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**No.56** FATIGUE ASSESSMENT OF SHIP  
(July 1999) **STRUCTURES**

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# **FATIGUE ASSESSMENT OF SHIP STRUCTURES**

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## **TABLE OF CONTENTS**

- 1. GENERAL**
- 2. DETERMINATION OF THE LONG TERM DISTRIBUTION OF STRESSES**
  - 2.1 General**
  - 2.2 Determination of loads**
    - 2.2.1 Selection of the loading conditions
    - 2.2.2 Determination of loads
  - 2.3 Long term distribution of stresses**
- 3. DESIGN S-N CURVES**
  - 3.1 General**
  - 3.2 Design S-N Curves**
    - 3.2.1 U.K. HSE Basic S-N Curves
    - 3.2.2 IIW S-N Curves
  - 3.3 Prototype testing**
- 4. ASSESSMENT OF THE FATIGUE STRENGTH**
  - 4.1 General**
  - 4.2 Calculation of stress ranges**
    - 4.2.1 General
    - 4.2.2 Stresses to be used
    - 4.2.3 Determination of stresses
  - 4.3 Selection of the design S-N curve**
    - 4.3.1 General
    - 4.3.2 Correction of the design S-N curve
  - 4.4 Determination of the fatigue life**
    - 4.4.1 General
    - 4.4.2 Palmgren-Miner approach
    - 4.4.3 Fatigue life

# **FATIGUE ASSESSMENT OF SHIP STRUCTURES**

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## **1. GENERAL**

**1.1** This document provides general information and recommendations pertaining to the assessment of the fatigue strength of structural details which are predominantly subjected to cyclic loads. It has been assembled as a joint effort of the IACS Members. However, it is neither comprehensive nor definitive and its application or use by IACS Members is not mandatory. Individual IACS Members have their own comprehensive, though different, methods of assessing fatigue strength of ship structures.

**1.2** The procedure described hereafter is based on the use of S-N curves and application of the Palmgren-Miner cumulative damage rule.

## **2. DETERMINATION OF THE LONG TERM DISTRIBUTION OF STRESSES**

### **2.1 General**

Ship structures are subjected to various types of loads :

- static loads,
- wave induced loads,
- impact loads, such as bottom slamming, bow flare impacts and sloshing in partly filled tanks,
- cyclic loads resulting from main engine or propeller induced vibratory forces,
- transient loads such as thermal loads, and
- residual stresses.

In the present procedure only static and wave induced loads are considered for calculation of the long term distribution of stresses, including :

- hull girder loads (i.e., bending and torsional moments and shear forces),
- external hydrodynamic pressures,
- internal inertial and fluctuating loads resulting from ship motion.

## 2.2 Determination of loads

### 2.2.1 Selection of the loading conditions

Fatigue analyses are to be carried out for the representative loading conditions according to the intended ship's operation. As a guidance, the following two loading conditions are generally to be examined, unless additional conditions need to be considered :

- full load condition, and
- ballast condition.

### 2.2.2 Determination of loads

i) Wave-induced loads are to take into account :

- global loads                      calculated according to UR S11 for vertical bending and each Society criteria for horizontal bending and torsion,
- local loads                        calculated according to each Society criteria.

Since fatigue is a process of cycle by cycle accumulation of damage in a structure undergoing fluctuating stresses, loads applied on the structure are to be calculated with an aim to determining the stress ranges for the various relevant loading conditions.

ii) Combination of stresses resulting from the action of global and local loads is to be performed according to each Society criteria and with consideration given to the probability level.

## 2.3 Long term distribution of stresses

2.3.1 The long term distribution of stresses may be obtained either from a direct wave spectral analysis or from rule loads.

2.3.2 Unless a direct spectral analysis is carried out, it is assumed that the probability density function of the long term distribution of stresses (hull girder + local bending) may be represented by a two-parameter Weibull distribution, given by :

$$f(s) = \frac{\xi}{k} \left( \frac{S}{k} \right)^{\xi-1} \exp \left( - \frac{S}{k} \right)^{\xi} \quad (2.1)$$

where :

S = stress range,

$\xi$  = shape parameter,

k = characteristic value of the stress range,  $k = \frac{S_R}{(\ln N_R)^{1/\xi}}$

$N_R$  = number of cycles corresponding to the probability of exceedance of  $1/N_R$ ,

$S_R$  = stress range with probability of exceedance of  $1/N_R$

This assumption enables the use of a closed form equation for calculation of the fatigue life when the two parameters of the Weibull distribution are determined.

In order to calculate the fatigue damage, it is recommended that individual component loads be determined with respect to a moderate exceeding probability level (e.g., probability level  $10^{-3}$  to  $10^{-5}$ ).

For each structural detail considered, the Weibull shape parameter is generally to be selected with due consideration given to the load categories contributing to the occurrence of cyclic stresses. As a first approximation, the Weibull shape parameter  $\xi$  may be taken as :

$$\xi = 1,1 - 0,35 \frac{L-100}{300} \quad \text{where L is the ship's length, in m.}$$

### 3. DESIGN S-N CURVES

#### 3.1 General

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

For ship structural details, S-N curves are represented by the following formula :

$$S^m N = K \quad (3.1)$$

where :

- S = stress range, as defined in 4.2.2,
- N = number of cycles to failure,
- m, K = constants depending on :
  - . material and weld type,
  - . type of loading,
  - . geometrical configuration,
  - . environmental conditions (air or sea water)

Experimental S-N curves are defined by their mean fatigue life and standard deviation. The mean S-N curve means that for a stress level S the structural detail will fail with a probability level of 50 per cent after N loading cycles. S-N curves considered in the present procedure represent two standard deviations below the mean lines, which corresponds to a survival probability of 97,5 per cent.

