April 2009/ John Wægter

# Note 2.1

# Fatigue design based on *S-N* data

# Fatigue design based on *S-N* data

## *General*

Fatigue analysis of welded components is based on the long term distribution of stresses from either a known load history or from design rules.

The capacity with respect to the fatigue strength is characterized by *S-N* curves, which give the relationship between the stress ranges applied to a given detail and the number of constant amplitude load cycles to failure.

Depending on the kind of stresses used in the calculation, the fatigue assessment may be categorised by the so-called 'nominal stress approach', 'hot spot stress approach' and 'notch stress approach'. The three stresses are defined as follows:

**Nominal stress** — *A general stress* in a structural component calculated by beam theory based on the applied loads and the sectional properties of the component. The sectional properties are determined at the section considered (i.e. the hot spot location) by taking into account the gross geometric changes of the detail (e.g. cut-outs, tapers, haunches, brackets, changes of scantlings, misalignments, etc.). The nominal stress can also be calculated using a coarse mesh FE analysis or an analytical approach.

**Hot spot stress** — *A local stress* at the hot spot (point with highest stress) where cracks may be initiated. The hot-spot stress takes into account the influence of structural discontinuities due to the geometry of the connection, but excludes the effects of the weld itself. The hot spot stress is also referred to as *structural stress* or *geometric stress*.

**Notch stress** — *A peak stress* at the root/toe of a weld or notch taking into account stress concentrations due to the effects of structural geometry as well as the presence of the weld.

For this course the emphasis is on the two first approaches, the nominal stress approach and the hot spot stress approach, as these approaches currently dominate practical design work. The notch stress approach is used in special cases where reliable results cannot be obtained based on the two first methods.

## *Nominal stress*

Traditional fatigue analysis of welded components is based on the use of nominal stresses and catalogues of classified details. A particular type of detail is assigned to a particular fatigue class with a given *S-N* curve.

In general, nominal stresses are determined using the beam theory

$$\sigma_{nom} = \frac{F}{A} + \frac{M}{I} y \qquad (1)$$

where
$F$ is axial force
$A$ is area of cross section
$M$ is bending moment
$I$ is moment of inertia of the cross section
$y$ is distance from centroid to the point considered

An example of the determination of the nominal stress at a welded attachment is shown in Figure 1. Here the nominal stress is simply determined as the beam stress in the region containing the weld detail, but without considering any influence of the attachment on the stress distribution.

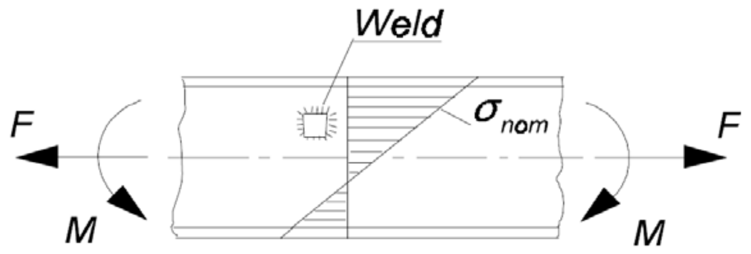



Figure 1 Nominal stress in beam-like component

In some cases it might also be necessary to include the effect of certain *macro-geometric features* as well as stress fields in the vicinity of *concentrated forces and reaction forces* when the nominal stress is determined.

Examples of welded structures that contain macro-geometrical forms that are not included in the classified detail in design codes are given in Figure 2. In all cases the stress field is altered as compared to the stresses calculated using elementary stress analysis formulas.

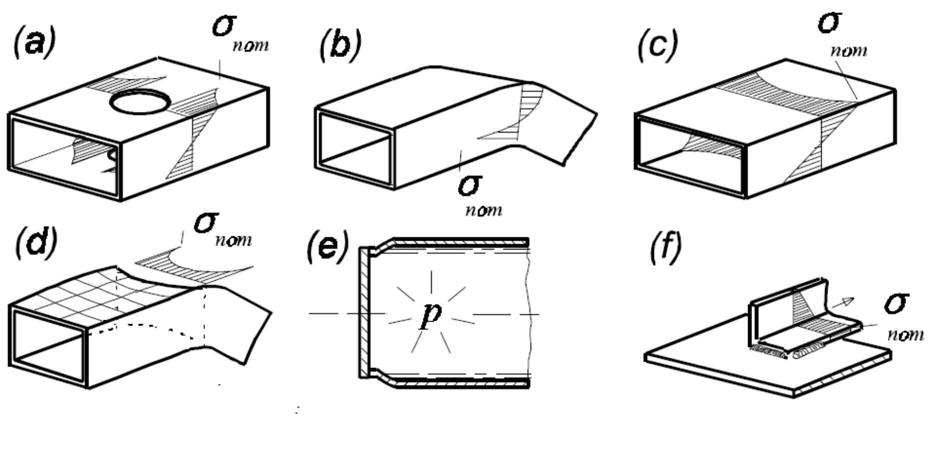



Figure 2 Examples of macro-geometric effects

Examples of stress fields in the vicinity of concentrated loads and reaction forces are shown in Figure 3.

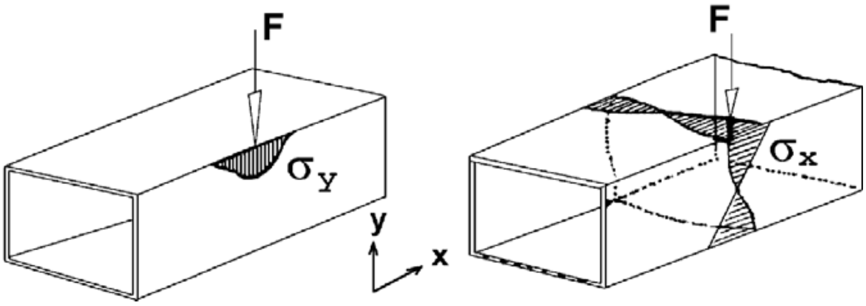



Figure 3 Modified (local) nominal stresses near concentrated loads

Another example shown in Figure 4 further illustrates the correct determination of the stress to be considered in the fatigue calculation. In b) the stress concentration from the hole is a macro-geometric effect that must be accounted for, giving the relevant local stress equal to $SCF_{macro} \cdot \sigma_{nom}$ where $SCF_{macro}$ is the stress concentration factor due to the hole, i.e.

$$\sigma_{local} = \begin{cases} \sigma_{nom} \\ SCF_{macro} \cdot \sigma_{nom} \end{cases} \tag{2}$$

This local stress shall be used together with the relevant *S-N* curves dependent on the joint classification.

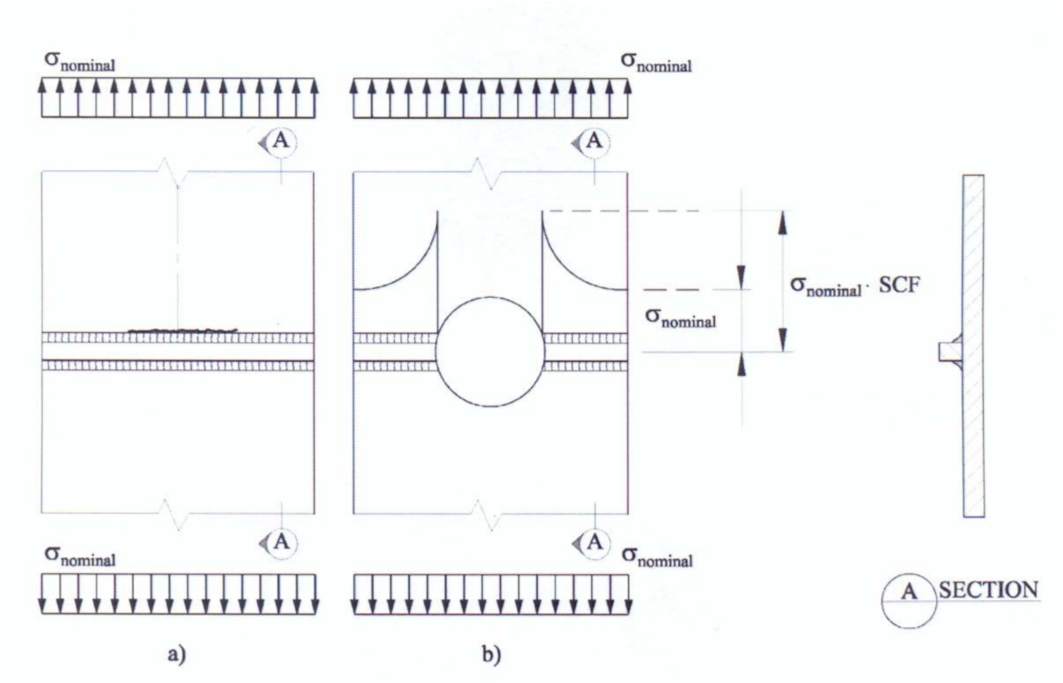



Figure 4 Local stresses

Summarizing these findings we can state that

- The joint classification and the corresponding *S-N* curve used in association with nominal stresses take the local stress concentration created by the joint itself and by the weld profile into account.

- The design stress can typically be determined as the nominal stress adjacent to the weld under consideration.

- However, in cases where macro-geometric features or local loading create a stress pattern different to that determined by simple stress analysis formulas, the relevant stress for the fatigue calculation is the local stress determined in Equation (2).

*Another aspect that may require special attention is the misalignment included in the fatigue strength from test specimens.*

Unfortunately, in most data reproduced in relation to fatigue strength, the built-in misalignment is not quantified. In some design standards it is assumed that the fatigue strength of a considered joint detail includes ‘normal’ fabrication tolerances for the actual type of detail, while in other design standards, it is required to include a specific stress concentration factor to take realistic fabrication tolerances into consideration. Generally, this aspect is *most critical for plated structures* for which most modern design standards today require the inclusion of an *SCF*, typically given by

$$SCF = 1 + 3\frac{e}{t} \qquad (3)$$

where $e$ is the eccentricity and $t$ the plate thickness.

## *Structural stress*

Structural stresses accounts for any stress created by the considered detail *exclusive* of the non-linear stress field due to the notch at the weld toe.

Stresses in shell structures which are determined based on the theory of shells are *structural stresses*. In the shell theory stresses are linearly distributed across the plate thickness and consists of two parts: *membrane stress* and *shell bending stress*, see Figure 5. It should be noted that membrane stresses and local bending stresses also occur in e.g. plated structures, and for ease of reference we still denote these stress components shell stresses.

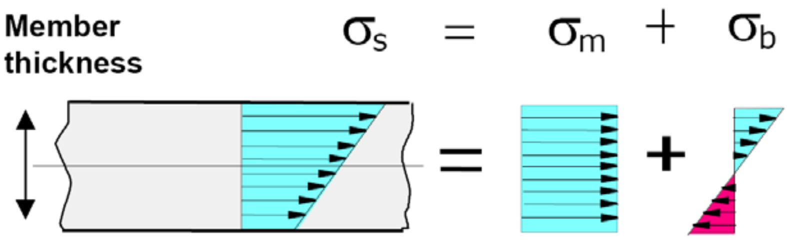



Figure 5 Shell stresses

The structural stress includes all stress raising effects of the structural detail, but excludes the stress concentration due to the local weld profile itself. Figure 6 shows examples of structural details together with the structural stress distribution.

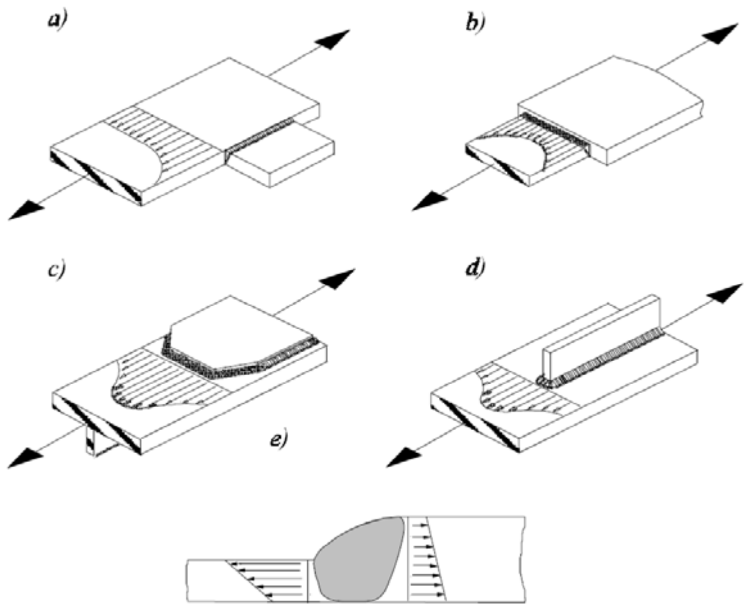



Figure 6 Structural details and structural stress

## *Notch stress*

The notch stresses accounts for any stress created by the considered detail *inclusive* of the non-linear stress field due to the notch at the weld toe. It is composed of the sum of the structural stress and the *nonlinear peak stress*, see Figure 7.

