ENGINEERING TRIPOS PART IIB

Monday 30 April 2007 9 to 10.30

Module 4D10

STRUCTURAL STEELWORK

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Unless otherwise indicated, in all questions the given loads are already factored and no partial material factors need to be applied, and self-weight can be ignored.

Attachment: 4D10 data sheets (9 pages)

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	Engineering Data Book CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator.

1 (a) List any four of the seven general principles for effective design of joints. [20%]

(b) Describe the difference between *simple* and *continuous* construction, and its implication for joint design. [20%]

(c) A particular joint is formed from a distributed bolted connection. Detail the calculation steps and any necessary assumptions required to estimate the maximum shear force in any given bolt. Assume that the bolt holes are co-planar and that the joint transmits both a shear force and a significant moment between connecting members. [40%]

(d) Describe briefly how you might assess the capacity of a typical bolted column base connection. [20%]

2 The tall portal frame in Fig. 1 is initially free of stresses and is then loaded by a pair of forces, W and λW, as shown, where λ is a load factor for the lateral force. The corners are rigid, and both feet and the upper mid-span are pinned.

(a) Show that the magnitude of the bending moment at the top left corner is equal to $WL(1+8\lambda)/2$. Hence, determine the distribution of bending moment in terms of W, λ and L. Sketch the bending moment profile, indicating salient values. [30%]

(b) The frame is constructed from hot-rolled sections of 305 × 102 × 33 kg/m grade S355 UB in which $L = 0.5$ m. Using the CDC method, determine whether a value of $W = 200$ kN can be safely carried when $\lambda = 0.25$. Assume that the columns do not buckle out-of-plane, there is no in-plane sway, and bending takes place about the major axis. Do not assess the top beam. [70%]

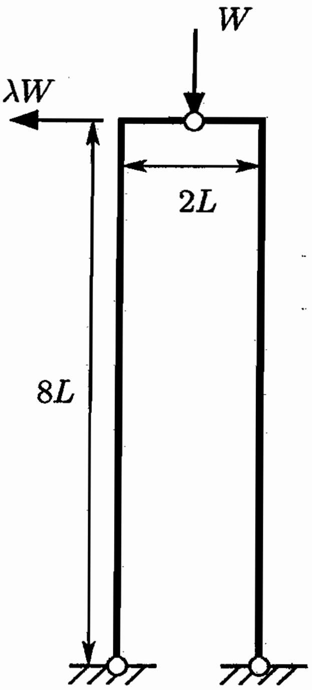


Fig. 1

3 The vertical, uniform beam in Fig. 2 is initially free of stresses and is then loaded by a horizontal force, F, applied to its top. The beam is free to move horizontally but not to rotate at its base, and is simply supported further up, as shown: both these supports and the position of loading accommodate warping but prevent out-of-plane deflections and twist.

(a) Show that the magnitude of the bending moment at the base is FL. Hence, determine the bending moment profile in terms of F and L. [20%]

(b) The beam is a 457 × 152 × 82 kg/m grade S275 UC. $L = 2$ m and the beam bends about its major axis. By consideration of lateral stability, calculate the maximum value of F for which the beam will be safe. [50%]

(c) The force, F, is now applied *vertically* at the top of the beam, resulting in axial compression. Determine the margin by which F can be increased or decreased safely compared to the result in (b). Assume that there are no out-of-plane deflections. [30%]

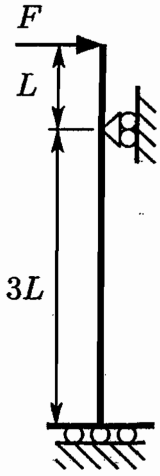


Fig. 2

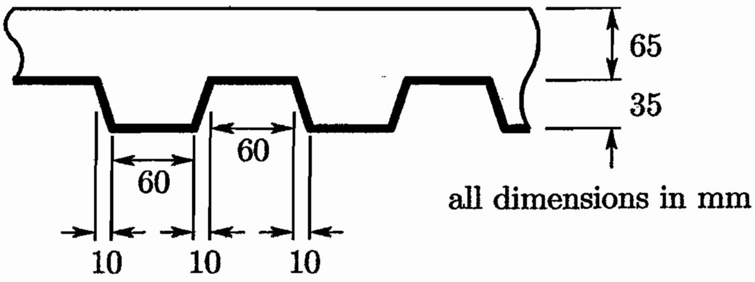
4 The composite floor in Fig. 3 carries 5.5 kN/m^2 of imposed load in addition to 3.0 kN/m^2 of permanent services, where the respective load factors are 1.6 and 1.4.