#### 3.2 Design S-N curves

Unless supported by direct measurements, the following sets of S-N curves may be used for assessment of the fatigue strength of structural details :

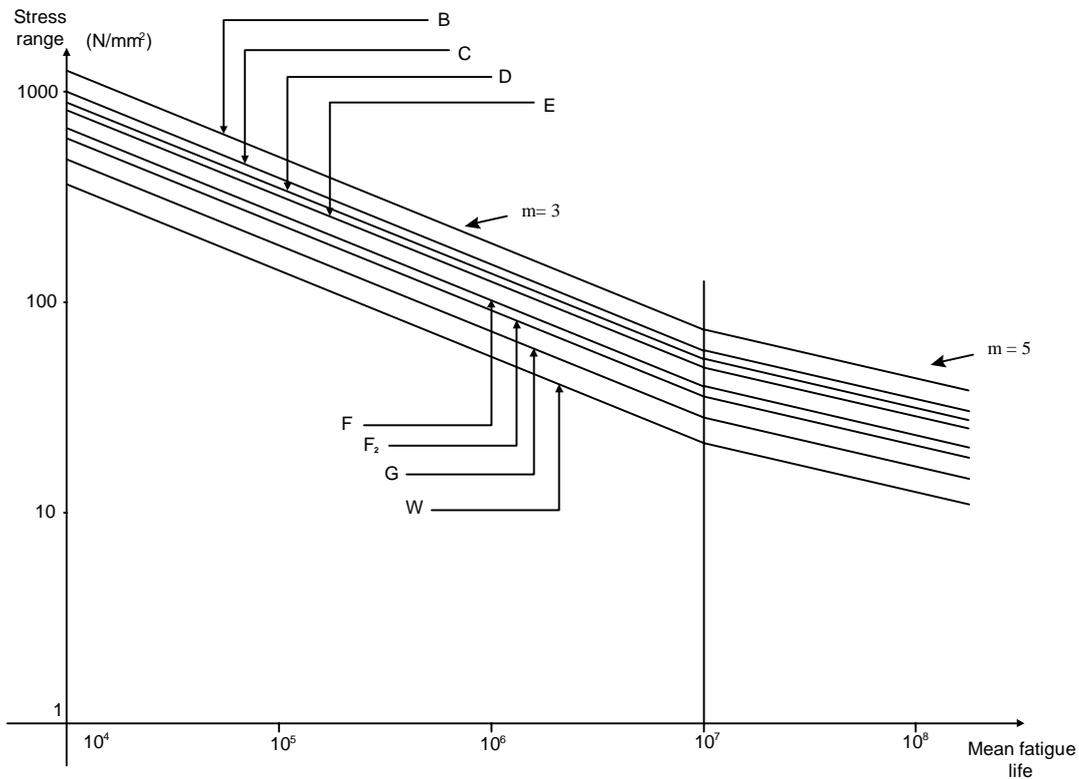
- U.K. HSE (previously DEn) Basic S-N Curves, or
- IIW S-N Curves.

These S-N curves are applicable to steels with minimum yield strength less than  $400 \text{ N/mm}^2$ . For steels with higher yield strength, data obtained from an approved test programme are to be used (refer to 3.3).

##### 3.2.1 U.K. HSE Basic S-N Curves

The HSE Basic S-N Curves for non-tubular joints consist of eight curves, as shown in Figure 1(a), identified by B, C, D, E, F, F2, G and W. These curves give the relationship between the nominal stress range and the number of constant amplitude load cycles to failure. Each curve represents a class of welded details, as categorized in Appendix A, depending on :

- 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.



**Figure 1(a) - "New" HSE Basic Design S-N Curves**

All the eight S-N curves have the same two slopes and change slope at  $N$  equal to  $10^7$  cycles. Table I(a) gives the constant  $K$  of the eight curves for which the slope is equal to :

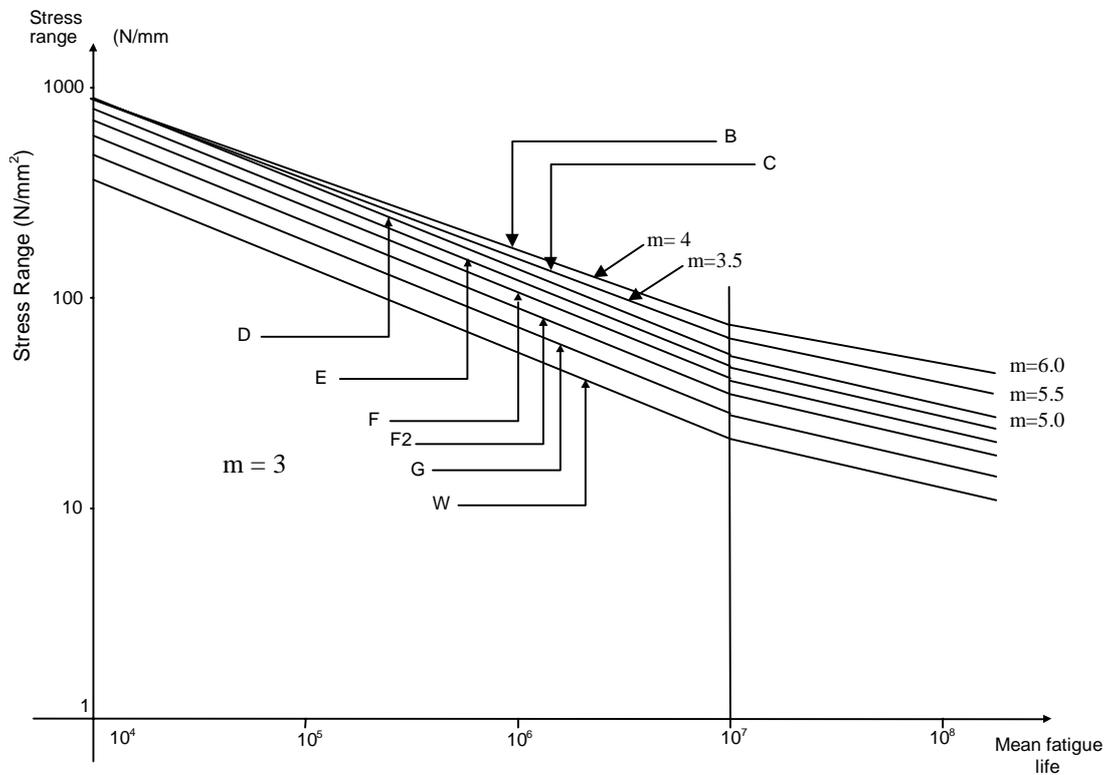
- 3 for  $N \leq 10^7$
- 5 for  $N > 10^7$