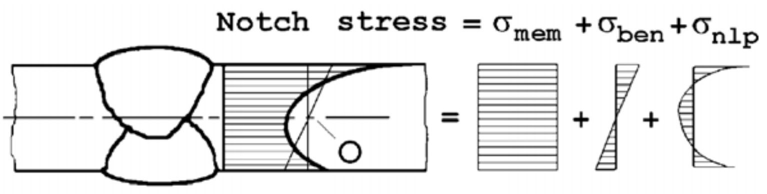



Figure 7 Local notch stress at a weld toe

The stress components of the notch stress $\sigma_{ln}$ are:

$\sigma_{mem}$ membrane stress

$\sigma_{ben}$ shell bending stress

$\sigma_{nlp}$ non-linear stress peak stress

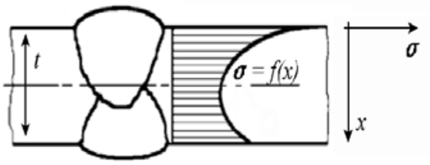
If a refined stress analysis method that gives a non-linear stress distribution is used, the stress components can be separated by the following method:

- The membrane stress $\sigma_{mem}$ is equal to the average stress calculated through the thickness of the plate. It is constant through the thickness.

- The shell bending stress $\sigma_{ben}$ is linearly distributed through the thickness of the plate. It is found by drawing a straight line through the point O where the membrane stress intersects the mid-plane of the plate. The gradient of the shell bending stress is chosen such that the remaining non-linearly distributed component is in equilibrium.

- The non-linear stress peak $\sigma_{nlp}$ is the remaining component of the stress.

The stress components can be separated analytically for a given stress distribution $\sigma(x)$ as follows




$$\sigma_{mem} = \frac{1}{t} \cdot \int_{x=0}^{x=t} \sigma(x) \cdot dx$$

$$\sigma_{ben} = \frac{6}{t^2} \cdot \int_{x=0}^{x=t} \sigma(x) \cdot \left(\frac{t}{2} - x\right) \cdot dx$$

$$\sigma_{nlp}(x) = \sigma(x) - \sigma_{mem} - \left(1 - \frac{x}{2}\right) \cdot \sigma_{ben}$$

Figure 8 Separation of stress components

## *Hot spot stress*

Fatigue design of more complicated details is normally based on structural hot spot stresses because the nominal stress approach has severe limitations. The nominal stress approach ignores the actual dimensional variations of a particular structural detail, and often the shape of the welded component is so complex that the determination of the nominal stress is difficult or impossible. Also, it requires a specific, experimentally determined *S-N* curve for the detail considered.

Thus, for details with no available design *S-N* curves, the designer needs a more general design tool based on structural hot spot stresses. Hot spots are points with the highest stresses, and while structural stresses are the general term for the shell stresses in the structure, *the hot spot stress is the value of the structural stress on the surface at the hot spot of the component which is to be assessed.*

The structural hot spot stress approach is generally applicable for the fatigue design of welded plate, shell and tubular structures where cracks at the weld toe are critical. If critical cracks grow from the weld root special care should be taken.

Thus, in Ref. /3/ the hot spot method is therefore limited to the assessment of the weld toe, i.e. cases **a** to **e** in Figure 9, while it is not immediately applicable in cases where cracks grow from the weld root and propagate through the weld metal, i.e. cases **f** to **i** in Figure 9.

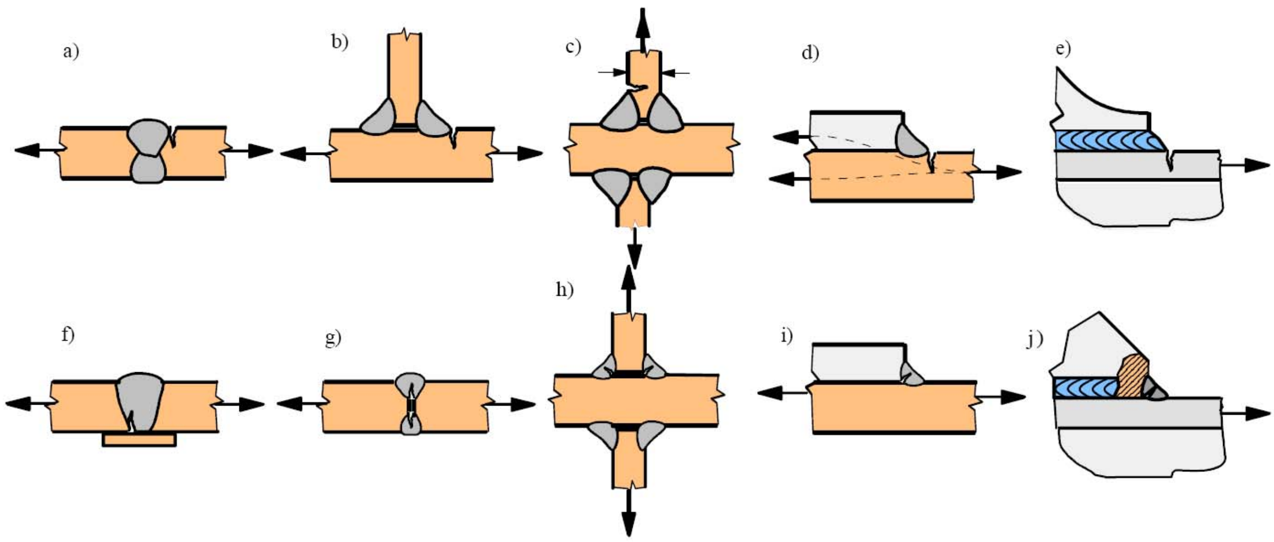



Figure 9 Various locations of crack propagation in welded joints

However, in Ref. /3/ it is also noted that:

The method of structural hot spot stress may be extended to the assessment of spots of the welded joint susceptible to fatigue cracking other than on plate surface, e.g. on a fillet weld root. In this case, structural hot spot stress on surface is used as an indication and estimation of the stress for the spot in consideration. The S-N curves or structural hot spot stress concentration factors used for verification in this case depend largely on geometric and dimensional parameters and are only valid within the range of these parameters.

The structural stress includes all stress raising effects of the structural detail, but excludes the stress concentration due to the local weld profile itself. Thus, when analyzing a detail the designer must be able to separate the appropriate stress components to derive the relevant stresses for the hot spot design.

A detailed FE analysis of a welded joint may result in the stresses shown as total stresses in Figure 10.

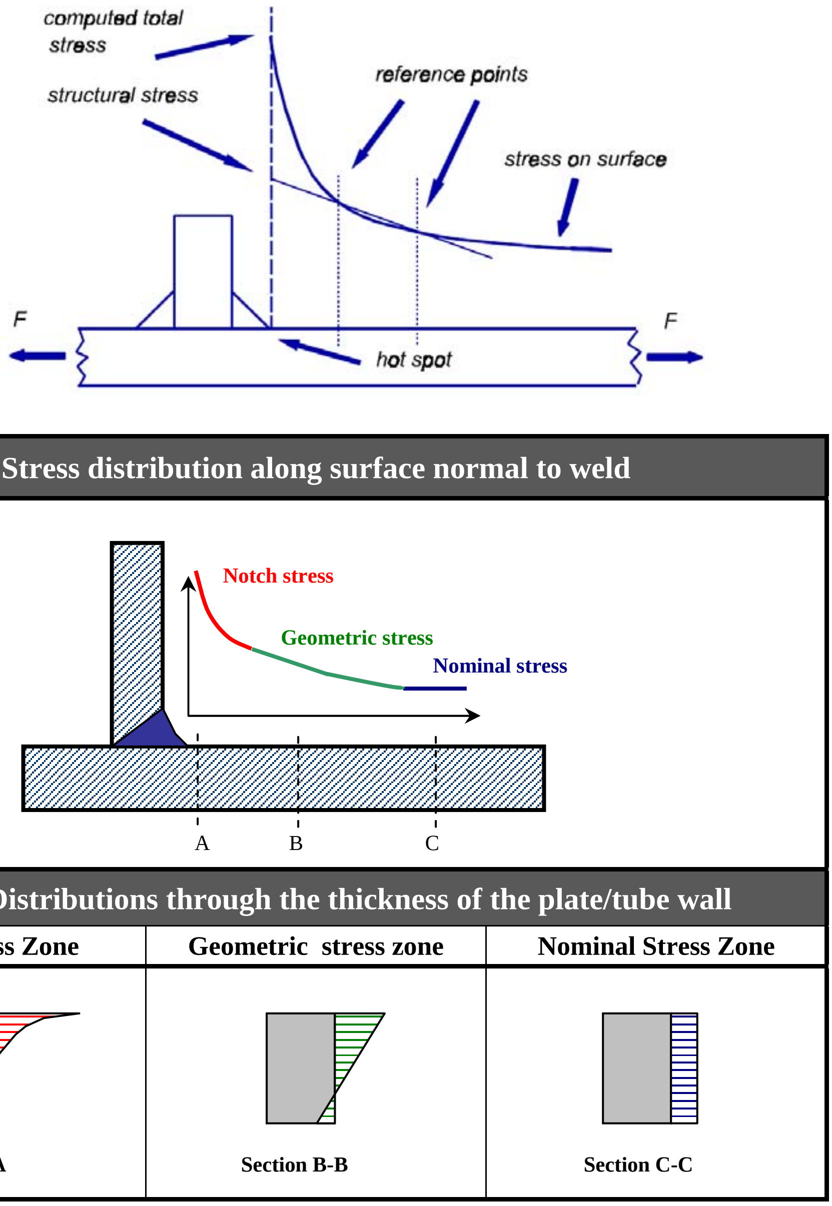



Figure 10 Definition of structural hot spot stress

The stresses far away from the weld are the nominal stresses. Closer to the weld the stress raising effect of the structural detail becomes important and in the close vicinity of the weld the stress concentration due to the weld itself generates very high notch stresses.

*In a hot spot stress design the appropriate stresses are those that catch the stress concentration from the structural detail, but not the stress concentration from the weld itself.* The structural hot spot stresses thus defined can be determined by using reference points and extrapolation to the weld toe at the hot spot in consideration as shown in Figure 10.

The stress extrapolation procedure given above is the classical approach to derive the hot spot stresses, but other procedures based on a single stress value in a read out points close to the weld toe are also used (Method B in Ref. /4/).

For a more complex state of stress, e.g. a biaxial stress state in a plate, the question arises in relation to which stress component should be considered. Traditionally, the principal stress has always been considered a significant parameter for the analysis of fatigue crack growth. At least as long as the principal stress is essentially normal to the weld. Some guidelines recommend using the normal to the weld stress component in cases where the principal stress tends to become parallel with the weld, while Ref. /4/ gives guidance to calculate an *effective hot spot stress* based on a more complex procedure.

## *Stress range*

The stress range, see Figure 11, is the main parameter to be determined for fatigue analysis. In the case of constant amplitude loading, Figure 11 (a), the stress range is defined as

$$\Delta\sigma = \sigma_{\max} - \sigma_{\min} \qquad (4)$$

This definition of stress range applies for any of the three stress categories defined previously.

In many real structures, in particular for welded structures, variable amplitude loading, Figure 11 (b) is more common than constant amplitude loading.

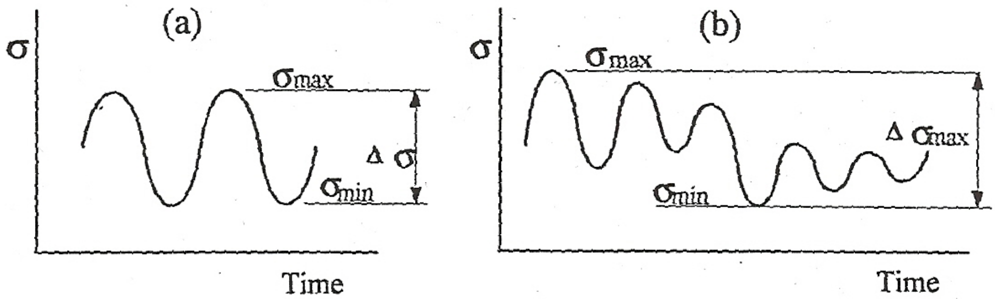



Figure 11 Constant (a) and variable (b) amplitude stress histories

Fatigue analysis is based on the cumulative effect of all stress range occurrences during the design life. A stress range occurrence table or a *stress range spectrum* must therefore be produced from the stress history by an appropriate counting method, typically *Rainflow counting*. The stress range spectrum, Figure 12, is a representation of stress ranges and the associated number of cycles. Using the stress range spectrum in combination with Miner's rule allows a direct calculation of the cumulative fatigue from the considered stress history.

