1 WELD FATIGUE [90 Marks – one mark/minute]

Note, to obtain maximum points for each problem clearly motivate solutions and equations used.

The steel H-beams shown below are joined by a complete joint penetration butt joint (double-bevel-groove weld made from both sides in the flat position) with no cope holes. The steel has yield strength 350 MPa and ultimate tensile strength 490 MPa and welding was done with a perfectly matched electrode.

The web and flange thickness are 35 mm.

Shielded metal arc welding (SMAW) was done with the following requirements:

- Weld run-on and run-off pieces were used during welding and removed. The edges were then ground flush in the direction of the stress. An NDT inspection revealed no defects in the weld.
- The operating temperature is 20 °C and the surface is corrosion protected.

In the formula sheet are extractions of some detail categories from BS EN 1993-1-9.

Please answer the following:

1. What is the fatigue life of the component, in years, for the load spectrum given below? Assume a high consequence of failure and damage tolerant design **[70 Marks]**
2. By what percentage will the constant amplitude fatigue limit increase when the toe is dressed? **[5 Marks]**
3. What percentage increase would you expect in the constant amplitude fatigue limit, and why, if the following modifications are made to the butt joint: **[5 Marks]**
    a. All welds are ground flush to the plate surface perpendicular to the weld toes
    b. Non-destructive testing (NDT) is done to prove the weld free of indications
4. Figure 2 shows a beam subject to variable amplitude distributed loading. The bending moment diagram, shear force diagram and deformation shown in Figures 3 to 5, where:
    a. The span of the beam between supports is 12 m
    b. The beam is supplied in 6 m sections

    Where will you place the butt joints in the construction, at Points A or at Points B? Why? **[10 Marks]**