The floor consists of a concrete slab of maximum thickness 100 mm, which has been cast onto a profiled decking, as shown. It acts compositely with 406 × 178 × 60 kg/m grade S275 UB, each of span 10 m and placed at 2.8 m spacing, and simply supported at their ends. The concrete has design strength, $f_{cd} = 30$ N/mm^2, and a density of 2400 kg/m^3. The beams are perpendicular to the direction of troughs in the decking.

(a) Show that the UB's acting compositely with the floor can carry the specified loading, imposed and permanent, and the self-weight, and by what margin. [50%]

(b) Calculate the total number of 13 mm × 65 mm shear studs needed in each UB to achieve full composite action. [20%]

(c) Estimate the central deflection induced by the short term application of the imposed load. [30%]



all dimensions in mm

Fig. 3

END OF PAPER

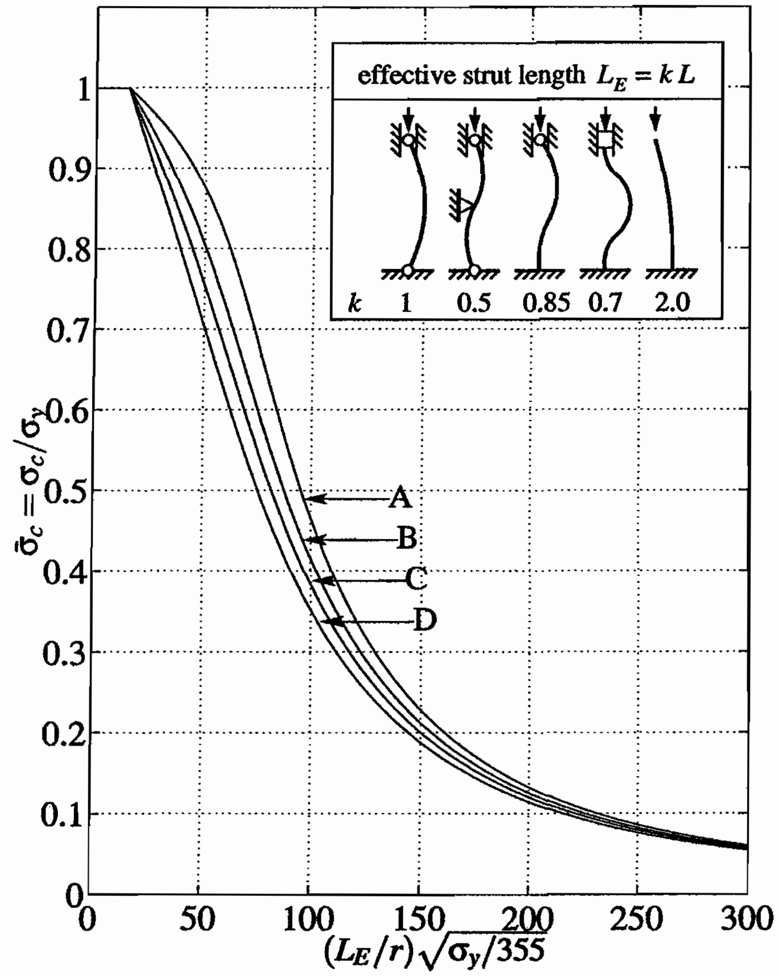
4D10 Structural Steelwork 2006/07

Data Sheets

DO NOT USE FOR ACTUAL DESIGN OF STRUCTURAL STEELWORK

KAS, September 14, 2006