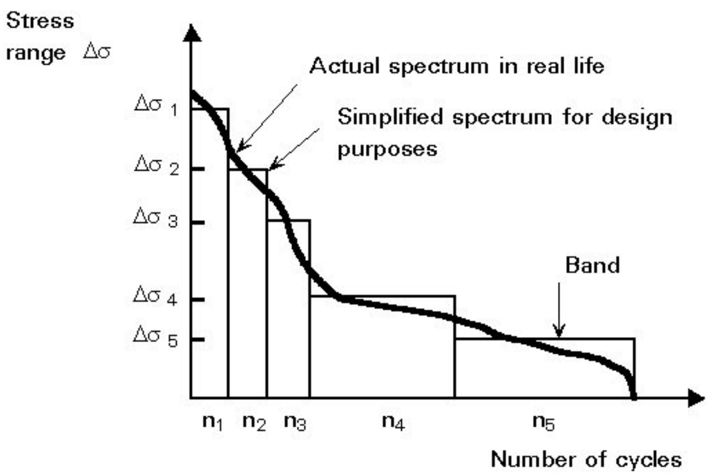



Figure 12 Stress range spectrum

## *Fatigue resistance according to DNV-RP-C203*

### Introduction

In the following the design *S-N* curves and procedures as recommended in Ref. /4/ are used as an example of a modern state of the art design code for fatigue. The text in this section is a copy of the corresponding parts of C203 and has not been edited or changed in any way (although not all clauses of C203 have been reproduced here), and the original references to figures and tables (in Ref. /4/) have been maintained for easy cross reference.

### General (2.4.1)

The fatigue design is based on use of S-N curves, which are obtained from fatigue tests. The design S-N curves which follows are based on the mean-minus-two-standard-deviation curves for relevant experimental data. The S-N curves are thus associated with a 97.6% probability of survival.

### Failure criterion inherent the S-N curves (2.4.2)

Most of the S-N data are derived by fatigue testing of small specimens in test laboratories. For simple test specimens the testing is performed until the specimens have failed. In these specimens there is no possibility for redistribution of stresses during crack growth. This means that most of the fatigue life is associated with growth of a small crack that grows faster as the crack size increases until fracture.

For details with the same calculated damage, the initiation period of a fatigue crack takes longer time for a notch in base material than at a weld toe or weld root. This also means that with a higher fatigue resistance of the base material as compared with welded details, the crack growth will be faster in base material when fatigue cracks are growing.

For practical purpose one defines these failures as being crack growth through the thickness.

When this failure criterion is transferred into a crack size in a real structure where some redistribution of stress is more likely, this means that this failure criterion corresponds to a crack size that is somewhat less than the plate thickness.

The tests with tubular joints are normally of a larger size. These joints also show larger possibility for redistribution of stresses as a crack is growing. Thus a crack can grow through the thickness and also along a part of the joint before a fracture occur during the testing. The number of cycles at a crack size through the thickness is used when the S-N curves are derived. As these tests are not very different from that of the actual behaviour in a structure, this failure criterion for S-N curves for tubular corresponds approximately to the thickness at the hot spot (chord or brace as relevant).

## S-N curves and joint classification (2.4.3)

For practical fatigue design, welded joints are divided into several classes, each with a corresponding design S-N curve. All tubular joints are assumed to be class T. Other types of joint, including tube to plate, may fall in one of the 14 classes specified in Table 2-1, Table 2-2 and Table 2-3, depending upon:

— the geometrical arrangement of the detail
— the direction of the fluctuating stress relative to the detail
— the method of fabrication and inspection of the detail.

Each construction detail at which fatigue cracks may potentially develop should, where possible, be placed in its relevant joint class in accordance with criteria given in Appendix A. It should be noted that, in any welded joint, there are several locations at which fatigue cracks may develop, e. g. at the weld toe in each of the parts joined, at the weld ends, and in the weld itself. Each location should be classified separately.

The basic design S-N curve is given as

$$\log N = \log \bar{a} - m \log \Delta\sigma \qquad (2.4.1)$$

| | | |
|---|---|---|
| N | = | predicted number of cycles to failure for stress range $\Delta\sigma$ |
| $\Delta\sigma$ | = | stress range |
| m | = | negative inverse slope of S-N curve |
| $\log \bar{a}$ | = | intercept of log N-axis by S-N curve |

$$\log \bar{a} = \log a - 2s \qquad (2.4.2)$$

where

| | | |
|---|---|---|
| a | = | constant relating to mean S-N curve |
| s | = | standard deviation of log N. |

The fatigue strength of welded joints is to some extent dependent on plate thickness. This effect is due to the local geometry of the weld toe in relation to thickness of the adjoining plates. See also effect of profiling on thickness effect in section 7.2. It is also dependent on the stress gradient over the thickness. Reference is made to Appendix D, Commentary. The thickness effect is accounted for by a modification on stress such that the design S-N curve for thickness larger than the reference thickness reads:

$$\log N = \log \bar{a} - m \log\left(\Delta\sigma\left(\frac{t}{t_{ref}}\right)^k\right) \quad (2.4.3)$$

where

$m$ = negative inverse slope of the S - N curve

$\log \bar{a}$ = intercept of log N axis

$t_{ref}$ = reference thickness equal 25 mm for welded connections other than tubular joints. For tubular joints the reference thickness is 32 mm. For bolts $t_{ref}$ = 25 mm

$t$ = thickness through which a crack will most likely grow. $t = t_{ref}$ is used for thickness less than $t_{ref}$

$k$ = thickness exponent on fatigue strength as given in Table 2-1, Table 2-2 and Table 2-3.

$k$ = 0.10 for tubular butt welds made from one side

$k$ = 0.25 for threaded bolts subjected to stress variation in the axial direction.

In general the thickness exponent is included in the design equation to account for a situation that the actual size of the structural component considered is different in geometry from that the S-N data are based on. The thickness exponent is considered to account for different size of plate through which a crack will most likely grow. To some extent it also accounts for size of weld and attachment. However, it does not account for weld length or length of component different from that tested such as e. g. design of mooring systems with a significant larger number of chain links in the actual mooring line than what the test data are based on. Then the size effect should be carefully considered using probabilistic theory to achieve a reliable design, see Appendix D, Commentary.

## S-N curves in air (2.4.4)

S-N curves for air environment are given in Table 2-1 and Figure 2-6. The T curve is shown in Figure 2-8. In the low cycle region the maximum stress range is that of the B1 curve as shown in Figure 2-6. However, for offshore structures subjected to typical wave and wind loading the main contribution to fatigue damage is in the region $N > 10^6$ cycles and the bilinear S-N curves defined in Table 2-1 can be used.

| Table 2-1 S-N curves in air | | | | | | |
|---|---|---|---|---|---|---|
| *S-N curve* | *N ≤ 10^7 cycles* | | *N > 10^7 cycles* $\log \bar{a}_2$ | *Fatigue limit at 10^7 cycles *)* | *Thickness exponent k* | *Structural stress concentration embedded in the detail (S-N class), ref. also equation (2.3.2)* |
| | $m_1$ | $\log \bar{a}_1$ | $m_2 = 5.0$ | | | |
| B1 | 4.0 | 15.117 | 17.146 | 106.97 | 0 | |
| B2 | 4.0 | 14.885 | 16.856 | 93.59 | 0 | |
| C | 3.0 | 12.592 | 16.320 | 73.10 | 0.15 | |
| C1 | 3.0 | 12.449 | 16.081 | 65.50 | 0.15 | |
| C2 | 3.0 | 12.301 | 15.835 | 58.48 | 0.15 | |
| D | 3.0 | 12.164 | 15.606 | 52.63 | 0.20 | 1.00 |
| E | 3.0 | 12.010 | 15.350 | 46.78 | 0.20 | 1.13 |
| F | 3.0 | 11.855 | 15.091 | 41.52 | 0.25 | 1.27 |
| F1 | 3.0 | 11.699 | 14.832 | 36.84 | 0.25 | 1.43 |
| F3 | 3.0 | 11.546 | 14.576 | 32.75 | 0.25 | 1.61 |
| G | 3.0 | 11.398 | 14.330 | 29.24 | 0.25 | 1.80 |
| W1 | 3.0 | 11.261 | 14.101 | 26.32 | 0.25 | 2.00 |
| W2 | 3.0 | 11.107 | 13.845 | 23.39 | 0.25 | 2.25 |
| W3 | 3.0 | 10.970 | 13.617 | 21.05 | 0.25 | 2.50 |
| T | 3.0 | 12.164 | 15.606 | 52.63 | 0.25 for SCF ≤ 10.0<br>0.30 for SCF >10.0 | 1.00 |
| *) see also section 2.10 | | | | | | |

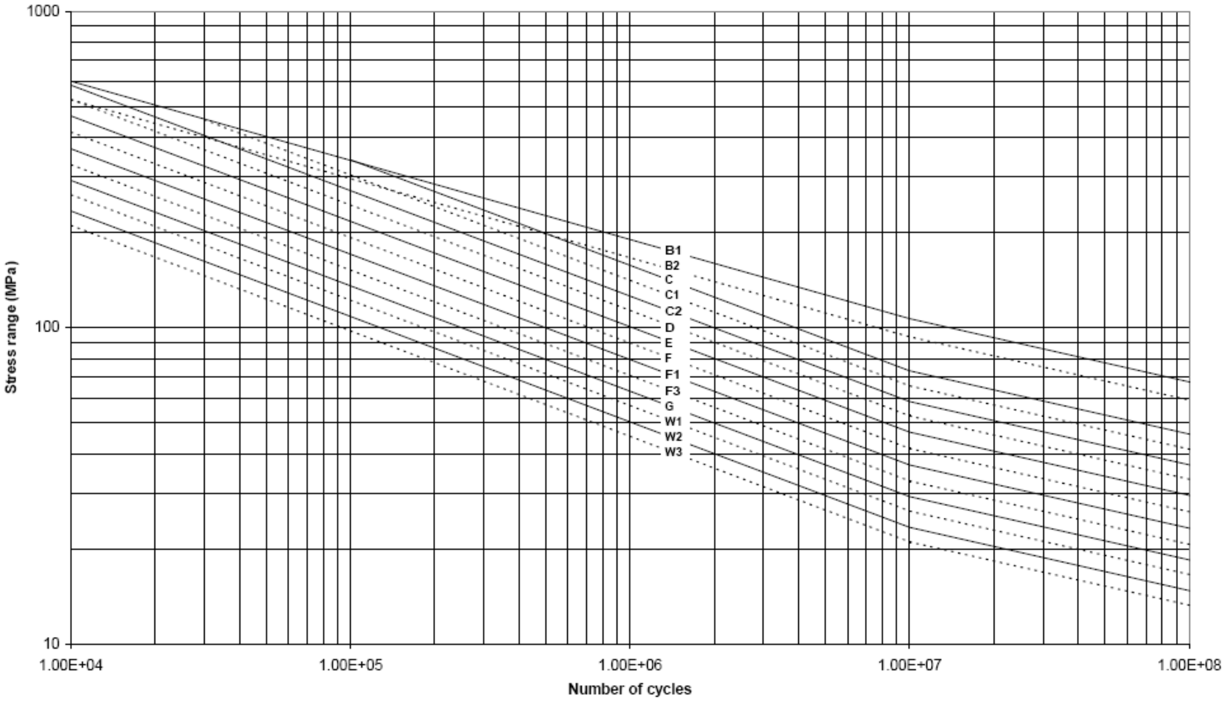



**Figure 2-6**
**S-N curves in air**

## S-N curves in seawater with cathodic protection (2.4.5)

S-N curves for seawater environment with cathodic protection are given in Table 2-2 and Figure 2-7. The T curve is shown in Figure 2-8. For shape of S-N curves see also comment in 2.4.4.