Table 1: Stress spectrum for a period of 10 days

$\Delta\sigma_R$ [MPa]	n_i
110	200
60	2 000
25	2 000 000

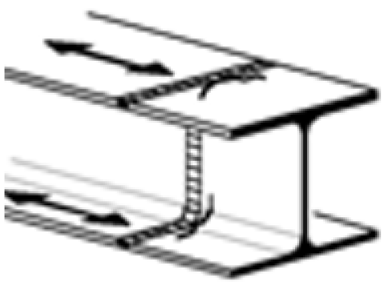


Figure 1: H-beam under axial loading

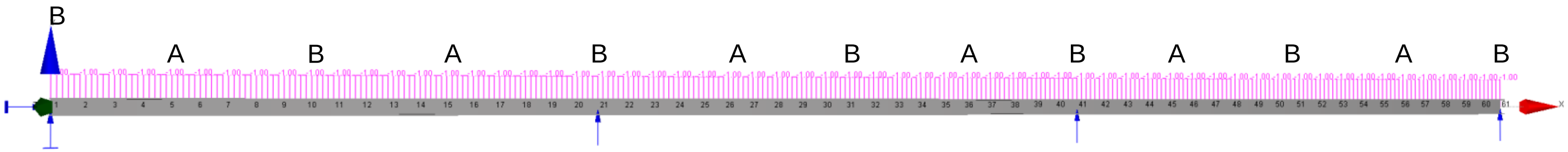


Figure 2: Beam with its supports and distributed load

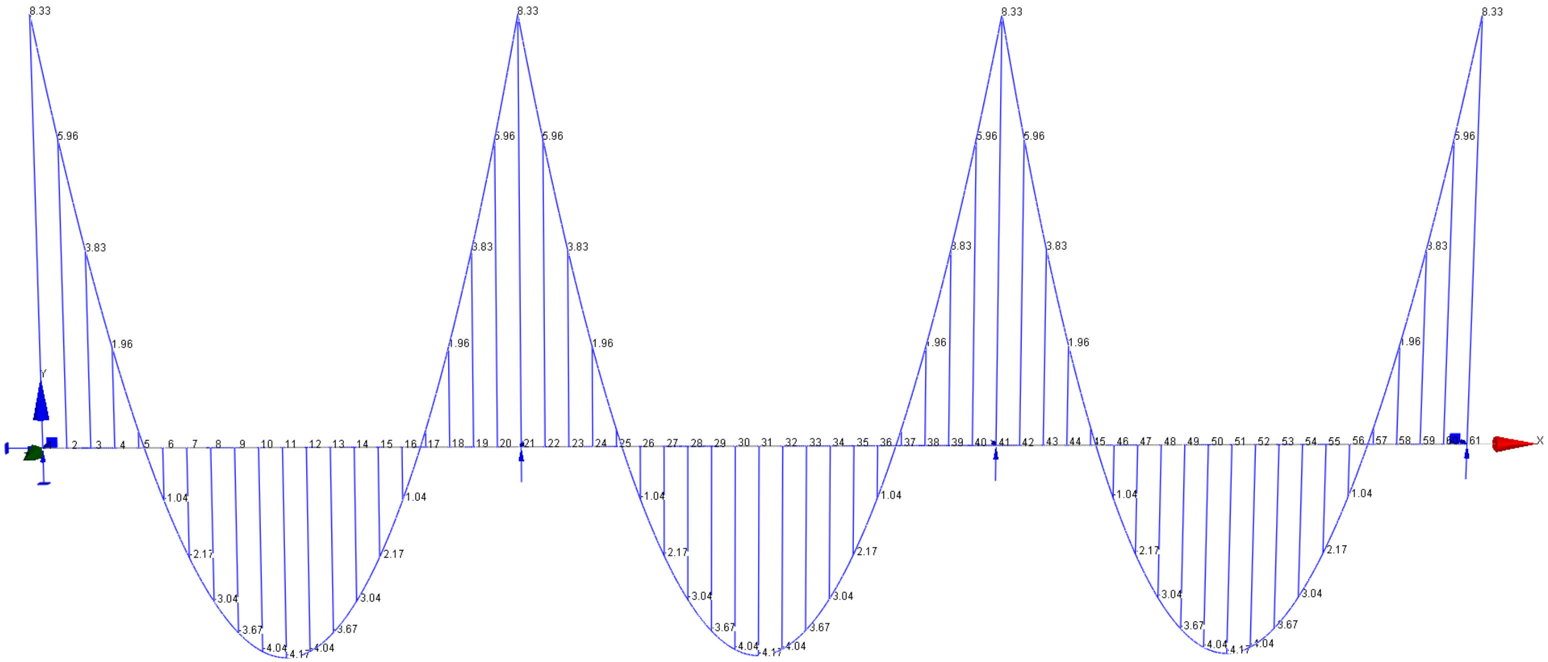


Figure 3: Bending moment diagram

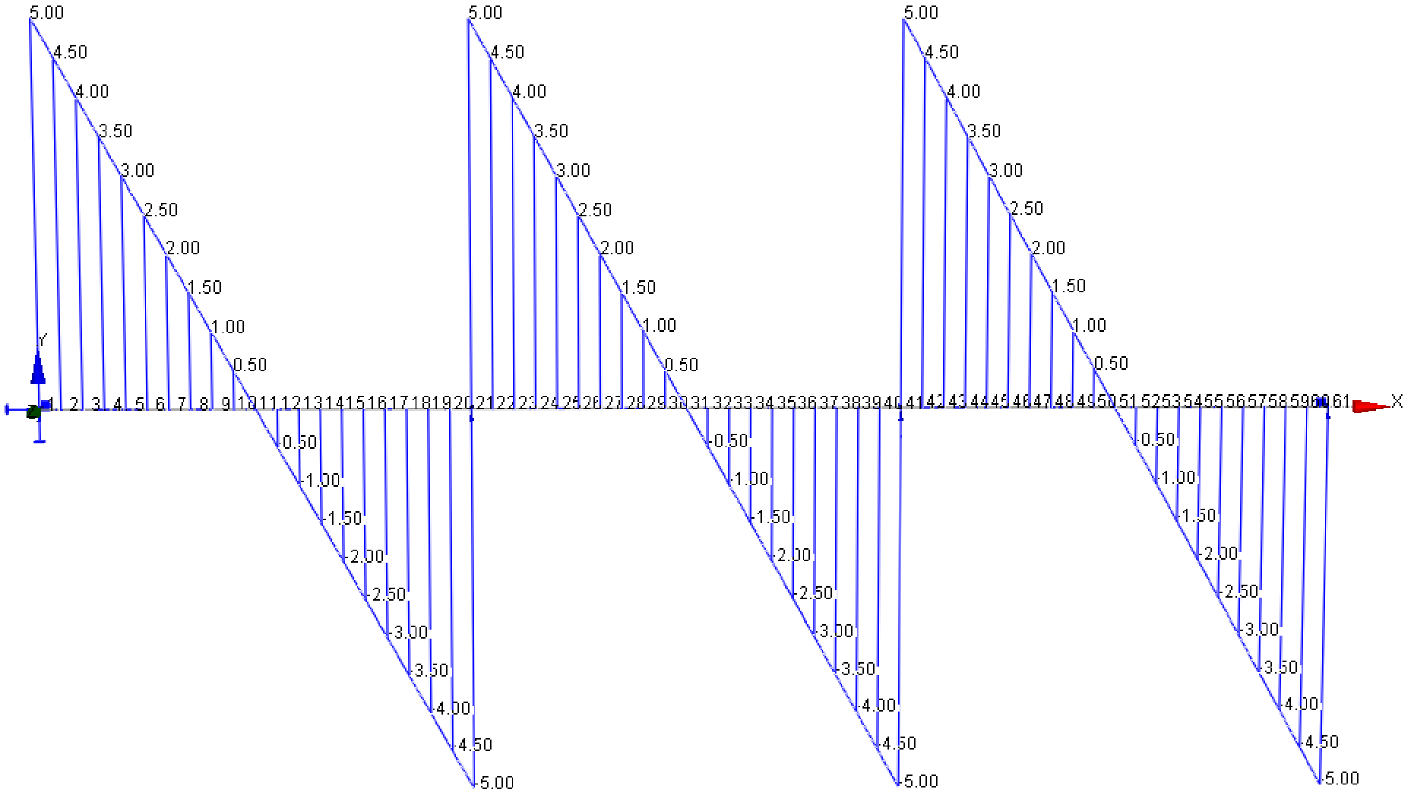


Figure 4: Shear force diagram

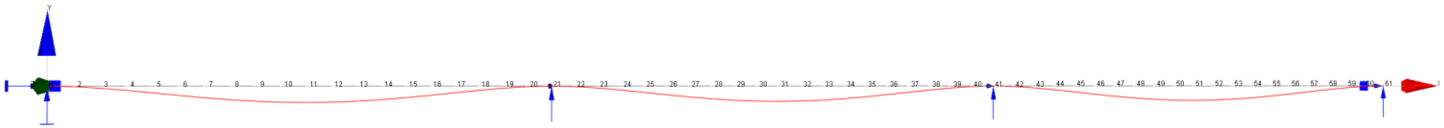


Figure 5: Deformation of the beam

1.1 Answers

1.1.1 Question 1 (16 minutes – allow 70 minutes) [70 Marks – one mark/minute]

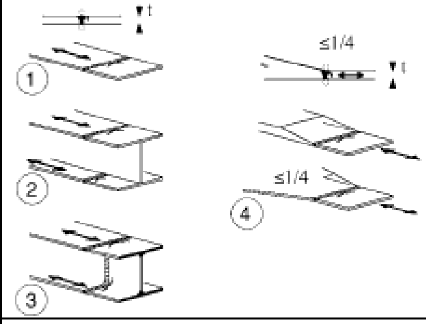
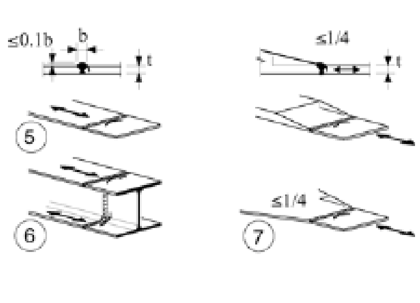
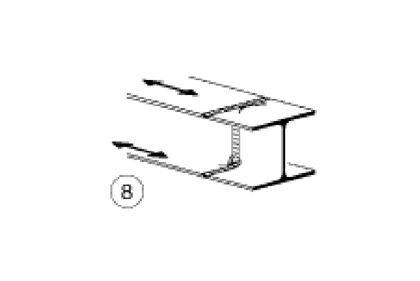
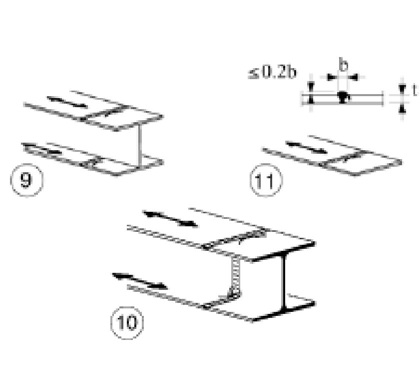
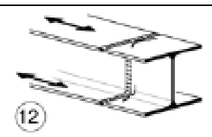
1.1.1.1 Partial factor for fatigue

From the formula sheet the partial factor for fatigue for high consequence of failure and damage tolerant assessment method is 1.15.

Assessment method	**Consequence of failure**	
	Low consequence	**High consequence**
Damage tolerant	1.00	**1.15**
Safe life	1.15	1.35
Source: BS EN 1993-1-9, 2005:11		

1.1.1.2 Detail category

The detail category is 63.

Detail category	Constructional detail		Description	Requirements
112	size effect for t>25mm: $k_s=(25/t)^{0.2}$		<u>Without backing bar:</u> 1) Transverse splices in plates and flats. 2) Flange and web splices in plate girders before assembly. 3) Full cross-section butt welds of rolled sections without cope holes. 4) Transverse splices in plates or flats tapered in width or in thickness, with a slope ≤ ¼.	- All welds ground flush to plate surface parallel to direction of the arrow. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. <u>Detail 3):</u> Applies only to joints of rolled sections, cut and rewelded.
90	size effect for t>25mm: $k_s=(25/t)^{0.2}$		5) Transverse splices in plates or flats. 6) Full cross-section butt welds of rolled sections without cope holes. 7) Transverse splices in plates or flats tapered in width or in thickness with a slope ≤ ¼. Translation of welds to be machined notch free.	- The height of the weld convexity to be not greater than 10% of the weld width, with smooth transition to the plate surface. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. <u>Details 5 and 7:</u> Welds made in flat position.