The HSE S-N curves correspond to non corrosive conditions and are given for mean minus two standard deviations. For various joint classifications, the respective S-N curves are related to D-curve by a "classification factor", which is used as a multiplier on stress ranges. The classification factors are also shown in Table I(a).

**Table I(a) "New" HSE Basic Design S-N Curve**

Class	K		Classification Factor
	$N \leq 10^7$ (m=3)	$N > 10^7$ (m=5)	
B	$5,800 \times 10^{12}$	$4,034 \times 10^{16}$	0,64
C	$3,464 \times 10^{12}$	$1,708 \times 10^{16}$	0,76
D	$1,520 \times 10^{12}$	$4,329 \times 10^{15}$	1
E	$1,026 \times 10^{12}$	$2,249 \times 10^{15}$	1,14
F	$6,319 \times 10^{11}$	$1,002 \times 10^{15}$	1,34
F2	$4,330 \times 10^{11}$	$5,339 \times 10^{14}$	1,52
G	$2,481 \times 10^{11}$	$2,110 \times 10^{14}$	1,83
W	$9,279 \times 10^{10}$	$4,097 \times 10^{13}$	2,13

The earlier version of the U.K. HSE (previously DEn) Basic Design S-N Curves are still in common use. Unlike the above new HSE S-N curves, the old HSE S-N curves have different slopes for both two segments of B and C curves, as shown in Figure 1(b). The relevant values for the old curves are given in Table I(b).



**Figure 1(b) - "Old" HSE Basic Design S-N Curves**

**Table I(b)** “Old” HSE Basic Design S-N Curves

Class	$N \leq 10^7$		$N > 10^7$	
	m	K	m	K
B	4,0	$1,013 \times 10^{15}$	6,0	$1,013 \times 10^{17}$
C	3,5	$4,227 \times 10^{13}$	5,5	$2,926 \times 10^{16}$
D	3,0	$1,519 \times 10^{12}$	5,0	$4,239 \times 10^{15}$
E	3,0	$1,035 \times 10^{12}$	5,0	$2,300 \times 10^{15}$
F	3,0	$6,315 \times 10^{11}$	5,0	$9,975 \times 10^{14}$
F2	3,0	$4,307 \times 10^{11}$	5,0	$5,278 \times 10^{14}$
G	3,0	$2,477 \times 10^{11}$	5,0	$2,138 \times 10^{14}$
W	3,0	$1,574 \times 10^{11}$	5,0	$1,016 \times 10^{14}$

### 3.2.2 IIW S-N Curves

The International Institute of Welding (IIW) has established, for various welded joints, a set of fatigue S-N curves. These S-N curves which are based on the nominal stress range and correspond to non corrosive conditions, are given for mean minus two standard deviations and are characterized by the fatigue strength at  $2 \times 10^6$  cycles, as shown in Figure 2. The slope of all S-N curves is  $m = 3$  and the change in slope ( $m = 5$ ) occurs for  $N = 5 \times 10^6$  cycles.

The fatigue classes considered for various welded structural details, identified by "FAT" corresponding to the S-N curves shown in Figure 2, are given in Appendix B.

### 3.3 Prototype testing

Prototype testing is the most direct way of assessing the fatigue strength for particular structural details. Fatigue tests may be generally performed for constant amplitude loadings and the following precautions should be taken :

- the steel grade used for the test pieces should be the same as that provided for the actual structural detail under consideration,
- welding procedures should be representative of the actual conditions of welding,
- the size of test specimens should be such that the level of residual stress is equivalent to that of the actual structure,
- the stress ratio  $R = \frac{\sigma_{\min}}{\sigma_{\max}}$  should remain constant during the experiments. Generally, this ratio is to be taken between 0 and 0,1.

3D FEM structural analyses are to be performed for the test specimens with a view to validating the calculation procedure used for determination of hot spot stresses in the actual structure. In particular, theoretical stresses will have to be computed at locations where stress measurements are carried out during the fatigue testing.

The fatigue testing procedure is to be approved by the Society.