| Table 2-2 S-N curves in seawater with cathodic protection | | | | | | |
|---|---|---|---|---|---|---|
| *S-N curve* | *$N \le 10^6$ cycles* | | *$N > 10^6$ cycles* $\log\bar{a}_2$ | *Fatigue limit at $10^7$ cycles*)* | *Thickness exponent k* | *Stress concentration in the S-N detail as derived by the hot spot method* |
| | $m_1$ | $\log\bar{a}_1$ | *$m_2 = 5.0$* | | | |
| B1 | 4.0 | 14.917 | 17.146 | 106.97 | 0 | |
| B2 | 4.0 | 14.685 | 16.856 | 93.59 | 0 | |
| C | 3.0 | 12.192 | 16.320 | 73.10 | 0.15 | |
| C1 | 3.0 | 12.049 | 16.081 | 65.50 | 0.15 | |
| C2 | 3.0 | 11.901 | 15.835 | 58.48 | 0.15 | |
| D | 3.0 | 11.764 | 15.606 | 52.63 | 0.20 | 1.00 |
| E | 3.0 | 11.610 | 15.350 | 46.78 | 0.20 | 1.13 |
| F | 3.0 | 11.455 | 15.091 | 41.52 | 0.25 | 1.27 |
| F1 | 3.0 | 11.299 | 14.832 | 36.84 | 0.25 | 1.43 |
| F3 | 3.0 | 11.146 | 14.576 | 32.75 | 0.25 | 1.61 |
| G | 3.0 | 10.998 | 14.330 | 29.24 | 0.25 | 1.80 |
| W1 | 3.0 | 10.861 | 14.101 | 26.32 | 0.25 | 2.00 |
| W2 | 3.0 | 10.707 | 13.845 | 23.39 | 0.25 | 2.25 |
| W3 | 3.0 | 10.570 | 13.617 | 21.05 | 0.25 | 2.50 |
| T | 3.0 | 11.764 | 15.606 | 52.63 | 0.25 for SCF ≤ 10.0<br>0.30 for SCF >10.0 | 1.00 |
| *) see also 2.10 | | | | | | |

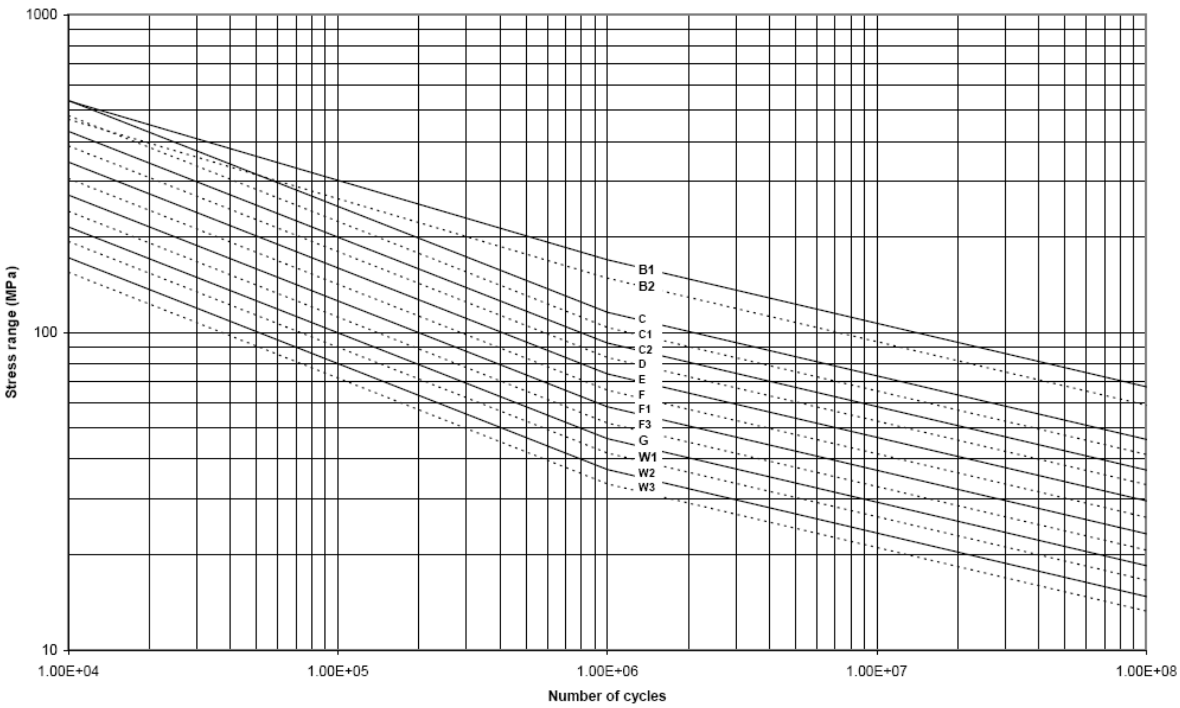



**Figure 2-7**
**S-N curves in seawater with cathodic protection**

## S-N curves for tubular joints (2.4.6)

S-N curves for tubular joints in air environment and in seawater with cathodic protection are given in Table 2-1, Table 2-2 and Table 2-3.

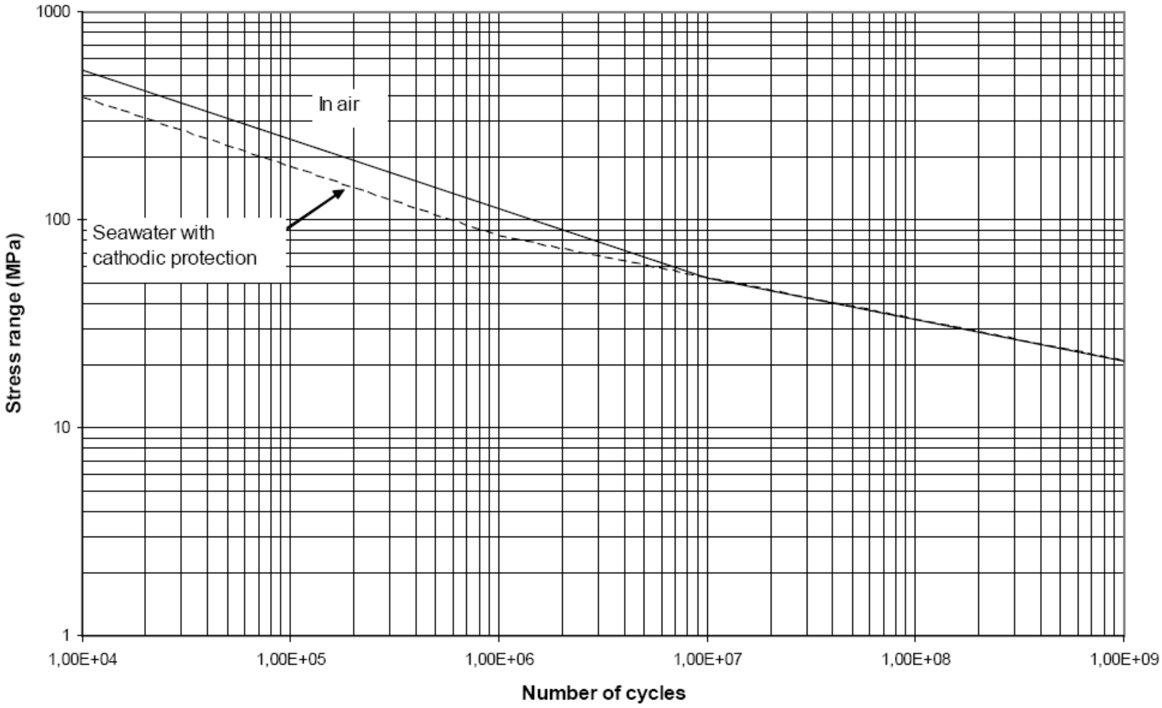



**Figure 2-8**
**S-N curves for tubular joints in air and in seawater with cathodic protection**

## S-N curves for free corrosion (2.4.9)

S-N curves for free corrosion, i.e. without corrosion protection, are given in Table 2-3.

See also Commentary section for consideration of corrosion protection of connections in the splash zone and inside tanks in FPSOs.

**Table 2-3 S-N curves in seawater for free corrosion**

| S-N curve | $\log \bar{a}$ For all cycles m = 3.0 | Thickness exponent k |
|---|---|---|
| B1 | 12.436 | 0 |
| B2 | 12.262 | 0 |
| C | 12.115 | 0.15 |
| C1 | 11.972 | 0.15 |
| C2 | 11.824 | 0.15 |
| D | 11.687 | 0.20 |
| E | 11.533 | 0.20 |
| F | 11.378 | 0.25 |
| F1 | 11.222 | 0.25 |
| F3 | 11.068 | 0.25 |
| G | 10.921 | 0.25 |
| W1 | 10.784 | 0.25 |
| W2 | 10.630 | 0.25 |
| W3 | 10.493 | 0.25 |
| T | 11.687 | 0.25 for SCF ≤ 10.0<br>0.30 for SCF >10.0 |

## Effect of fabrication tolerances (2.6)

Normally larger fabrication tolerances are allowed in real structures than that accounted for in the test specimens used to derive S-N data, ref. *DNV OS-C401; Fabrication and Testing of Offshore Structures*. Therefore, additional stresses resulting from normal fabrication tolerances should be included in the fatigue design. Special attention should be given to the fabrication tolerances for simple butt welds in plates and tubulars as these give the most significant increase in additional stress. Stress concentration factors for butt welds are given in section 3.1.2 and at tubular circumferential welds in section 3.3.7.

## Stress Concentration Factors (3)

### Stress concentration factors for plated structures (3.1)

### General (3.1.1)

A stress concentration factor may be defined as the ratio of hot spot stress range over nominal stress range.

### Stress concentration factors for butt welds (3.1.2)

The eccentricity between welded plates may be accounted for in the calculation of stress concentration factor. The following formula applies for a butt weld in an unstiffened plate or for a pipe butt weld with a large radius:

$$SCF = 1 + \frac{3(\delta_m - \delta_0)}{t}$$

where

$\delta_m$ is eccentricity (misalignment) and t is plate thickness, see Figure 3-9.

$\delta_0 = 0.1\ t$ is misalignment inherent in the S-N data for butt welds. See DNV-OS-C401 for fabrication tolerances.

The stress concentration for the weld between plates with different thickness in a stiffened plate field may be derived from the following formula:

$$\mathrm{SCF} = 1 + \frac{6(\delta_m + \delta_t - \delta_0)}{t\left[1 + \frac{T^{1.5}}{t^{1.5}}\right]} \qquad (3.1.2)$$

where

$\delta_m$ = maximum misalignment

$\delta_t$ = ½ (T− t) eccentricity due to change in thickness.
Note: This applies also at transitions sloped as 1:4.

$\delta_0$ = 0.1 t is misalignment inherent in the S-N data for butt welds. See DNV-OS-C401 for fabrication tolerances.

T = thickness of thicker plate

t = thickness of thinner plate

See also Figure 3-8.

## Stress concentration factors for tubular butt weld connections (3.3.7)

Due to less severe S-N curve for the outside weld toe than the inside weld root, it is strongly recommended that tubular butt weld connections subjected to axial loading are designed such that any thickness transitions are placed on the outside (see Figure 3-8). For this geometry, the SCF for the transition applies to the outside. On the inside it is then conservative to use SCF = 1.0. Thickness transitions are normally to be fabricated with slope 1:4.

Stress concentrations at tubular butt weld connections are due to eccentricities resulting from different sources. These may be classified as concentricity (difference in tubular diameters), differences in thickness of joined tubulars, out of roundness and centre eccentricity, see Figure 3-10 and Figure 3-11. The resulting eccentricity may be conservatively evaluated by a direct summation of the contribution from the different sources. The eccentricity due to out of roundness normally gives the largest contribution to the resulting eccentricity $\delta$.

It is conservative to use the formula for plate eccentricities for calculation of SCF at tubular butt welds. The effect of the diameter in relation to thickness may be included by use of the following formula, provided that T/t $\leq$ 2:

$$\mathrm{SCF} = 1 + \frac{6(\delta_t + \delta_m - \delta_0)}{t} \frac{1}{1 + \left(\frac{T}{t}\right)^{\beta}} e^{-\alpha} \qquad (3.3.4)$$

where

$$\alpha = \frac{1.82L}{\sqrt{Dt}} \cdot \frac{1}{1 + \left(\frac{T}{t}\right)^{\beta}}$$

$$\beta = 1.5 - \frac{1.0}{\mathrm{Log}\left(\frac{D}{t}\right)} + \frac{3.0}{\left[\mathrm{Log}\left(\frac{D}{t}\right)\right]^2}$$

$\delta_0 \quad = \quad 0.1\ t$ is misalignment inherent in the S-N data

This formula also takes into account the length over which the eccentricity is distributed: L, ref. Figure 3-9 and Figure 3-8. The stress concentration is reduced as L is increased and or D is reduced. It is noted that for small L and large D the last formula provides stress concentration factors that are close to but lower than that of the simpler formula for plates.