90	size effect for t>25mm: $k_s=(25/t)^{0.2}$		8) As detail 3) but with cope holes.	- All welds ground flush to plate surface parallel to direction of the arrow. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. - Rolled sections with the same dimensions without tolerance differences
80	size effect for t>25mm: $k_s=(25/t)^{0.2}$		9) Transverse splices in welded plate girders without cope hole. 10) Full cross-section butt welds of rolled sections with cope holes. 11) Transverse splices in plates, flats, rolled sections or plate girders.	- The height of the weld convexity to be not greater than 20% of the weld width, with smooth transition to the plate surface. - Weld not ground flush - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. <u>Detail 10:</u> The height of the weld convexity to be not greater than 10% of the weld width, with smooth transition to the plate surface.
63			12) Full cross-section butt welds of rolled sections without cope hole.	- Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides.

1.1.1.3 Thickness compensation

The factor to compensate for thickness more than 25 mm is:

$$k_s = \left(\frac{25}{t}\right)^{0.2} = \left(\frac{25}{35}\right)^{0.2} = 0.93$$

1.1.1.4 Temperature compensation

At room temperature $C_T = 1.0$.

1.1.1.5 Constant amplitude fatigue limit

The characteristic strength is given at 2 million cycles, and the constant amplitude fatigue limit at 5 million cycles. Therefore, the thickness modified constant amplitude fatigue limit is:

$$\begin{aligned}\Delta\sigma_D &= \left(\frac{2}{5}\right)^{\frac{1}{3}}\left(\frac{\Delta\sigma_C}{\gamma_F}\right)k_s \\ &= \left(\frac{2}{5}\right)^{\frac{1}{3}} \times \frac{63}{1.15} \times 0.93 \\ &= 37.5\ MPa\end{aligned}$$

1.1.1.6 Cut-off limit

The cut-off limit is:

$$\begin{aligned}\Delta\sigma_L &= \left(\frac{5}{100}\right)^{\frac{1}{5}}\Delta\sigma_D \\ &= \left(\frac{5}{100}\right)^{\frac{1}{5}} 37.5 \\ &= 20.6\ MPa\end{aligned}$$

