t_1 = t_2 = t)
1. \[ SCF = 1 + 0.53 \sqrt{\frac{D}{t}} \tan \alpha \]

2. Results from LR program

![Graph showing SCF vs D/t for different values of \( \alpha \).]

**Figure 19.4.2**
Comparison of SCF for bulkhead stiffened conical/tubular intersection butt welds
19.5 Surface Attachment Weld (see also section 10)

Clarification is required as to what effective SCF, if any, is included in the use of the 'F' S-N curve for these details, particularly for details where an additional SCF, determined by F.E. analysis, is to be included.

19.6 Ring Reinforced Penetration Weld (see also section 11)

Additional data would be useful for weld toes (location 1) of ring reinforced rectangular holes with a corner radius and weld throat (location 2) shear stresses for all penetration geometries except circular holes.

It would also be useful to determine what value of SCF if any is inherent account in the S-N curve specified for failure in the weld throat.

19.7 Column to Pontoon Joint (see section 14)

Very little suitable data is available. However experience suggests that few problems are encountered at this location. The possibility of fatigue cracking may be minimised by attention to detail design. For some particularly complex structural arrangements a specific analysis may be required.

19.8 Bracing to Column Joint (see section 15)

An attempt has been made in section 15 to give some information on SCFs for various locations within these complex joints. In general final design SCF data for an actual joint should be obtained by an appropriate method (e.g. FE analysis, model testing).

19.9 Bracing to Bracing Joints (see section 16)

Considerable effort has been applied towards obtaining SCF data for these joints on fixed platforms. There is, however, very little data available on stiffened joints common on semi-submersibles.

An attempt has been made in section 16 to give some information on SCFs for various locations within these joints. In general final design SCF data for an actual joint should be obtained by an appropriate method.

19.10 Cruciform Joint (see section 17)

Although the data considered from various sources are broadly consistent for the cases given one source implies that the theoretical values may be too conservative. In addition some of the factors given in reference 28 for angular misalignment require confirmation.