The transition of the weld to base material on the outside of the tubular can normally be classified to S-N curve E. If welding is performed in a horizontal position it can be classified as D. This means that the pipe would have to be rotated during welding.

Equation (3.3.4) applies for the outside tubular side shown in Figure 3.8. For the inside the following formula may be used:

$$\mathrm{SCF} = 1 - \frac{6(\delta_t - \delta_m)}{t} \frac{1}{1 + \left(\frac{T}{t}\right)^{\beta}} e^{-\alpha} \qquad (3.3.5)$$

If the transition in thickness is on the inside of the tubular and the weld is made from both sides, equation (3.3.4) may be applied for the inside weld toe and equation (3.3.5) for the outside weld toe.

If the transition in thickness is on the inside of the tubular and the weld is made from the outside only, the following formulae may be used for the inside weld root:

$$\mathrm{SCF} = 1 + \frac{6\delta_t}{t} \frac{1}{1 + \left(\frac{T}{t}\right)^{\beta}} e^{-\alpha} \qquad (3.3.6)$$

And equation (3.3.5) may be applied for the outside weld toe.

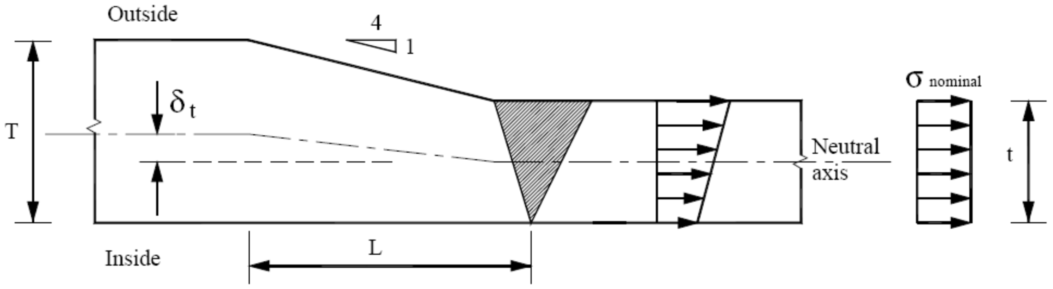



**Figure 3-8**
**Preferred transition in thickness is on outside of tubular butt weld**

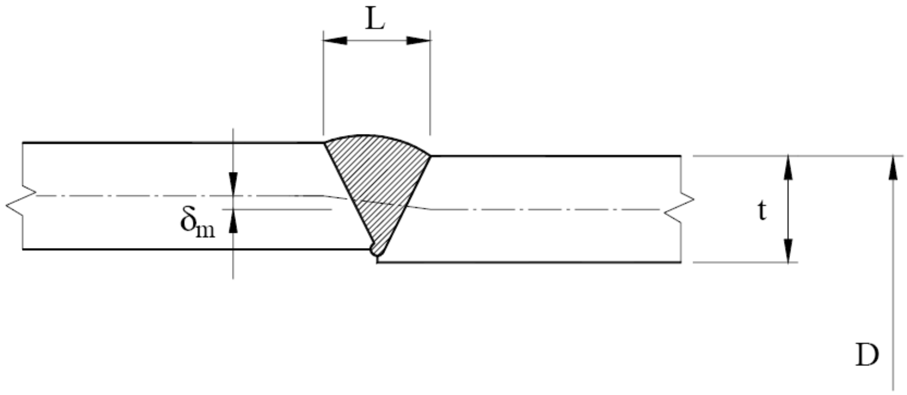



**Figure 3-9**
**Section through weld**

In tubulars, the root side of welds made from one side is normally classified as F3. This requires good workmanship during construction, in order to ensure full penetration welds, and that work is checked by non-destructive examination. It may be difficult to document a full penetration weld in most cases due to limitations in the non-destructive examination technique to detect defects in the root area. The F3 curve can be considered to account for some lack of penetration, but it should be noted that a major part of the fatigue life is associated with the initial crack growth while the defects are small. This may be evaluated by fracture mechanics such as described in BS 7910 “Guidance on Methods for Assessing the Acceptability of Flaws in Fusion Welded Structures”, ref /7/. Therefore, if a fabrication method is used where lack of penetration is to be expected, the design S-N curves should be adjusted to account for this by use of fracture mechanics.

For global moments over the tubular section it is the nominal stress derived at the outside that should be used together with an SCF from equation (3.3.4) for calculation of hot spot stress for fatigue assessment of the outside weld toe. The nominal stress on the inside should be used for assessment of fatigue cracks initiating from the inside.

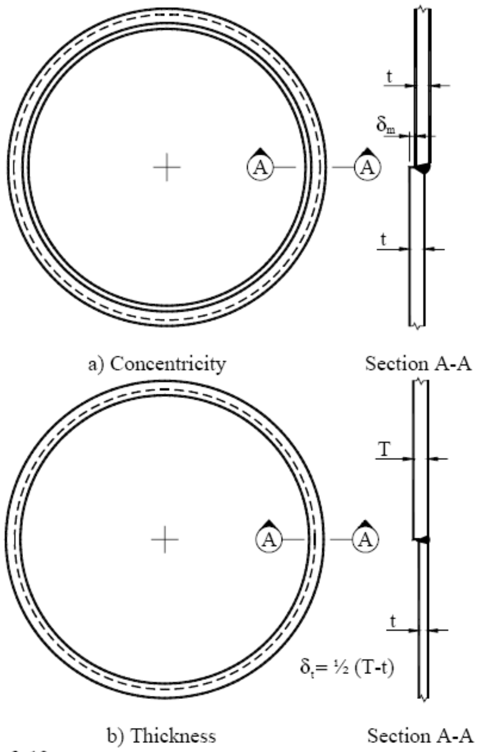



**Figure 3-10**
**Geometric sources of local stress concentrations in tubular butt welds**

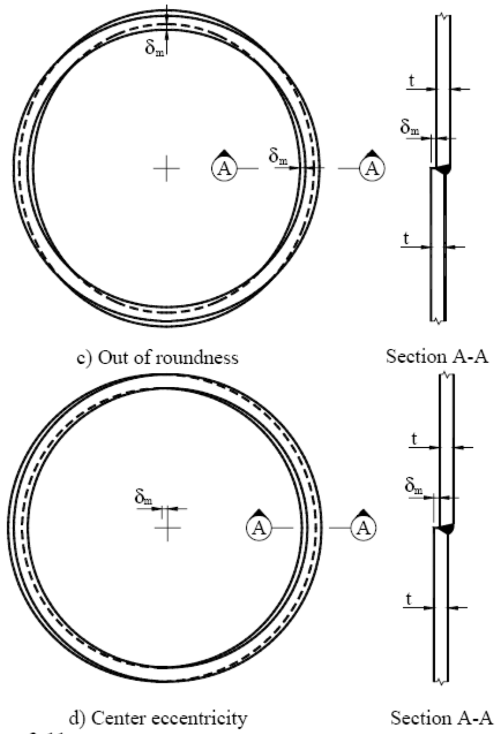



**Figure 3-11**
**Geometric sources of local stress concentrations in tubular butt welds**

## DNV Appendix A

# APPENDIX A
# CLASSIFICATION OF STRUCTURAL DETAILS

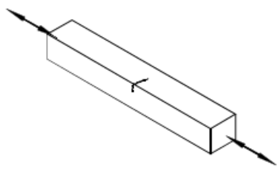
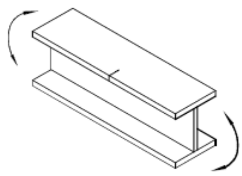
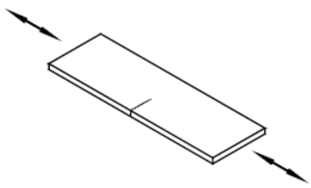
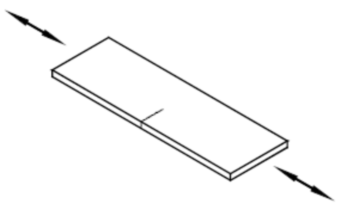
## A.1 Non-welded details

**Table A-1 Non-welded details**

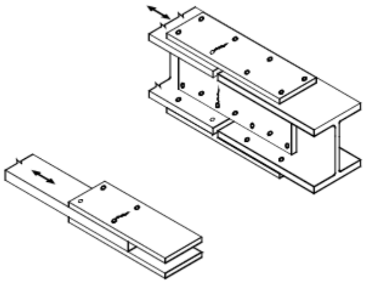
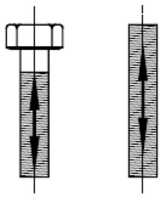
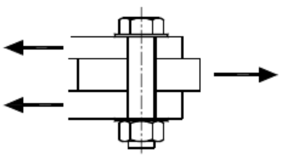
**Notes on potential modes of failure**

In plain steel, fatigue cracks will initiate at the surface, usually either at surface irregularities or at corners of the cross-section. In welded construction, fatigue failure will rarely occur in a region of plain material since the fatigue strength of the welded joints will usually be much lower. In steel with boltholes or other stress concentrations arising from the shape of the member, failure will usually initiate at the stress concentration. The applied stress range shall include applicable stress concentration factors arising from the shape of the member.

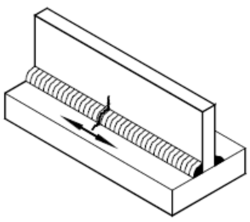
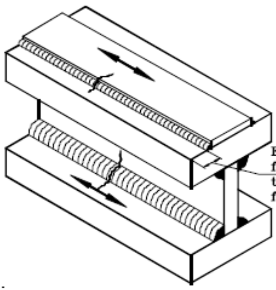
Reference is made to section 2.4.10 for non-welded components made of high strength steel with a surface finish Ra = 3.2 or better.

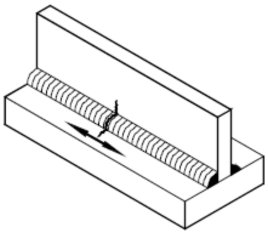
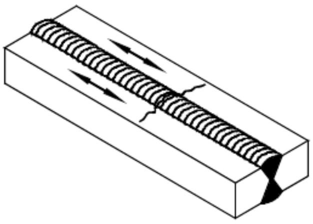
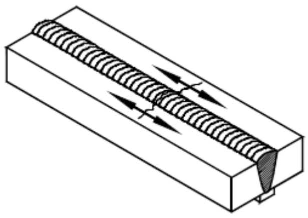
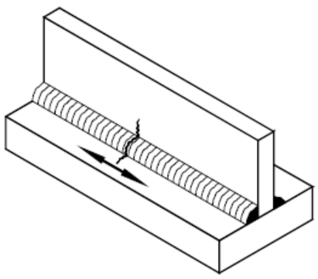
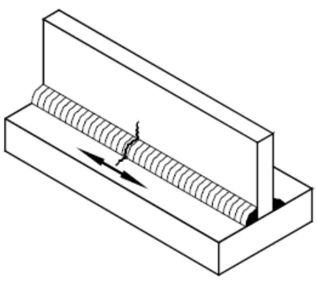
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
|---|---|---|---|
| B1 | 1.<br><br>2.<br> | 1.<br>Rolled or extruded plates and flats<br>2.<br>Rolled sections | 1. to 2.<br>— Sharp edges, surface and rolling flaws to be improved by grinding.<br>— For members that can acquire stress concentrations due to rust pitting etc. curve C is required. |
| B2 | 3.<br> | 3.<br>Machine gas cut or sheared material with no drag lines | 3.<br>— All visible signs of edge discontinuities should be removed.<br>— No repair by weld refill.<br>— Re-entrant corners (slope <1:4) or aperture should be improved by grinding for any visible defects.<br>— At apertures the design stress area should be taken as the net cross-section area. |
| C | 4.<br> | 4.<br>Manually gas cut material or material with machine gas cut edges with shallow and regular draglines. | 4.<br>— Subsequently dressed to remove all edge discontinuities<br>— No repair by weld refill.<br>— Re-entrant corners (slope <1:4) or aperture should be improved by grinding for any visible defects.<br>— At apertures the design stress area should be taken as the net cross-section area. |