1.1.1.7 S_r-N curve

The fatigue curve for the weld detail is then shown below from which the endurance at any stress range can be calculated:

$$N_R = \begin{cases} \left(\frac{\Delta\sigma_D}{\Delta\sigma_R}\right)^{m_1} N_D & m_1 = 3 \quad for\ 1.5f_y > \Delta\sigma_R \geq \Delta\sigma_D \\ \left(\frac{\Delta\sigma_D}{\Delta\sigma_R}\right)^{m_2} N_D & m_2 = 5 \quad for\ \Delta\sigma_D > \Delta\sigma_R \geq \Delta\sigma_L \\ \infty & for\ \Delta\sigma_R < \Delta\sigma_L \end{cases}$$

1.1.1.8 Calculations

For $\Delta\sigma_R = 110, n_1 = 200$

The endurance at this stress range is then:

$$\begin{aligned}N_R &= \left(\frac{\Delta\sigma_D}{\Delta\sigma_R}\right)^{m_1} N_D \\ &= \left(\frac{37.5}{110}\right)^3 \times 5 \times 10^6 \\ &= 198\ 100\ cycles\end{aligned}$$

The damage is then: $D_1 = \frac{200}{198100} = 0.001$

For $\Delta\sigma_R = 60, n_2 = 2\ 000$

The endurance is:

$$\begin{aligned}N_R &= \left(\frac{\Delta\sigma_D}{\Delta\sigma_R}\right)^3 N_D \\ &= \left(\frac{37.5}{60}\right)^3 \times 5 \times 10^6 \\ &= 1\ 220\ 700\end{aligned}$$

The damage is then:

$$\begin{aligned}D_2 &= \frac{2\ 000}{1\ 220\ 700} \\ &= 0.0016\end{aligned}$$

For $\Delta\sigma_R = 25, n_2 = 2\,000$

$$N_R = \left(\frac{\Delta\sigma_D}{\Delta\sigma_R}\right)^5 N_D$$
$$= \left(\frac{37.5}{25}\right)^5 \times 5 \times 10^6$$
$$= 37\,965\,750$$

The damage is then $D_3 = \frac{2000000}{37965750} = 0.053$

1.1.1.9 Total damage and fatigue life

The total damage over 10 days is:

$$D_{total} = 0.001 + 0.0016 + 0.053$$
$$= 0.0556$$

The number of repetitions to 5% probability of crack initiation in logN is then:

$$B_f = \frac{1}{D_{total}}$$
$$= 18$$

If one repetition was 10 days, then the fatigue life in days is:

$$L = 10 \times B_f$$
$$= 180\ days$$
$$= 0.5\ years$$

1.1.1.10 Verification in Excel

Detail category		63		$\Delta\sigma_{C,mod}$	51.2	MPa
γ_{Mf}		1.15		N_C	2.00E+06	
Thickness		35	mm	N_D	5.00E+06	
C_t		0.9349199		$\Delta\sigma_D$	37.7	MPa
C_T		1		N_L	1.00E+08	
m1		3		$\Delta\sigma_L$	20.7	MPa
m2		5				
$\Delta\sigma_R$	n_i	N_R	Damage			
[MPa]						
110	200	201 885	0.000990665			
60	2 000	1 244 021	0.00160769			
25	2 000 000	39 185 205	0.051039672			
		Total damage	0.053638027			
		Period	10	days		
		Fatigue life	186	days		
			0.51	years		

Marking:
1 mark for gamma MF
1 mark for Ct for thickness
1 mark for Delta Sigma D
1 mark for Delta Sigma L
3 marks for correct damage
1 mark for total damage – mark with error
1 mark for fatigue life – mark with error

1.1.2 Question 2 [5 Marks – one mark/minute]

The benefit of weld toe dressing is 1.3. Therefore, the weld detail category, the constant amplitude fatigue limit and the cut-off limit will increase by 30 %. Note, the upper limit for the benefit is 112 MPa. If the detail category is higher than 112/1.3 = 86, the percentage increase will be less.

Marking:
100% for motivation of answer. Consider both as acceptable answers if properly motivated – taking into consideration that the weld is ground.
2 marks for yes as answer with motivation.

1.1.3 Question 3

In this case the detail category will increase from 63 to 112 which is an increase of $\frac{112-63}{63} \times 100\% = 77.8\ \%$. The reasons for this increase is:

1. Stress concentrations in the joint have been removed.
2. Internal defects that cause stress concentrations and are crack initiation points are not present.

Mark out of 2 for 100%:
2 if the correct answer is given with reasons.
1 if correct answer is given with no valid reasons.

1.1.4 Question 4

The best position to put the butt joints in the beam is at Position A, for the following reasons:

1. Points A are close to the inflection points (where the moment is zero) and will see significantly lower bending stresses compared to Positions B
2. The shear force is maximum at Positions B on the supports and much lower than at Positions A
3. The areas of the beam when butt joined at Positions A with the highest bending moments and shear forces will not have welded butt joints.

Mark out of 3 for 100%:
3 if the correct answer is given with reasons.
1 if correct answer is given with no valid reasons.

2 References

Dowling, N. (2013). *Mechanical Behavior of Materials: Engineering Methods for Deformation, Fracture, and Fatigue* (4th ed.). Boston: Pearson.