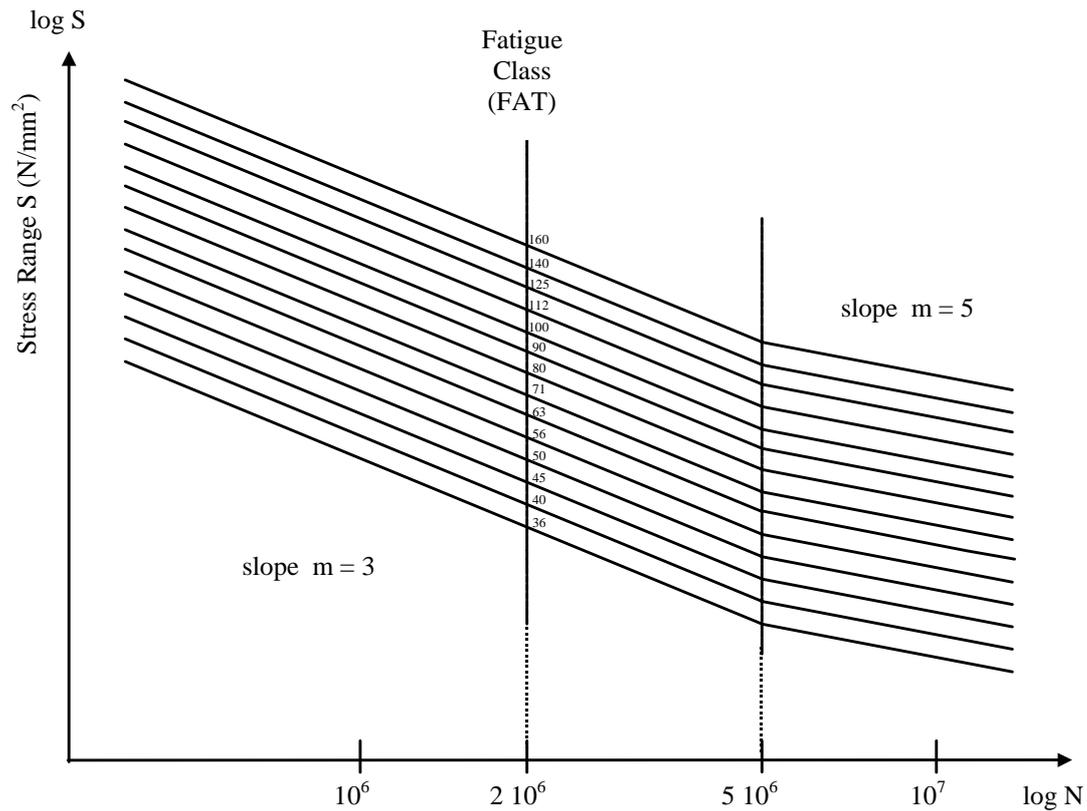


Figure 2 - IIW S-N Curves

## 4 ASSESSMENT OF THE FATIGUE STRENGTH

### 4.1 General

4.1.1 Assessment of the fatigue adequacy of the structure is based on the application of the Palmgren-Miner cumulative damage rule given by :

$$D = \sum_{i=1}^{i=n_k} \frac{n_i}{N_i} \quad (4.1)$$

where :

$n_i$  = number of cycles of stress range  $S_i$ ,

$N_i$  = number of cycles to failure at stress range  $S_i$ .

From this definition, the structure is generally considered as failed when the cumulative damage ratio  $D$  is equal to unity or greater.

4.1.2 Assessment of the fatigue strength of welded structural members includes the following three phases :

- calculation of stress ranges,
- selection of the design S-N curve,
- calculation of the cumulative damage ratio.

### 4.2 Calculation of stress ranges

#### 4.2.1 General

Assuming that the resultant stresses follow a two-parameter Weibull distribution, the stress ranges have to be calculated for one probability of exceedance only.

As indicated in 2.3, it is recommended that stresses be calculated at a moderate probability of exceedance, e.g.  $10^{-3}$  to  $10^{-5}$ .

#### 4.2.2 Stresses to be used

Depending on the kind of stresses used in the calculation, the fatigue assessment may be categorized 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. cutouts, tapers, haunches, brackets, changes of scantlings, misalignments, etc.). The nominal stress can also be calculated using a coarse mesh FE analysis or analytical approach.

*Hot spot stress* A local stress at the hot spot (a critical point) 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 welds.

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

Table II summarizes these definitions in terms of stress concentration factors:

**Table II**

Approach / Detail	Welded Connection	Free Edge of Plate
Stress	$\sigma = K_G K_W \sigma_N$	$\sigma = K_G K_W \sigma_N$
Nominal stress	$K_G = 1, K_W = 1$	$K_G = 1, K_W = 1$
Hot-spot stress	$K_G \neq 1, K_W = 1$	$K_G \neq 1, K_W = 1$
Notch stress	$K_G \neq 1, K_W \neq 1$	$K_G \neq 1, K_W = 1$

where :

$\sigma_N$  = "nominal" stress obtained from beam idealization,

$K_G$  = stress concentration factor due to the geometrical configuration of the connection,

$K_W$  = stress concentration factor due to weld geometry.

### 4.2.3 Determination of stresses

#### i) Nominal stress approach

The following may be applied for determination of nominal stresses :

- nominal stresses are determined by taking into account the gross geometric changes of the detail. The effect of stress concentration due to the weld profile should be disregarded,
- if the stress field is more complex than a uniaxial field, the principal stresses adjacent to the potential crack location are to be used,
- if a finite element stress analysis is used, a uniform mesh is to be used with smooth transition and avoidance of abrupt changes in mesh size.

#### ii) Hot spot stress approach

Determination of hot spot stresses necessitates generally to carry out 2D or 3D fine mesh stress analyses, further to the 3D coarse mesh analysis. In that case, boundary nodal displacements or forces obtained from the 3D coarse mesh model are applied to the fine mesh models as boundary conditions. In highly stressed areas, in particular in the vicinity of structural discontinuities, the level of stresses depends on the size of elements, due to the high stress gradient.