## A.2 Bolted connections

| **Table A-2 Bolted connections** | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| C1 | 1. 2.<br> | 1.<br>Unsupported one-sided connections shall be avoided or else effects of eccentricities shall be taken into account when calculating stresses.<br>2.<br>Beam splices or bolted cover plates. | 1. and 2.<br>— Stresses to be calculated in the gross section.<br>— Bolts subjected to reversal forces in shear shall be designed as a slip resistant connection and only the members need to be checked for fatigue. |
| | 3.<br> | 3.<br>Bolts and threaded rods in tension. | 3.<br>— Tensile stresses to be calculated using the tensile stress area of the bolt.<br>— For preloaded bolts, the stress-range in the bolt depends upon the level of preload and the geometry of the connection, see e.g. "*Maskindeler 2*", ref. /23/. |
| F1 | | Cold rolled threads with no following heat treatment like hot galvanising | |
| W3 | | Cut threads | |
| See Section 2.8.3 |  | 4.<br>Bolts in single or double shear. Fitted bolts and normal bolts without load reversal. | Thread not in shear plane.<br>The shear stress to be calculated on the shank area of the bolt. |

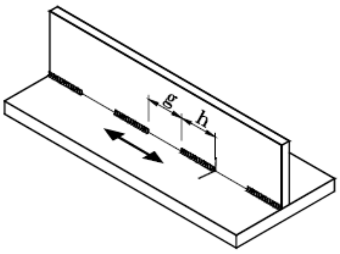
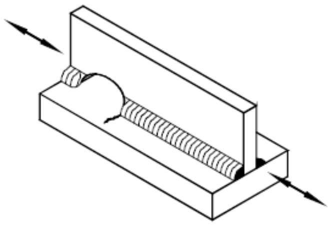
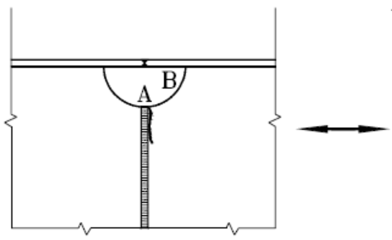
## A.3 Continuous welds essentially parallel to the direction of applied stress

<table>
<tr><th colspan="4">Table A-3 Continuous welds essentially parallel to the direction of applied stress</th></tr>
<tr><td>Detail category</td><td>Constructional details</td><td>Description</td><td>Requirement</td></tr>
<tr><td colspan="4">Notes on potential modes of failure.<br>With the excess weld material dressed flush, fatigue cracks would be expected to initiate at weld defect locations. In the as welded condition, cracks may initiate at start-stop positions or, if these are not present, at weld surface ripples.<br>General comments<br>a) Backing strips<br>If backing strips are used in these joints, they must be continuous. If they are attached by welding, such welds must also comply with the relevant joint classification requirements (note particularly that tack welds, unless subsequently ground out or covered by a continuous weld, would reduce the joint to class F)<br>b) Edge distance<br>An edge distance criterion exists to limit the possibility of local stress concentrations occurring at unwelded edges as a result, for example, of undercut, weld spatter, or accidental overweave in manual fillet welding (see also notes in Table A-7). Although an edge distance can be specified only for the "width" direction of an element, it is equally important to ensure that no accidental undercutting occurs on the unwelded corners of, for example cover plates or box girder flanges. If undercutting occurs it should subsequently be ground smooth.</td></tr>
<tr><td>C</td><td>1.<br><br>2.<br>
</td><td>1.<br>Automatic welds carried out from both sides. If a specialist inspection demonstrates that longitudinal welds are free from significant flaws, category B2 may be used.<br>2.<br>Automatic fillet welds. Cover plate ends shall be verified using detail 5. in Table A-8</td><td>1. and 2.<br>— No start-stop position is permitted except when the repair is performed by a specialist and inspection carried out to verify the proper execution of the repair.</td></tr>
</table>

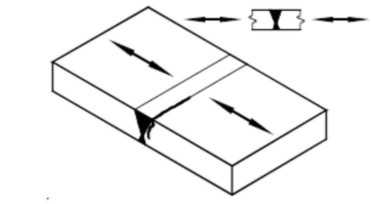
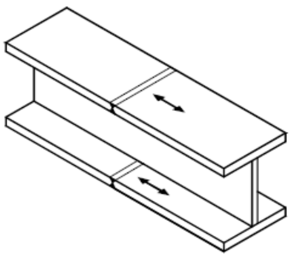
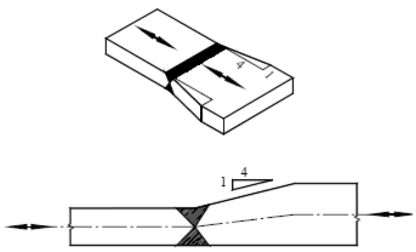
| Table A-3 Continuous welds essentially parallel to the direction of applied stress (Continued) | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| C1 | 3.   4.  | 3.<br>Automatic fillet or butt welds carried out from both sides but containing stop-start positions.<br>4.<br>Automatic butt welds made from one side only, with a backing bar, but without start-stop positions. | 4.<br>— When the detail contains start-stop positions use category C2 |
| C2 |  | 5.<br>Manual fillet or butt welds.<br>6.<br>Manual or automatic butt welds carried out from one side only, particularly for box girders | 6.<br>— A very good fit between the flange and web plates is essential. Prepare the web edge such that the root face is adequate for the achievement of regular root penetration with out brake-out. |
| C2 |  | 7.<br>Repaired automatic or manual fillet or butt welds | 7.<br>— Improvement methods that are adequately verified may restore the original category. |

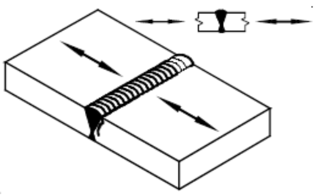
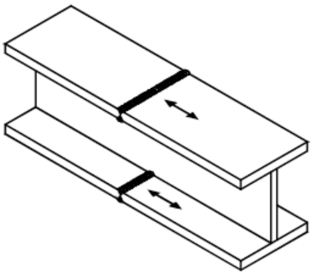
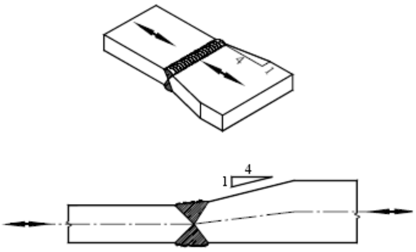
## A.4 Intermittent welds and welds at cope holes

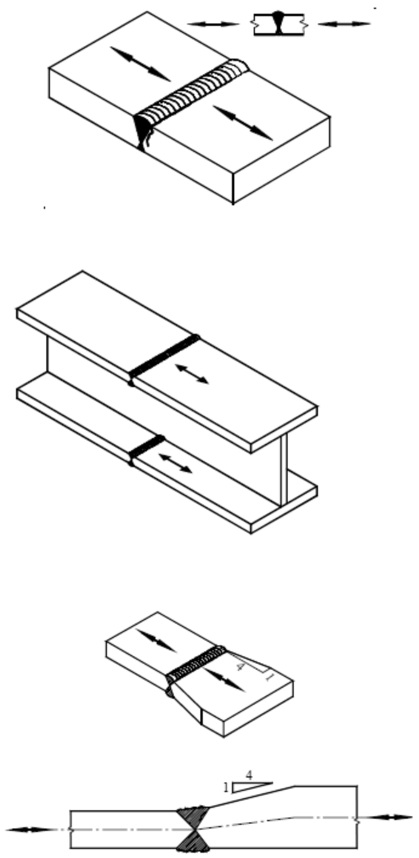
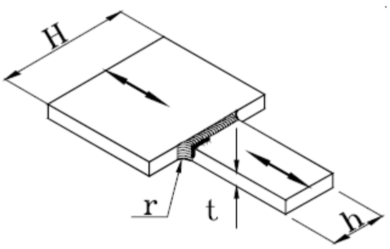
**Table A-4 Intermittent welds and welds at cope holes**

| *Detail category* | *Constructional details* | *Description* | *Requirement* |
|---|---|---|---|
| E | 1.<br> | 1.<br>Stitch or tack welds not subsequently covered by a continuous weld | 1.<br>— Intermittent fillet weld with gap ratio $g/h \leq 2.5$. |
| F | 2.<br> | 2.<br>Ends of continuous welds at cope holes. | 2.<br>— Cope hole not to be filled with weld material. |
| | 3.<br> | 3.<br>Cope hole and transverse butt weld. | 3.<br>— For butt weld in material with cope hole advice on fatigue assessment may be found in 3.1.6.<br>— The SCFs from 3.1.6 may be used together with the D-curve. |

## A.5 Transverse butt welds, welded from both sides

| Table A-5 Transverse butt welds, welded from both sides | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| **Notes on potential modes of failure**<br>With the weld ends machined flush with the plate edges, fatigue cracks in the as-welded condition normally initiate at the weld toe, so that the fatigue strength depends largely upon the shape of the weld overfill. If the overfill is dressed flush, the stress concentration caused by it is removed, and failure is then associated with weld defects.<br>**Design stresses**<br>In the design of butt welds that are not symmetric about the root and are not aligned, the stresses must include the effect of any eccentricity (see section 3.1 and 3.3).<br>With connections that are supported laterally, e.g. flanges of a beam that are supported by the web, eccentricity may be neglected. | | | |
| C1 | 1.<br><br>2.<br><br>3.<br> | 1.<br>Transverse splices in plates flats and rolled sections<br>2.<br>Flange splices in plate girders.<br>3.<br>Transverse splices in plates or flats tapered in width or in thickness where the slope is not greater than 1:4. | 1. and 2.<br>— Details 1. and 2. may be increased to Category C when high quality welding is achieved and the weld is proved free from significant defects by non-destructive examination (it is assumed that this is fulfilled by inspection category I).<br>1., 2. and 3.<br>— All welds ground flush to plate surface parallel to direction of the arrow.<br>— Weld run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress.<br>— All welds welded in horizontal position in shop. |

| Table A-5 Transverse butt welds, welded from both sides (Continued) | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| D | 4.<br><br>5<br><br>6.<br><br> | 4.<br>Transverse splices in plates and flats.<br>5.<br>Transverse splices in rolled sections or welded plate girders<br>6.<br>Transverse splices in plates or flats tapered in width or in thickness where the slope is not greater than 1:4. | 4., 5. and 6.<br>— The height of the weld convexity not to be greater than 10% of the weld width, with smooth transitions to the plate surface.<br>— Welds made in flat position in shop.<br>— Weld run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. |

| Table A-5 Transverse butt welds, welded from both sides (Continued) | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| E | 7.<br><br> | 7.<br>Transverse splices in plates, flats, rolled sections or plate girders made at site.<br>(Detail category D may be used for welds made in flat position at site meeting the requirements under 4., 5. and 6 and 100 % MPI of the weld is performed.) | 7.<br>— The height of the weld convexity not to be greater than 20% of the weld width.<br>— Weld run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. |
| | 8.<br><br> | 8.<br>Transverse splice between plates of unequal width, with the weld ends ground to a radius. | 8.:<br>— The stress concentration has been accounted for in the joint classification.<br>— The width ratio H/h should be less than 2. |
| F1 | $\frac{r}{h} \geq 0.16$ | | |
| F3 | $\frac{r}{h} \geq 0.11$ | | |

## A.6 Transverse butt welds, welded from one side

**Table A-6 Transverse butt welds, welded from one side**

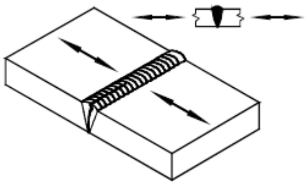
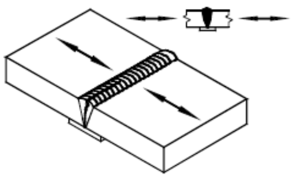
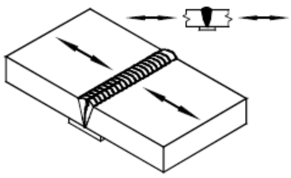
**Notes on potential modes of failure**

With the weld ends machined flush with the plate edges, fatigue cracks in the as-welded condition normally initiate at the weld toe, so that the fatigue strength depends largely upon the shape of the weld overfill. If the overfill is dressed flush, the stress concentration caused by it is removed, and failure is then associated with weld defects. In welds made on permanent backing strip, fatigue cracks most likely initiate at the weld metal/strip junction.
By grinding of the root after welding this side of the welded connection can be categorised to C1 or C; ref. Table A-5.