FORMULA SHEET: Fatigue, Fracture Mechanics

2.1 Structural Mechanics

$$\sigma_i = \frac{M_x y_i}{I_{xx}} - \frac{M_y x_i}{I_{yy}} + \frac{F}{A}$$

$$\varepsilon_x = \frac{\sigma_x}{E} - \frac{\nu}{E}\left(\sigma_y + \sigma_z\right) + \alpha\Delta T$$

2.2 Fatigue: Machined Components

$$\sigma_{ar}^m N = C$$

$$\sigma_{ar,1}^m N_1 = \sigma_{ar,2}^m N_2$$

$$m = \frac{\log\left(\frac{N_2}{N_1}\right)}{\log\left(\frac{\sigma_{ar,1}}{\sigma_{ar,2}}\right)}$$

$$N_R = \begin{cases} \left(\frac{\sigma_{ar,1}}{\sigma_{ar}}\right)^m N_1 & 0.9f_{ut} \geq \sigma_{ar} \geq S_e \\ \infty & \sigma_{ar} < S_e \end{cases}$$

OR

$$\sigma_{ar} N^b = C$$

$$\sigma_{ar,1} N_1^b = \sigma_{ar,2} N_2^b$$

$$b = \frac{\log\left(\frac{\sigma_{ar,1}}{\sigma_{ar,2}}\right)}{\log\left(\frac{N_2}{N_1}\right)}$$

$$N_R = \begin{cases} \left(\frac{\sigma_{ar,1}}{\sigma_{ar}}\right)^{\frac{1}{b}} N_1 & 0.9f_{ut} \geq \sigma_{ar} \geq S_e \\ \infty & \sigma_{ar} < S_e \end{cases}$$

Endurance limit estimates:

$$\sigma_{erb} = \begin{cases} 0.25BHN\ ksi & for\ BHN \leq 400 \\ 100\ ksi & for\ BHN > 400 \end{cases}$$

Steel

$$\sigma_{erb} = \begin{cases} 0.5\sigma_u & for\ \sigma_u \leq 200\ ksi\ (1\,400\ MPa) \\ 100\ ksi\ (700\ MPa) & for\ \sigma_u > 200\ ksi\ (1\,400\ MPa) \end{cases}$$

Cast Iron + Cast Steels:

$$\sigma_{erb} = \begin{cases} 0.45\sigma_u & for\ \sigma_u \leq 600\ MPa \\ 275\ MPa & for\ \sigma_u > 600\ MPa \end{cases}$$

Stress concentrations

$$\sigma_{sc} = K_t S$$

$$K_t = \frac{\sigma_{sc}}{S}$$

$$K_f = \frac{\sigma_{erb}^{(un-notched)}}{\sigma_{erb}^{(nothced)}}$$

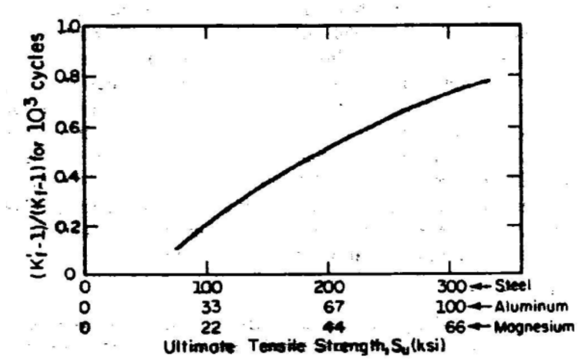
$$K_f = 1 + \frac{K_t - 1}{\left(1 + \frac{a}{r}\right)}$$

$$a = \left[\frac{300}{\sigma_u[ksi]}\right]^{1.8} \times 10^{-3}\ in.$$

$$\frac{K_f' - 1}{K_f - 1} = f(\sigma_u) = q$$

$$\sigma_{arb,1000}' = \frac{\sigma_{arb,1000}}{K_f'}$$

$$\sigma_{erb}' = \frac{\sigma_{erb}}{K_f}$$



Mean stress:

Approach	Equations
Modified Goodman	$\sigma_{ar} = \frac{\sigma_a}{1 - \frac{\sigma_m}{\sigma_u}}$
Gerber	$\sigma_{ar} = \frac{\sigma_a}{1 - \left(\frac{\sigma_m}{\sigma_u}\right)^2}, for\ \sigma_m \geq 0$
Morrow	$\sigma_{ar} = \frac{\sigma_a}{1 - \frac{\sigma_m}{\sigma_f'}}$
SWT	$\sigma_{ar} = \sqrt{\sigma_{max}\sigma_a} = \sqrt{(\sigma_m + \sigma_a)\sigma_a} = \sigma_{max}\sqrt{\frac{1-R}{2}}$
Walker	$\sigma_{ar} = \sigma_{max}^{1-\gamma}\sigma_a^{\gamma}\quad (\sigma_{max} > 0)$ $= \sigma_{max}\left(\frac{1-R}{2}\right)^{\gamma}\quad (\sigma_{max} > 0)$ $\gamma = -0.000200\sigma_u + 0.8818\quad (\sigma_u\ in\ MPa)$

Modifying factors

$$\sigma_{er} = \sigma_{\mathrm{erb}}' C_{size} C_{load} C_{surf} C_T C_{rel}$$

$$\sigma_{erb}' = \frac{0.5\sigma_u}{K_f}$$

$$\sigma_{ar,10^3} = \sigma'_{arb,10^3} C_{load} C_T C_{rel}$$
$$\sigma'_{arb,10^3} = \frac{0.9\sigma_u}{K'_f}$$