Following rules define a general basis for the modelling of local structures, as recommended by the International Institute of Welding (IIW document XIII-1539-96/XV-845-96) :

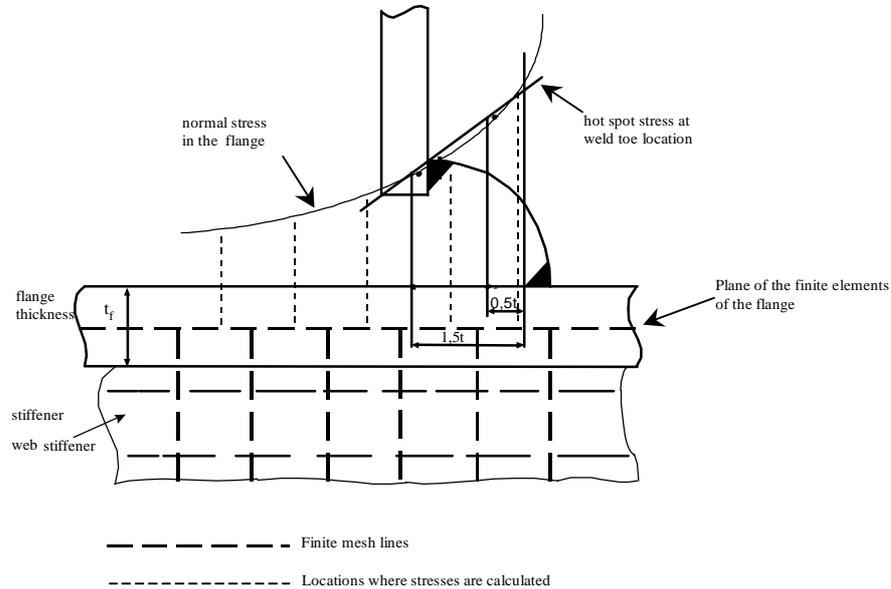
- *hot-spot stresses are calculated using an idealized welded joint with no misalignment,*
- *the finite element mesh is to be fine enough near the hot spot such that stresses and stress gradients can be determined at points comparable with the extrapolation points used for strain gauge measurements,*
- *plating, webs and face plates of primary and secondary members are modelled by 4-node thin shell or 8-node solid elements. In case of steep stress gradient 8-node thin shell elements or 20-node solid elements are recommended,*
- *when thin shell elements are used, the structure is modelled at mid-face of the plates. The stiffness of the weld intersection should be taken into account (e.g., by modelling the welds by inclined shell elements),*
- *the aspect ratio of elements is not to be greater than 3,*
- *the size of elements located in the vicinity of the « hot spot » is to be about the thickness of the structural member,*
- *the centroid of the first element adjacent to the weld toe is to be located between the weld toe and  $0.4t$  of this toe, where  $t$  is the plate thickness,*
- *stresses are to be calculated at the surface of the plate with a view to taking into account the plate bending moment, where relevant.*

Normally, the element stresses are derived at the gaussian integration points. Other derivations may be considered subject to the acceptance by the Society. Depending on the element type, it may be necessary to perform several extrapolations in order to determine the actual stress at the considered hot spot location.

For critical structural details, the hot spot stresses are generally highly dependent on the finite element model considered for representation of the structure. In such cases, the procedure chosen for derivation of the hot spot stress may preferably be confirmed or documented by reference to available fatigue test results for similar structural details. Three different procedures may be used to determine the hot spot stresses :

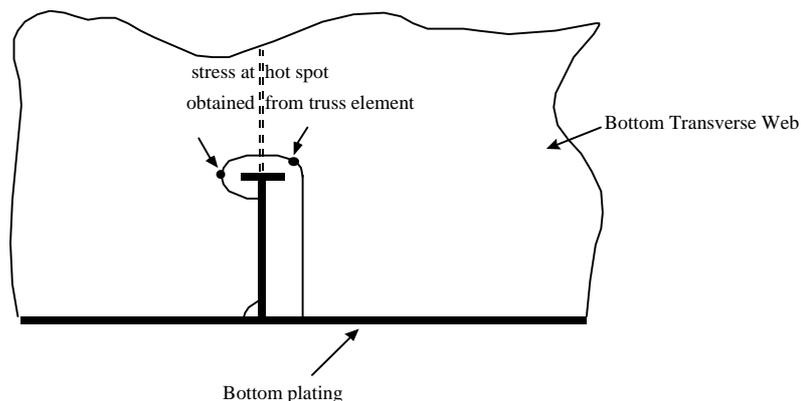
- stress extrapolation at the structural discontinuity where large stress gradient is expected, e.g., toe of brackets as shown in Figure 3. As illustrated, stress values at given distances from the

weld toe related to the intersection line representing the structural discontinuity (e.g.  $0,5t$  and  $1,5t$ ) are determined by interpolation of the element centroid stresses and the hot spot stress is then obtained by extrapolation to the weld toe. The maximum principal stress range within 45 degrees of the normal to the weld toe is to be considered for determination of the hot spot stress.



**Figure 3 - Definition of the Hot Spot Stress at Weld Toe Location**

- stress in the element at the hot spot where the geometry does not permit a clear development of a stress gradient,
- stress in the free edge of plate for areas where no structural discontinuity exists ( e.g. : radius of cut-out as shown in Figure 4. If 4-node shell elements are used, the hot spot stress may be obtained using truss elements with minimal stiffness along the free edge.
- 



**Figure 4 - Definition of the Hot Spot Stress**

Hot spot stresses may also be determined by using parametric formulae giving the stress concentration factor  $K_G$  of typical structural connections for which "nominal" stresses can be easily calculated. In such a case, the "hot spot" stress is taken as :

$$\sigma_{hot\ spot} = K_G \sigma_N$$

Appropriate Stress Concentration Factors are to be used according to the type of applied loads (axial loading, bending and shear) and determined at the discretion of each Society.

### iii) *Notch stress approach*

Determination of the peak or notch stress which depends on the weld profile necessitates to determine the weld concentration factor  $K_w$  and is given by :

$$\sigma_{notch} = K_w K_G \sigma_N$$

Stress concentration factors  $K_w$  may be obtained from diagrammes or parametric formulae or calculated from the results of finite element analyses or from measurements. The weld concentration factor  $K_w$  is to be determined at the discretion of each Society. Where relevant, an additional stress concentration factor is to be included to cover misalignments effects.