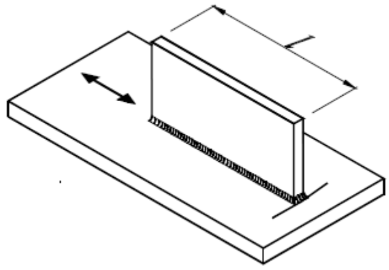
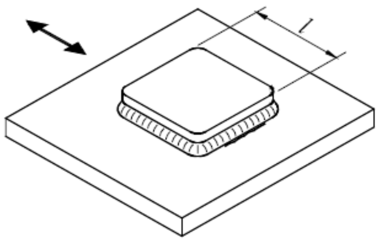
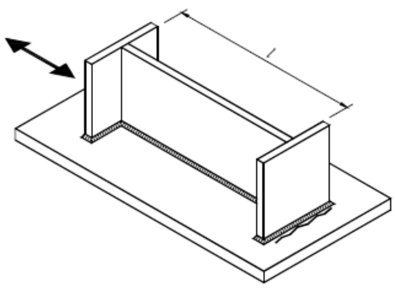
**Design stresses**

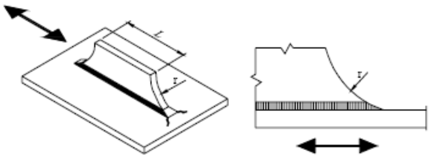
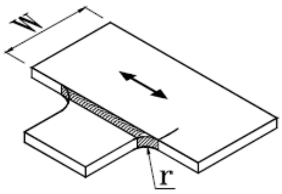
In the design of butt welds that are not symmetric about the root and are not aligned, the stresses must include the effect of any eccentricity (see section 3.1 and 3.3).

With connections that are supported laterally, e.g. flanges of a beam that are supported by the web, eccentricity may be neglected.

| *Detail category* | *Constructional details* | *Description* | *Requirement* |
|---|---|---|---|
| W3 | 1.  | 1.<br>Butt weld made from one side only and without backing strip. | 1.<br>With the root proved free from defects larger than 1-2 mm (in the thickness direction) by non-destructive testing, detail 1 may be categorised to F3 (it is assumed that this is fulfilled by inspection category I). If it is likely that larger defects may be present after the inspection the detail may be downgraded from F3 based on fatigue life calculation using fracture mechanics. The analysis should then be based on a relevant defect size. |
| F | 2.  | 2.<br>Transverse butt weld on a temporary or a permanent backing strip without fillet welds. | |
| G | 3.  | 3.<br>Transverse butt weld on a backing strip fillet welded to the plate. | |

## A.7 Welded attachments on the surface or the edge of a stressed member

| **Table A-7 Welded attachments on the surface or the edge of a stressed member** | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| **Notes on potential modes of failure**<br>When the weld is parallel to the direction of the applied stress, fatigue cracks normally initiate at the weld ends. When the weld is transverse to direction of stressing, cracks usually initiate at the weld toe; for attachments involving a single, as opposed to a double, weld cracks may also initiate at the weld root. The cracks then propagate into the stressed member. When the welds are on or adjacent to the edge of the stressed member the stress concentration is increased and the fatigue strength is reduced; this is the reason for specifying an "edge distance" in some of this joints (see also note on edge distance in Table A-3). | | | |
| | 1.<br><br>2.<br> | 1.<br>Welded longitudinal attachment<br><br>2.<br>Doubling plate welded to a plate. | 1. and 2. The detail category is given for:<br>— Edge distance ≥ 10mm<br>— For edge distance < 10 mm the detail category shall be downgraded with one S-N-curve |
| E | $l \leq 50$ mm | | |
| F | $50 < l \leq 120$ mm | | |
| F1 | $120 < l \leq 300$ mm | | |
| F3 | $l > 300$ mm | | |
| | 3.<br> | 3.<br>Longitudinal attachment welded to transverse stiffener. | |
| E | $l \leq 120$ mm | | |
| F | $120 < l \leq 300$ mm | | |
| F1 | $l > 300$ mm | | |

| Table A-7 Welded attachments on the surface or the edge of a stressed member (Continued) | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| E | 4.<br>r > 150 mm<br> | 4.<br>Longitudinal fillet welded gusset with radius transition to plate or tube; end of fillet weld reinforcement (full penetration); length of reinforcement weld > r. | 4.<br>Smooth transition radius r formed by initially machining or gas cutting the gusset plate before welding, then subsequently grinding the weld area parallel to the direction of the arrow so that the transverse weld toe is fully removed. |
| | 5.<br> | 5.<br>Gusset plate with a radius welded to the edge of a plate or beam flange. | 5.<br>The specified radius to be achieved by grinding. |
| E | $\frac{1}{3} \leq \frac{r}{W}, r \geq 150\text{mm}$ | | |
| F | $\frac{1}{6} \leq \frac{r}{W} < \frac{1}{3}$ | | |
| F1 | $\frac{1}{10} \leq \frac{r}{W} < \frac{1}{6}$ | | |
| F3 | $\frac{1}{16} \leq \frac{r}{W} < \frac{1}{10}$ | | |
| G | $\frac{1}{25} \leq \frac{r}{W} < \frac{1}{16}$ | | |

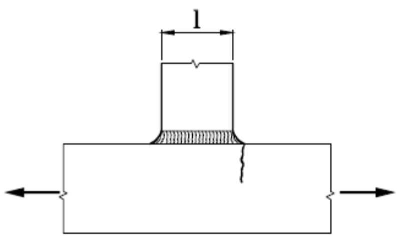
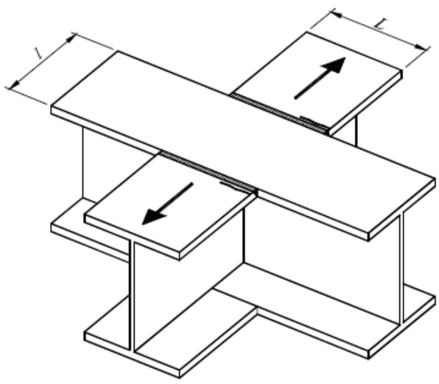
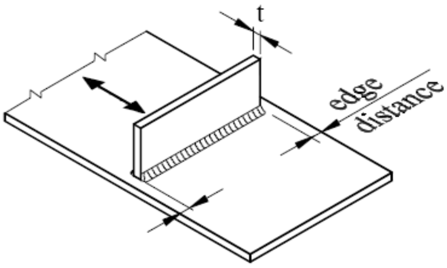
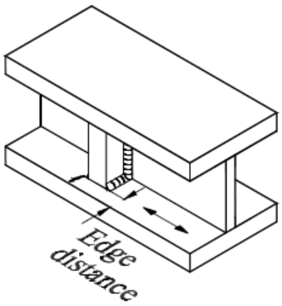
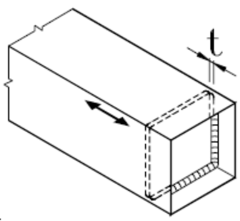
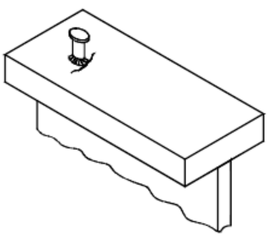
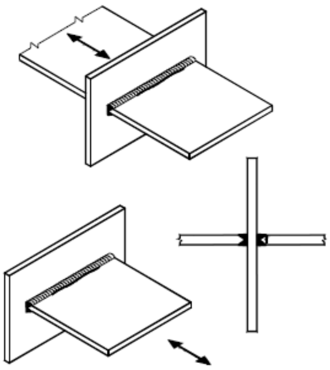
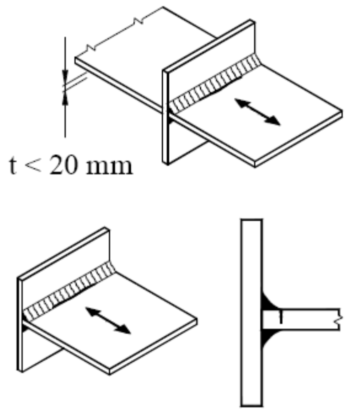
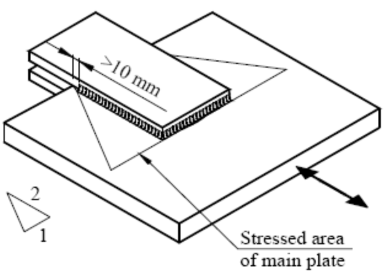
| Table A-7 **Welded attachments on the surface or the edge of a stressed member (Continued)** | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| | 6.<br><br>7.<br> | 6.<br>Gusset plate welded to the edge of a plate or beam flange.<br>7.<br>Flange welded to another flange at crossing joints. | 6. and 7:<br>The distance *l* is governing detail category for the stress direction shown in sketch. For main stress in the other beam the distance L will govern detail category. |
| G | $l \leq 150$ mm | | |
| W1 | $150 < l \leq 300$ mm | | |
| W2 | $l > 300$ mm | | |

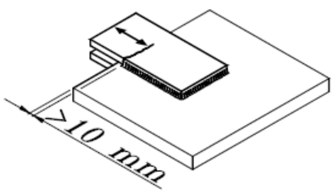
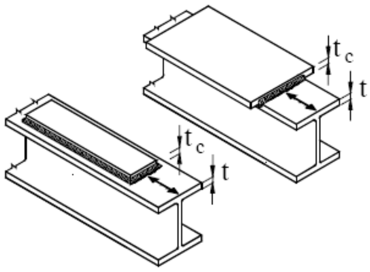
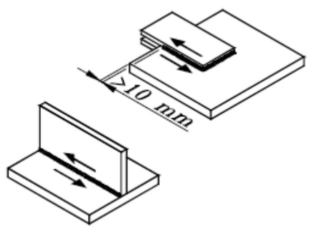
**Table A-7 Welded attachments on the surface or the edge of a stressed member (Continued)**

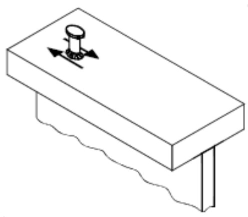
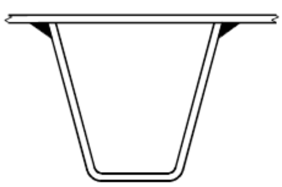
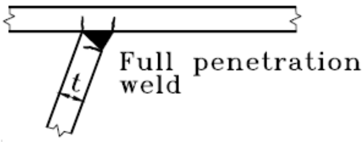
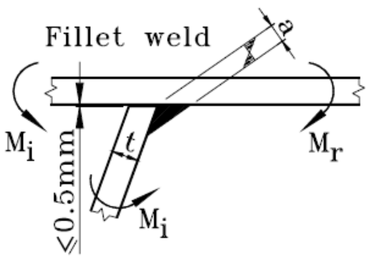
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
|---|---|---|---|
| | 8.<br><br>9.<br><br>10.<br> | 8.<br>Transverse attachments with edge distance ≥ 10 mm<br>9.<br>Vertical stiffener welded to a beam or a plate girder.<br>10.<br>Diaphragms of box girders welded to the flange or web | 9.<br>— The stress range should be calculated using principal stresses if the stiffener terminates in the web.<br>8., 9. and 10.<br>The detail category is given for:<br>— Edge distance ≥ 10 mm<br>— For edge distance < 10 mm the detail category shall be downgraded with one SN-curve |
| E | t ≤ 25 mm | | |
| F | t > 25 mm | | |
| | 11.<br> | 11.<br>Welded shear connector to base material. | |
| E | Edge distance ≥ 10 mm | | |
| G | Edge distance < 10 mm | | |

## A.8 Welded joints with load carrying welds

**Table A-8 Welded joints with load carrying welds**

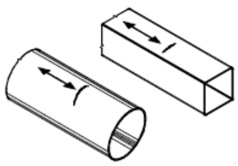
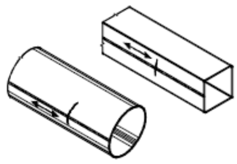
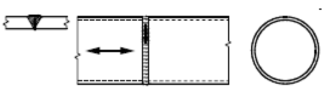
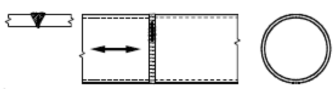
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
|---|---|---|---|
| **Notes on potential modes of failure**<br>Failure in cruciform or T joints with full penetration welds will normally initiate at the weld toe. In joints made with load-carrying fillet or partial penetration butt welds, cracking may initiate either at the weld toe and propagate into the plate, or at the weld root and propagate through the weld. In welds parallel to the direction of the applied stress, however, weld failure is uncommon. In this case, cracks normally initiate at the weld end and propagate into the plate perpendicular to the direction of applied stress. The stress concentration is increased, and the fatigue strength is therefore reduced, if the weld end is located on or adjacent to the edge of a stressed member rather than on its surface.<br>**Design stresses**<br>In the design of cruciform joints, which are not aligned the stresses, must include the effect of any eccentricity. The maximum value of the eccentricity may normally be taken from the fabrication tolerances. The design stress may be obtained as the nominal stress multiplied by the stress concentration factor due to the eccentricity. | | | |
| F | 1.<br> | 1.Full penetration butt welded cruciform joint | 1.:<br>— Inspected and found free from significant defects.<br>The detail category is given for:<br>— Edge distance ≥ 10mm<br>— For edge distance < 10mm the detail category shall be downgraded with one SN-curve |
| W3 | 2.<br> | 2.Partial penetration tee-butt joint or fillet welded joint and effective full penetration in tee-butt joint. See also section 2.7. | 2.:<br>— Two fatigue assessments are required. Firstly, root cracking is evaluated taking Category W3 for $\sigma_W$. $\sigma_W$ is defined in section 2.3.5. Secondly, toe cracking is evaluated by determining the stress range in the load-carrying plates and use Category G.<br>— If the requirement in section 2.7 that toe cracking is the most likely failure mode is fulfilled and the edge distance ≥ 10mm, Category F1 may be used for partial penetration welds and F3 for fillet welds. |
| F1 | 3.<br> | 3.<br>Fillet welded overlap joint. Crack in main plate. | 3.<br>— Stress in the main plate to be calculated on the basis of area shown in the sketch.<br>— Weld termination more than 10 mm from plate edge.<br>— Shear cracking in the weld should be verified using detail 7. |