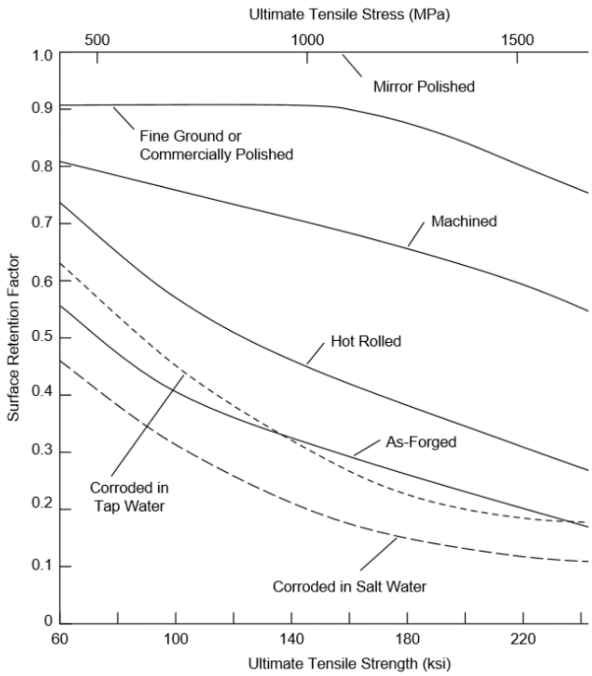
Size:

$$C_{size} = \begin{cases} 1.0, if\ d \le 8\ mm \\ 1.189 d^{-0.097}, if\ 8\ mm < d \le 250\ mm \end{cases}$$

Load:

$$\sigma_{er,axial} = 0.70\sigma_{erb}$$

C_{load} = 0.7 for axial loading if the fatigue S-N curve was obtained from completely reversed loading.



Temperature:

$$C_T = \begin{cases} 1.0\ for\ T \le 450\ ℃ \\ 1 - 5.8^{-3}(T - 450),\ for\ 450 < T \le 550\ ℃ \end{cases}$$

Reliability:

Reliability $1 - p_f$	C_r
0.5	1
0.9	0.897
0.95	0.868
0.99	0.814
0.999	0.753
0.9999	0.702
0.99999	0.659
0.999999	0.620

2.3 Fatigue: Large scale manufactured components

$$N_R = \begin{cases} \left(\frac{\Delta\sigma_D}{\Delta\sigma_R}\right)^{m_1} N_D & m_1 = 3 & 1.5f_y > \Delta\sigma_R \ge \Delta\sigma_D \\ \left(\frac{\Delta\sigma_D}{\Delta\sigma_R}\right)^{m_2} N_D & m_2 = 5 & \Delta\sigma_D > \Delta\sigma_R \ge \Delta\sigma_L \\ \infty & & \Delta\sigma_R < \Delta\sigma_L \end{cases}$$

$N_C = 2 \times 10^6\ cycles$
$N_D = 5 \times 10^6\ cycles$
$N_L = 100 \times 10^6\ cycles$

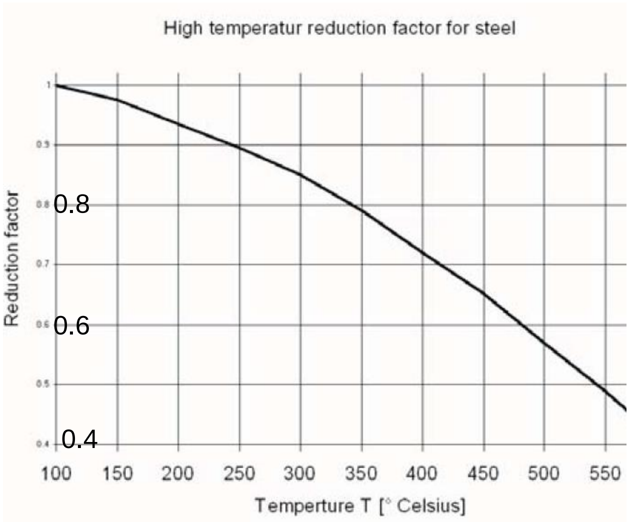
$$\Delta\sigma_{C,mod} = \frac{\Delta\sigma_C}{\gamma_{Mf}} C_t C_T C_{PWT}$$

Partial factor for fatigue:

Assessment	Consequence of failure	
	Low	High
Damage tolerant	1.0	1.15
Safe life	1.15	1.35

Temperature:

$$\Delta_{C,HT} = \Delta\sigma_C \frac{E_{HT}}{E_{20°C}}$$



Grinding & TIG dressing:

Effective stress range: $\Delta\sigma = \Delta\sigma$

Steel:

$$\Delta\sigma_C = min\begin{cases}1.3 \times \Delta\sigma_C \\ 112\end{cases}$$

Aluminium:

$$\Delta\sigma_C = min\begin{cases}1.3 \times \Delta\sigma_C \\ 45\end{cases}$$

Peening:

Effective stress range:

$$\Delta\sigma = \begin{cases}\Delta\sigma & R > 0 \\ \sigma_{max} & 0 < R \leq 0.4 \\ No\ benefit & R > 0.4\end{cases}$$

$$\Delta\sigma_{c,mod} = \begin{cases}Steel & f_y < 355 & \min(1.3\Delta\sigma_c, 112) \\ Steel & f_y \geq 355 & \min(1.6\Delta\sigma_c, 125) \\ Al & & \min(1.6\Delta\sigma_c, 56)\end{cases}$$