When calculating notch stresses, the recommendations given by IIW may be followed :

- *an effective weld root radius of  $r = 1\text{ mm}$  is to be considered,*
- *the method is restricted to weld joints which are expected to fail from weld toe or weld root,*
- *flank angles of  $30^\circ$  for butt welds and  $45^\circ$  for fillet welds may be considered,*
- *the method is limited to thicknesses  $\geq 5\text{ mm}$ .*

## 4.3 Selection of the Design S-N curve

### 4.3.1 *General*

The class of S-N curve selected for determination of the cumulative damage ratio D is to be coherent with the type of stress approach considered :

- Nominal stress approach

Experimental S-N curves give the relationship between the "nominal" stress range and the number of cycles to failure. Therefore, when using these S-N curves the calculated stresses should correspond to the nominal stresses used in creating these curves.

- Hot-spot or notch stress approach

The fatigue analysis is to be performed in conjunction with a higher-class S-N curve selected in agreement with the Society. When using the "hot spot" or "notch stress" approach the same

S-N curve is to be used irrespective of the structural detail considered.

### 4.3.2 *Correction of the design S-N curve*

Moreover, the selected S-N curve may be adjusted at the discretion of each Society to take into account the following :

- effect of compressive stresses,
- effect of plate thickness,
- workmanship,
- influence of the environment.

## 4.4 Determination of the fatigue life

### 4.4.1 General

As indicated in 4.1, the fatigue strength is expressed by the cumulative damage ratio  $D$  which has to be less than unity for the expected ship's life. Unless otherwise specified, the full load and ballast conditions (refer to 2.2.1) may be considered to calculate the resultant cumulative damage ratio :

$$D = D_1 + D_2 \quad (4.2)$$

where:

$D_1$  = cumulative fatigue damage for the loaded condition,

$D_2$  = cumulative fatigue damage for the ballast condition.

### 4.4.2 Palmgren-Miner approach

Assuming the long term distribution of stresses fitted into a two-parameter Weibull probability distribution, the cumulative fatigue damage  $D_i$  for each relevant condition is given by :

$$D_i = \frac{\alpha_i N_L}{K} \frac{S_{Ri}^m}{(\ln N_R)^{m/\xi}} \mu_i \Gamma \left( 1 + \frac{m}{\xi} \right) \quad (4.3)$$

where:

$N_L$  : number of cycles for the expected ship's life. Unless other information is available,  $N_L$  may be taken as  $N_L = \frac{\alpha_0 T}{4 \log L}$ . The value is generally between  $0,5 \times 10^8$  and  $0,7 \times 10^8$  cycles for a ship's life of 20 years,

$\alpha_0$  = factor taking into account the time needed for loading / unloading operations, repairs, etc. In general,  $\alpha_0$  may be taken equal to 0.85,

$T$  = design life, in seconds,

$L$  = ship's length, in m,

$m, K$  = constants as explained in paragraph 3.1,

$\alpha_1$  = part of the ship's life in loaded condition, as given in Table III,

$\alpha_2$  = part of the ship's life in ballast, as given in Table III.

$S_{Ri}$  = stress range, in MPa, for the basic case considered, at the probability level of  $1/N_R$

$N_R$  = number of cycles corresponding to the probability level of  $1/N_R$

$\xi$  = Weibull shape parameter,

$\Gamma$  = Gamma function,

$\mu_i$  = coefficient taking into account the change in slope of the S-N curve,

$$\mu_i = 1 - \frac{\left\{ \gamma \left( 1 + \frac{m}{\xi}, v_i \right) - v^{-\Delta m / \xi} \gamma \left( 1 + \frac{m + \Delta m}{\xi}, v_i \right) \right\}}{\Gamma \left( 1 + \frac{m}{\xi} \right)}$$

$$v_i = \left( \frac{S_q}{S_{Ri}} \right)^\xi \ln N_R$$

$S_q$  = stress range at the intersection of the two segments of the S-N curve,

$\Delta m$  = slope change of the upper to lower segment of the S-N curve,

$\gamma(a,x)$  = incomplete gamma function, Legendre form.

**Table III**

	Full load	Ballast
Oil tankers, Liquefied gas carriers	$\alpha_1 = 0,5$	$\alpha_2 = 0,5$
Bulk carriers	$\alpha_1 = 0,6$	$\alpha_2 = 0,4$
Container ships, Cargo ships	$\alpha_1 = 0,75$	$\alpha_2 = 0,25$

#### 4.4.3 Fatigue life

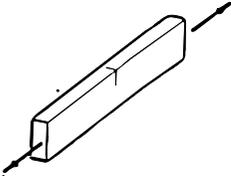
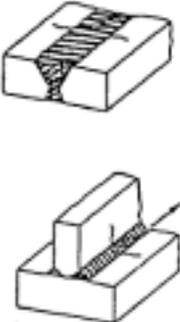
For a fatigue damage  $D$  calculated as indicated in 4.4.1, the expected fatigue life is given by :

$$\text{Fatigue life} = \frac{\text{Design life}}{D} \quad (4.4)$$

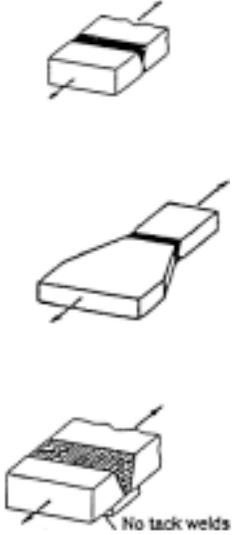
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**APPENDIX A            U.K. HSE Welded Joint Classification**

*(Excerpt from UK, Health and Safety Executive "Proposed Revisions to Fatigue Damage" of August 1993)*

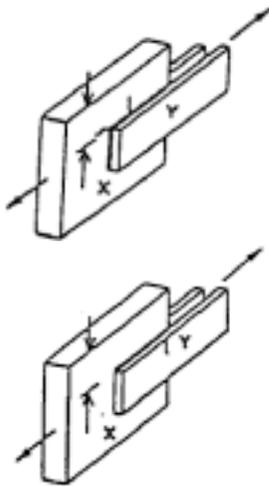
DEn Welded Joint Classification		
Joint Classification	Description	Examples
Category 1  B  C	1) Parent metal in the as-rolled condition with no flame-cut edges or with flame-cut edges ground or machined.  2) Parent material in the as-rolled condition with automatic flame-cut edges and ensured to be free from cracks.	
Category 2  B  C  D	1) Full penetration butt welds with the weld cap ground flush with the surface and with the weld proved to be free from defects by NDT.  2) Butt or fillet welds made by an automatic submerged or open arc process and with no stop-start positions within their length.  3) As (2) but with stop-start positions within the length.	