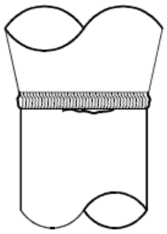
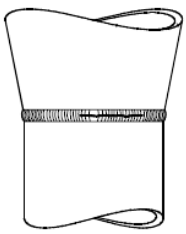
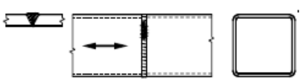
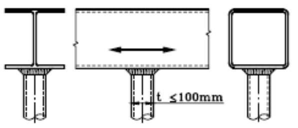
| Table A-8 Welded joints with load carrying welds (Continued) | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| W1 | 4.<br> | 4.<br>Fillet welded overlap joint.<br>Crack in overlapping plate. | 4.<br>— Stress to be calculated in the overlapping plate elements<br>— Weld termination more than 10 mm from plate edge.<br>— Shear cracking in the weld should be verified using detail 7. |
| | 5.<br> | 5.<br>End zones of single or multiple welded cover plates in beams and plate girders. Cover plates with or without frontal weld. | 5.<br>— When the cover plate is wider than the flange, a frontal weld, carefully ground to remove undercut, is necessary. |
| G | t and $t_c \le 20$ mm | | |
| W3 | t and $t_c > 20$ mm | | |
| E | 6. and 7.<br> | 6.<br>Continuous fillet welds transmitting a shear flow, such as web to flange welds in plate girders. For continuous full penetration butt weld in shear use Category C2.<br>7.<br>Fillet welded lap joint. | 6.<br>— Stress range to be calculated from the weld throat area.<br>7.<br>— Stress range to be calculated from the weld throat area considering the total length of the weld.<br>— Weld terminations more than 10 mm from the plate edge. |

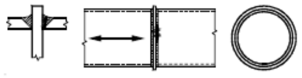
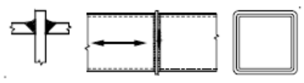
| **Table A-8 Welded joints with load carrying welds (Continued)** | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| E | 8.<br> | 8.<br>Stud connectors (failure in the weld or heat affected zone). | 8.<br>— The shear stress to be calculated on the nominal cross section of the stud. |
| | 9.<br> | 9.<br>Trapezoidal stiffener welded to deck plate with fillet weld or full or partial penetration butt weld. | 9.<br>— For a full penetration butt weld, the bending stress range shall be calculated on the basis of the thickness of the stiffener.<br>— For a fillet weld or a partial penetration butt weld, the bending stress range shall be calculated on the basis of the throat thickness of the weld, or the thickness of the stiffener if smaller. |
| F |  | | |
| G |  | | |

## A.9 Hollow sections

**Table A-9 Hollow sections**

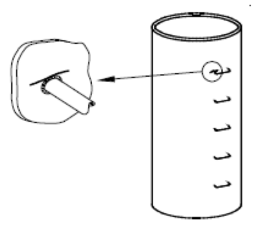
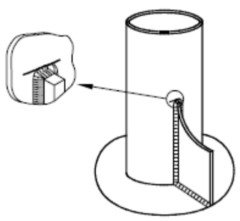
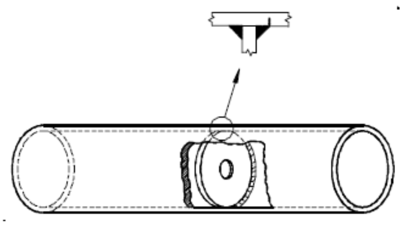
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
|---|---|---|---|
| B1 | 1.  | 1.<br>Non-welded sections | 1.<br>— Sharp edges and surface flaws to be improved by grinding |
| B2 | 2.  | 2.<br>Automatic longitudinal seam welds (for all other cases, see Table A-3) | 2.<br>— No stop /start positions, and free from defects outside the tolerances of OS-C401 Fabrication and Testing of Offshore Structures. |
| C1 |  | 3.<br>Circumferential butt weld made from both sides dressed flush. | 3., 4., 5. and 6.<br>— The applied stress must include the stress concentration factor to allow for any thickness change and for fabrication tolerances, ref. section 3.3.7.<br>— The requirements to the corresponding detail category in Table A-5 apply. |
| D | | 4.<br>Circumferential butt weld made from both sides. | |
| E | | 5.<br>Circumferential butt weld made from both sides made at site. | |
| F | | 6.<br>Circumferential butt weld made from one side on a backing bar. | |
| F3 | 7.  | 7.<br>Circumferential butt weld made from one side without a backing bar. | 7.<br>— The applied stress should include the stress concentration factor to allow for any thickness change and for fabrication tolerances, ref. section 3.3.7.<br>— The weld root proved free from defects larger than 1-2 mm. |
| C1 | | 8.<br>Circumferential butt welds made from one side that are machined flush to remove defects and weld overfill. | 8.<br>A machining of the surfaces will reduce the thickness. Specially on the root side material will have to be removed. A reduced thickness should be used for calculation of stress. The weld should be proved free from defects by non-destructive examination (It is assumed that this is fulfilled by Inspection category I). Category C may be achieved; ref. Table A-5. |

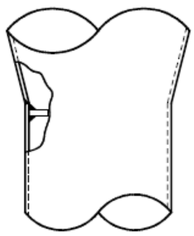
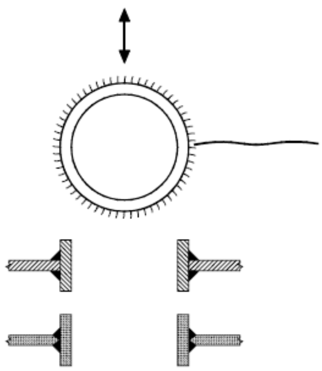
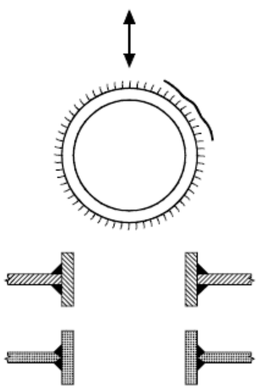
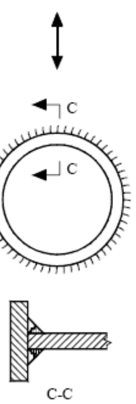
| Table A-9 Hollow sections (Continued) | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| C1 | 8., 9., 10 and 11.<br> | 8.<br>Circumferential butt welds between tubular and conical sections, weld made from both sides dressed flush. | 8., 9., 10., and 11.<br>— The applied stress must also include the stress concentration factor due to the overall form of the joint, ref. section 3.3.9.<br>— The requirements to the corresponding detail category in Table A-5 apply. |
| D | | 9.<br>Circumferential butt welds between tubular and conical sections, weld made from both sides. | |
| E | | 10.<br>Circumferential butt welds between tubular and conical sections, weld made from both sides made at site. | |
| F | | 11.<br>Circumferential butt welds between tubular and conical sections, weld made from one side on a backing bar. | |
| F3 | 12.<br> | 12.<br>Circumferential butt welds between tubular and conical sections, weld made from one side without a backing bar. (This classification is for the root. For the outside weld toe see 8-11). | 12.<br>— The applied stress must also include the stress concentration factor due to the overall form of the joint<br>— The weld root proved free from defects larger than 1-2 mm. |
| F3 | 13.<br> | 13.<br>Butt welded end to end connection of rectangular hollow sections. | 13.<br>— With the weld root proved free from defects larger than 1-2 mm |
| F | 14.<br> | 14.<br>Circular or rectangular hollow section, fillet welded to another section. | 14.<br>— Non load carrying welds.<br>— Section width parallel to stress direction ≤ 100 mm.<br>— All other cases, see Table A-7 |

| Table A-9 Hollow sections (Continued) | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| G | 15.  | 15.<br>Circular hollow section butt welded end to end with an intermediate plate. | 15.<br>— Load carrying welds.<br>— Welds inspected and found free from defects outside the tolerances of DNV-OS-C401 *Fabrication and testing of Off-shore Structures*<br>— Details with wall thickness greater than 8mm may be classified Category F3. |
| W1 | 16.  | 16.<br>Rectangular hollow section butt welded end to end with an intermediate plate. | 16.<br>— Load carrying welds.<br>— Welds inspected and found free from defects outside the tolerances of DNV-OS-C401 *Fabrication and Testing of Off-shore Structures*<br>— Details with wall thickness greater than 8 mm may be classified as Category G. |

## A.10 Details relating to tubular members

**Table A-10 Details relating to tubular members**

| *Detail category* | *Constructional details* | *Description* | *Requirement* |
|---|---|---|---|
| T | | 1.<br>Parent material adjacent to the toes of full penetration welded tubular joints. | 1.<br>— The design should be based on the hot spot stress. |
| F1 | 2.<br> | 2.<br>Welded rungs. | |
| D | 3. and 4.<br> | 3.<br>Gusseted connections made with full penetration welds. | 3.<br>— The design stress must include the stress concentration factor due to the overall form of the joint. |
| F | | 4.<br>Gusseted connections made with fillet welds. | 4.<br>— The design stress must include the stress concentration factor due to the overall form of the joint. |
| | 5.<br> | 5.<br>Parent material at the toe of a weld attaching a diaphragm to a tubular member. | The nominal design stress for the inside may be determined from section 3.3.8. |
| E | t ≤ 25 mm | | |
| F | t > 25 mm | | |

| Table A-10 Details relating to tubular members (Continued) | | | |
|---|---|---|---|
| *Detail category* | *Constructional details* | *Description* | *Requirement* |
| E to G, see Table A-7 | 6.  | 6. Parent material (of the stressed member) adjacent to the toes of a bevel butt or fillet welded attachments in region of stress concentration. | 6. — Class depends on attachment length (see Table A-7) but stress must include the stress concentration factor due to the overall shape of adjoining structure. |
| C | 7.  | 7. Parent material to, or weld metal in welds around a penetration through a wall of a member (on a plane essentially perpendicular to the direction of stress) | 7. In this situation the relevant stress must include the stress concentration factor due to the overall geometry of the detail. Without start and stop at hot spot region. See also section 3.1.5. |
| D | 8.  | 8. At fillet weld toe in parent metal around a penetration in a plate. | 8. — The stress in the plate should include the stress concentration factor due to the overall geometry of the detail. See also section 3.1.5. |
| W3 |  | 9. Weld metal in partial penetration or fillet welded joints around a penetration through the wall of a member (on a plane essentially parallel to the plane of stress). | 9. — The stress in the weld should include an appropriate stress concentration factor to allow for the overall joint geometry. Reference is also made to Appendix C. See also section 3.1.5. |

## *References*


Ref. /1/ IACS Recommendation No. 56 Fatigue Assessment of Ship Structures. Recom. 56.1, July 1999.

Ref. /2/ Niemi, E.: Stress Determination for Fatigue Analysis of Welded Components. IIS/IIW-1221-93. Abington Publishing, Cambridge, England 1995.

Ref. /3/ Hobbacher, A.: Recommendation for Fatigue Design of Welded Joints and Components. IIW document XIII-1965-03/XV-1127-03. Update July 2004.

Ref. /4/ DNV-RP-C203: Fatigue Design of Offshore Steel Structures. October 2008. Det Norske Veritas.

Ref. /5/ Niemi, E.: Structural Stress Approach to Fatigue Analysis of Welded Components – Designer's Guide. IIS/IIW-XIII-1819-00. Final draft subject to editorial amendments. Last modified August 12, 2001.