2.4 Fracture Mechanics

Universal equation: $K = \beta\sigma\sqrt{\pi a}$

Plastic collapse: $F_{pc} = \frac{f_y}{A_{nett}}$

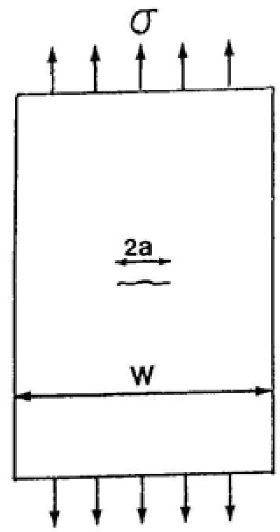
Fracture:

$$K = K_{Ic}$$
$$K_{Ic} = \beta\sigma\sqrt{\pi a_f}$$
$$a_f = \frac{1}{\pi}\left(\frac{K_{Ic}}{\beta\sigma}\right)^2$$
$$\sigma_f = \frac{K_{Ic}}{\beta\sqrt{\pi a_{fr}}}$$

$$a_{cri} = \min\begin{cases}a_{pc} & for\ plastic\ collapse \\ a_f & for\ fracture\end{cases}$$

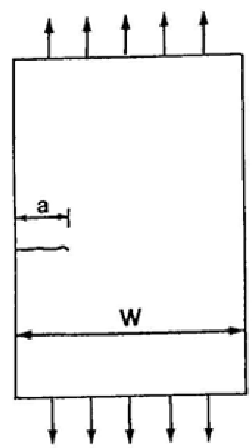
Stress concentration factors:

Centre cracked plate: $\beta = 1 + 0.256\left(\frac{a}{W}\right) - 1.152\left(\frac{a}{W}\right)^2 + 12.2\left(\frac{a}{W}\right)^3$



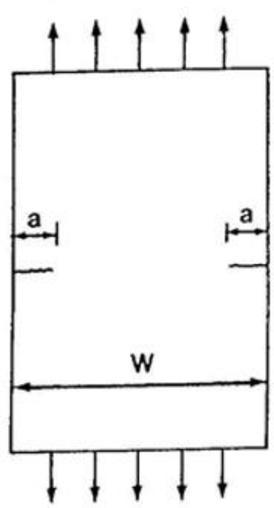
Single edge crack:

$$\beta = 1.12 - 0.23\left(\frac{a}{W}\right) + 10.56\left(\frac{a}{W}\right)^2 - 21.74\left(\frac{a}{W}\right)^3 + 30.42\left(\frac{a}{W}\right)^4$$



Double edge crack:

$$\beta = 1.12 + 0.43\left(\frac{a}{W}\right) - 4.79\left(\frac{a}{W}\right)^2 + 15.46\left(\frac{a}{W}\right)^3$$



LEFM

$$B, W - a, a \geq 2.5\left(\frac{K_{Ic}}{f_{yt}}\right)^2$$

$$W \geq 5.0\left(\frac{K_{Ic}}{f_{yt}}\right)^2$$

Fracture toughness estimation: $K_{IC} = 11.4\sqrt{C_v}$

Lower limit: $K_{IC} = 21.6(C_v)^{0.17}$

Note, C_v in Joule, K_{IC} in $MPa.\sqrt{m}$

Crack growth

$$\frac{da}{dN} = C_p(\Delta K^+)^{m_p}$$

$$\int_0^N dN = \int_{a_i}^{a_e} \frac{1}{C_p\left(\beta\Delta\sigma\sqrt{\pi a}\right)^{m_p}} da$$

2.5 Pressure equipment

$$P_{des} = P + \rho g h$$

Part	Thickness, t_p, [mm]	Pressure, P, [MPa]	Stress, S, [MPa]
Cylindrical shell	$\frac{Pr}{SE_1 - 0.6P}$	$\frac{SE_1 t}{r + 0.6t}$	$\frac{P(r + 0.6}{tE_1}$
Spherical shell	$\frac{Pr}{2SE_1 - 0.2P}$	$\frac{2SE_1 t}{r + 0.2t}$	$\frac{P(r + 0.2}{2tE_1}$
2:1 Semi-elliptical head	$\frac{PD}{2SE - 0.2P}$	$\frac{2SEt}{D + 0.2t}$	$\frac{P(D + 0.2}{2tE}$
Torispherical head with 6% knuckle	$\frac{0.885PL}{SE - 0.1P}$	$\frac{SEt}{0.885L + 0.1t}$	$\frac{P(0.885L + (}{tE}$
Conical section ($\alpha = 30°$)	$\frac{PD}{2\cos\alpha\,(SE - 0.6P)}$	$\frac{2SEt\cos\alpha}{D + 1.2t\cos\alpha}$	$\frac{P(D + 1.2t\,c}{2tE\cos c}$

Notes, all dimension in mm and pressure in MPa. You can also use m and Pa.

D Internal diameter [mm]. Add twice the corrosion allowance

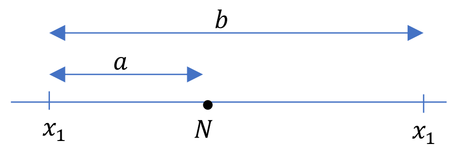
L Inside crown radius of Torispherical head [mm]. Add corrosion allowa