D<sub>EN</sub> Welded Joint Classification  
(cont'd)

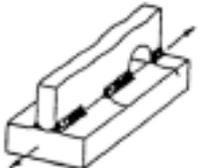
Joint Classification	Description	Examples
<p style="text-align: center;">Category 3</p> <p style="text-align: center;">C</p> <p style="text-align: center;">D</p> <p style="text-align: center;">F</p>	<p>Full penetration butt joints welded from both sides between plates of equal width and thickness or with smooth transition not steeper than 1 in 4 :</p> <p>1) with the weld cap ground flush with the surface and with the weld proved to be free from significant defects by NDT.</p> <p>2) with the welds made either manually or by an automatic process other than submerged arc and in flat position.</p> <p>3) Welds made on a permanent backing strip between plates of equal width and thickness or tapered with a maximum slope of 1/4.</p>	 <p>The examples column contains three 3D perspective drawings of butt joints. The top drawing shows two plates joined by a weld with a smooth, rounded transition on the surface. The middle drawing shows two plates joined by a weld with a backing strip visible on the underside. The bottom drawing shows two plates joined by a weld with a backing strip, and a label 'No tack welds' with an arrow pointing to the joint interface.</p>

DEn Welded Joint Classification  
(cont'd)

Joint Classification	Description	Examples
Category 4	<p>1) Parent material (of the stressed member) or ends of butt or fillet welded attachments (parallel to the direction of applied stresses) on stressed members :</p> <ul style="list-style-type: none"> <li>- attachment length <math>\ell \leq 150</math> mm</li> <li>- edge distance <math>d \geq 10</math> mm</li> </ul>	
F	<ul style="list-style-type: none"> <li>- attachment length <math>\ell &gt; 150</math> mm</li> <li>- edge distance <math>d \geq 10</math> mm</li> </ul>	
F2	<p>2) Parent material (of the stressed member) at toes or ends of butt or fillet welded attachments on or within 10 mm of edges or corners.</p>	
Category 5	<p>1) Parent metal of cruciform or T Joints made with full penetration welds and with any undercut at the corners of the member ground out.</p>	
F	<p>2) As (1) with partial penetration or fillet welds with any undercut at the corners of the member ground out.</p>	
F2		

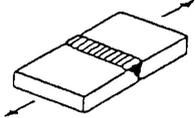
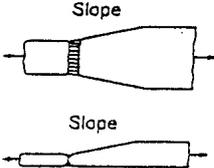
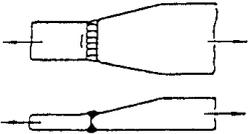
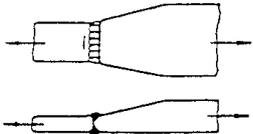
Den Welded Joint Classification (cont'd)		
Joint Classification	Description	Examples
<p>Category 5</p> <p>F2</p> <p>G</p> <p>G</p>	<p>3) Parent metal of load-carrying fillet welds transverse to the direction of stresses (member X) :</p> <p>edge distance <math>d \geq 10</math> mm</p> <p>edge distance <math>d &lt; 10</math> mm</p> <p>4) Parent metal of load-carrying fillet welds parallel to the direction of stresses, with the weld end on plate edge (member Y).</p>	
<p>Category 6</p> <p>F</p> <p>G</p>	<p>1) Parent metal at the toe of weld connection of web stiffeners to girder flanges :</p> <p>edge distance <math>d \geq 10</math> mm</p> <p>edge distance <math>d &lt; 10</math> mm</p>	

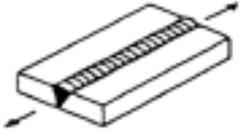
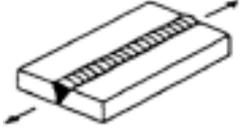
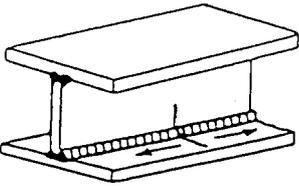
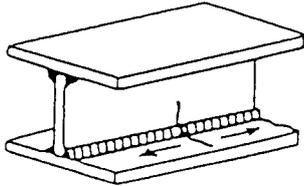
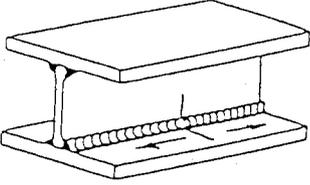
Den Welded Joint Classification  
(cont'd)

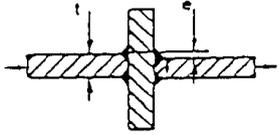
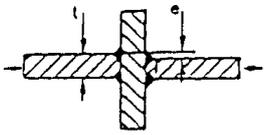
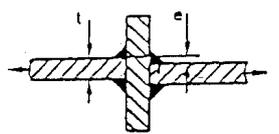
Joint Classification	Description	Examples
<p style="text-align: center;">Category 6</p> <p style="text-align: center;">E</p>  <p style="text-align: center;">F</p>	<p>2) Intermittent fillet welds</p>  <p>3) As (2) but adjacent to cut-outs.</p>	