2.6 Interpolation on a logarithmic scale using your ruler

$$\frac{\log_{10} N - \log_{10} x_1}{\log_{10} x_2 - \log_{10} x_1} = \frac{a}{b}$$

$$\log_{10} N = \frac{a}{b}(\log_{10} x_2 - \log_{10} x_1) + \log_{10} x_1$$

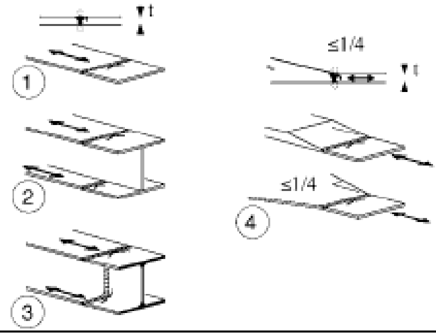
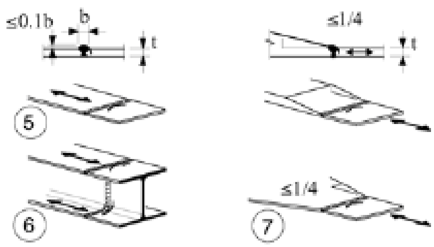
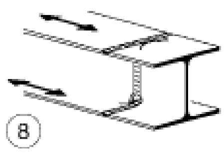
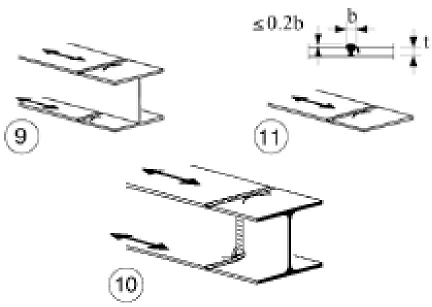
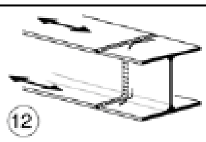
$$N = 10^{\left(\frac{a}{b}(\log_{10} x_2 - \log_{10} x_1) + \log_{10} x_1\right)}$$



CONVERSIONS

1 ksi = 6.89 MPa

2.7 Detail catgories

Detail category	Constructional detail		Description	Requirements
112	size effect for t>25mm: $k_s=(25/t)^{0,2}$		<u>Without backing bar:</u> 1) Transverse splices in plates and flats. 2) Flange and web splices in plate girders before assembly. 3) Full cross-section butt welds of rolled sections without cope holes. 4) Transverse splices in plates or flats tapered in width or in thickness, with a slope ≤ ¼.	- All welds ground flush to plate surface parallel to direction of the arrow. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. <u>Detail 3):</u> Applies only to joints of rolled sections, cut and rewelded.
90	size effect for t>25mm: $k_s=(25/t)^{0,2}$		5) Transverse splices in plates or flats. 6) Full cross-section butt welds of rolled sections without cope holes. 7) Transverse splices in plates or flats tapered in width or in thickness with a slope ≤ ¼. Translation of welds to be machined notch free.	- The height of the weld convexity to be not greater than 10% of the weld width, with smooth transition to the plate surface. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. <u>Details 5 and 7:</u> Welds made in flat position.
90	size effect for t>25mm: $k_s=(25/t)^{0,2}$		8) As detail 3) but with cope holes.	- All welds ground flush to plate surface parallel to direction of the arrow. - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. - Rolled sections with the same dimensions without tolerance differences
80	size effect for t>25mm: $k_s=(25/t)^{0,2}$		9) Transverse splices in welded plate girders without cope hole. 10) Full cross-section butt welds of rolled sections with cope holes. 11) Transverse splices in plates, flats, rolled sections or plate girders.	- The height of the weld convexity to be not greater than 20% of the weld width, with smooth transition to the plate surface. - Weld not ground flush - Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides; checked by NDT. <u>Detail 10:</u> The height of the weld convexity to be not greater than 10% of the weld width, with smooth transition to the plate surface.
63			12) Full cross-section butt welds of rolled sections without cope hole.	- Weld run-on and run-off pieces to be used and subsequently removed, plate edges to be ground flush in direction of stress. - Welded from both sides.

2.8 Joint efficiencies

TABLE UW-12
MAXIMUM ALLOWABLE JOINT EFFICIENCIES[1,5] FOR ARC AND GAS WELDED JOINTS

Type No.	Joint Description	Limitations	Joint Category	Degree of Radiographic Examination (a) Full[2]	(b) Spot[3]	(c) None
(1)	Butt joints as attained by double-welding or by other means which will obain the same quality of deposited weld metal on the inside and outside weld surfaces to agree with the requirements of UW-35. Welds using metal backing strips which remain in place are excluded.	None	A, B, C, & D	1.00	0.85	0.70
(2)	Single-welded butt joint with backing strip other than those included under (1)	*(a)* None except as in (b) below	A, B, C, & D	0.90	0.80	0.65
		(b) Circumferential butt joints with one plate offset; see UW-13(b)(4) and Fig. UW-13.1, sketch (k)	A, B, & C	0.90	0.80	0.65
(3)	Single-welded butt joint without use of backing strip	Circumferential butt joints only, not over 5/8 in. (16 mm) thick and not over 24 in. (610 mm) outside diameter	A, B, & C	NA	NA	0.60
(4)	Double full fillet lap joint	*(a)* Longitudinal joints not over 3/8 in. (10 mm) thick	A	NA	NA	0.55
		(b) Circumferential joints not over 5/8 in. (16 mm) thick	B & C[6]	NA	NA	0.55
(5)	Single full fillet lap joints with plug welds conforming to UW-17	*(a)* Circumferential joints[4] for attachment of heads not over 24 in. (610 mm) outside diameter to shells not over 1/2 in. (13 mm) thick	B	NA	NA	0.50
		(b) Circumferential joints for the attachment to shells of jackets not over 5/8 in. (16 mm) in nominal thickness where the distance from the center of the plug weld to the edge of the plate is not less than 1 1/2 times the diameter of the hole for the plug.	C	NA	NA	0.50

(continued)