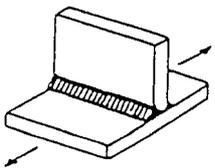
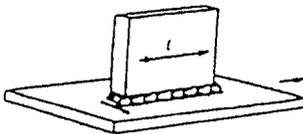
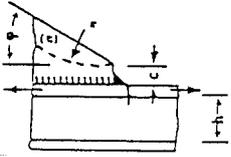
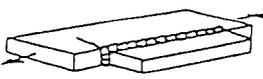
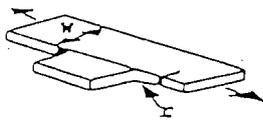
**APPENDIX B            IIW S-N Curves**

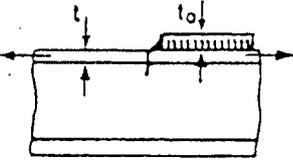
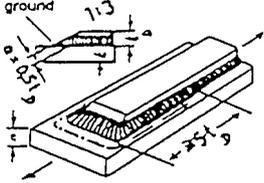
*("Recommendations on Fatigue of Welded Components" of April 1996)*

Structural Detail	Description	FAT
<b>Butt welds transversely loaded</b>		
	Transverse butt weld made in shop in flat position, toe angle $\leq 30^\circ$ , NDT	100
	Transverse butt weld on permanent backing bar	71
	Transverse butt welds welded from one side without backing bar, full penetration : - root controlled by NDT - no NDT	71 45
	Transverse butt weld ground flush, NDT, with transition in thickness and width :  - slope 1:5 - slope 1:3 - slope 1:2	125 100 80
	Transverse butt weld made in shop, welded in flat position, weld profile controlled, NDT, with transition in thickness and width :  - slope 1:5 - slope 1:3 - slope 1:2	100 90 80
	Transverse butt weld, NDT, with transition on thickness and width :  - slope 1:5 - slope 1:3 - slope 1:2	80 71 63

Structural Detail	Description	FAT
<b>Longitudinal load-carrying welds</b>		
	Longitudinal butt weld, both sides ground flush parallel to load direction, 100 % NDT	125
	Longitudinal butt weld : - without stop/start positions, NDT -with stop/start positions	125 90
	Continuous automatic longitudinal fully penetrated K-butt weld, without stop/start positions (based on stress range in flange), NDT	125
	Continuous automatic longitudinal double-sided fillet weld, without stop/start positions (based on stress range in flange)	100
	Continuous manual longitudinal fillet or butt weld (based on stress range in flange)	90

Structural Detail	Description	FAT
<b>Cruciform joints and/or T-joints</b>		
	<p>Cruciform joint or T-joint, K-butt welds, full penetration, no lamellar tearing, misalignment <math>e &lt; 0.15 t</math>, weld toes ground, toe crack</p>	80
	<p>Cruciform joint or T-joint, K-butt welds, full penetration, no lamellar tearing, misalignment <math>e &lt; 0.15 t</math>, toe crack</p>	71
	<p>Cruciform joint or T-joint, fillet welds, no lamellar tearing, misalignment <math>e &lt; 0.15 t</math>, toe crack</p>	63

Structural Detail	Description	FAT
<b>Non-load-carrying attachments</b>		
	<p>Transverse non-load-carrying attachment not thicker than main plate :</p> <ul style="list-style-type: none"> <li>- K-butt weld, toe ground</li> <li>- two-sided fillets, toe ground</li> <li>- fillet weld(s), as welded</li> <li>- thicker than main plate</li> </ul>	<p>100 100 80 71</p>
	<p>Longitudinal fillet welded gusset at length <math>l</math> :</p> <ul style="list-style-type: none"> <li>- <math>l &lt; 50</math> mm</li> <li>- <math>l &lt; 150</math> mm</li> <li>- <math>l &lt; 300</math> mm</li> <li>- <math>l &gt; 300</math> mm</li> </ul>	<p>80 71 63 50</p>
	<p>Longitudinal fillet welded gusset with smooth transition (sniped end or radius) welded on beam flange or plate :</p> <p><math>c &lt; 2t</math>, max 25 mm</p> <ul style="list-style-type: none"> <li>- <math>r &gt; 0,5 h</math></li> <li>- <math>r &lt; 0,5 h</math> or <math>\phi &lt; 20^\circ</math></li> </ul>	<p>71 63</p>
	<p>Longitudinal flat side gusset welded on plate edge or beam flange edge, gusset length <math>l</math> :</p> <ul style="list-style-type: none"> <li>- <math>l &lt; 150</math> mm</li> <li>- <math>l &lt; 300</math> mm</li> <li>- <math>l &lt; 300</math> mm</li> </ul>	<p>50 45 40</p>
	<p>Longitudinal flat side gusset welded on edge of plate or beam flange, radius transition ground :</p> <ul style="list-style-type: none"> <li>- <math>r &gt; 150</math> or <math>r/w &gt; 1/3</math></li> <li>- <math>1/6 &lt; r/w &lt; 1/3</math></li> <li>- <math>r/w &lt; 1/6</math></li> </ul>	<p>90 71 50</p>

Structural Detail	Description	FAT
<b>Reinforcements</b>		
	<p>End of long doubling plate on I-beam, welded ends (based on stress range in flange at weld toe) :</p> <ul style="list-style-type: none"> <li>- <math>t_D \leq 0.8 t</math></li> <li>- <math>0.8 t &lt; t_D \leq 1.5 t</math></li> <li>- <math>1.5 t &lt; t_D</math></li> </ul>	<p>56 50 45</p>
	<p>End of long doubling plate on beam, reinforced welded ends ground (based on stress range in flange at weld toe) :</p> <ul style="list-style-type: none"> <li>- <math>t_D \leq 0.8 t</math></li> <li>- <math>0.8 t &lt; t_D \leq 1.5 t</math></li> <li>- <math>1.5 t &lt; t_D</math></li> </ul>	<p>71 63 56</p>