DS1: Column Buckling Capacity σ_c

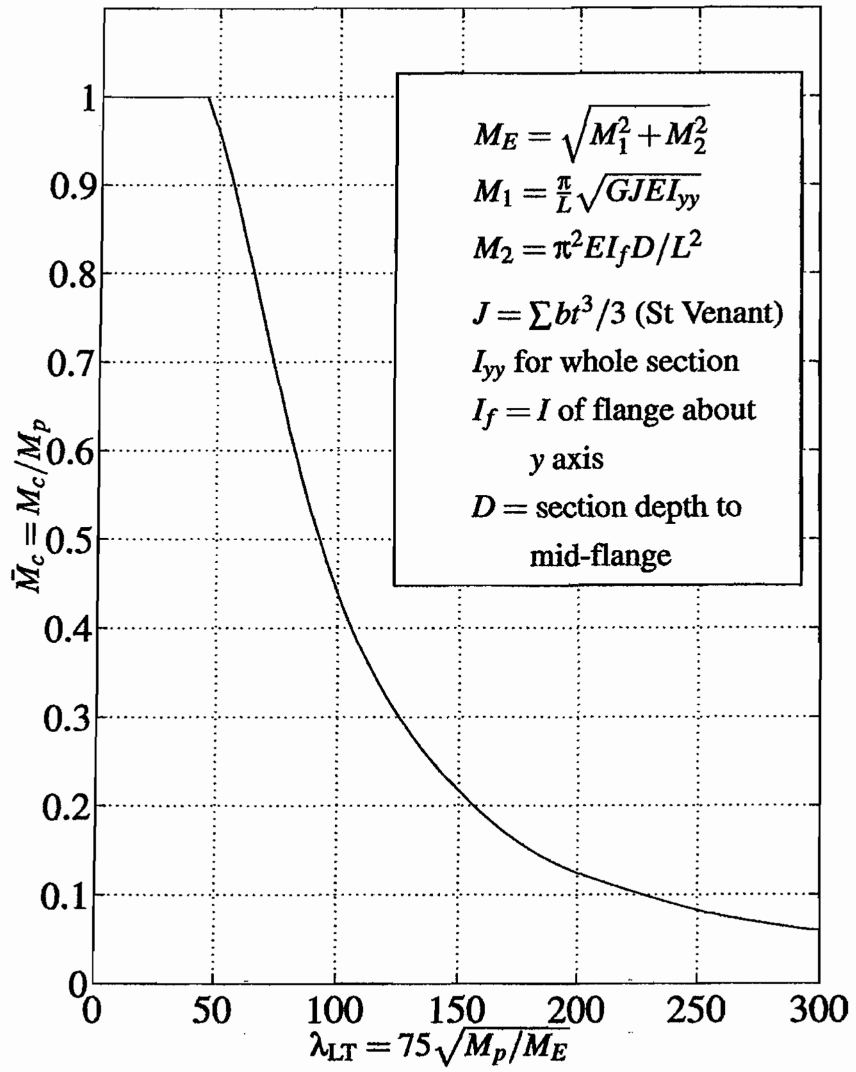


note 1: σ_y in $\mathrm{N/mm^2}$; r is the radius of gyration about centroid of cross-section; curves are selected as follows (linear interpolation used for intermediate r/y values.)

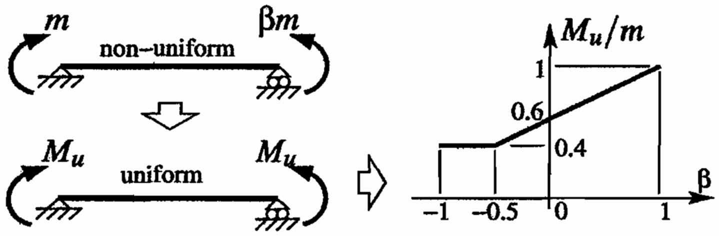
	members fabricated by welding	all other members including stress-relieved welded members
$r/y \geq 0.7$	curve B	curve A
$r/y = 0.6$	curve C	curve B
$r/y = 0.5$	curve C	curve B
$r/y \leq 0.45$	curve C	curve C
all rolled sections with flange thickness > 40 mm	curve D	curve D
hot-finished hollow sections	curve A	curve A

note 2: y is extreme fibre distance from centroid for the same axis as r.
note 3: intermediate bracing stiffness $> 16P_E/L$ for buckling force $P_c = 4P_E$ (pin-ends only).

DS2: Lateral Torsional Buckling Uniform Moment Capacity M_c



note 1: for non-uniform end moments in the ratio of β



$$M_u = (0.6 + 0.4\beta)m, \quad -0.5 \le \beta \le 1;$$
$$M_u = 0.4m, \quad -1 \le \beta \le -0.5$$

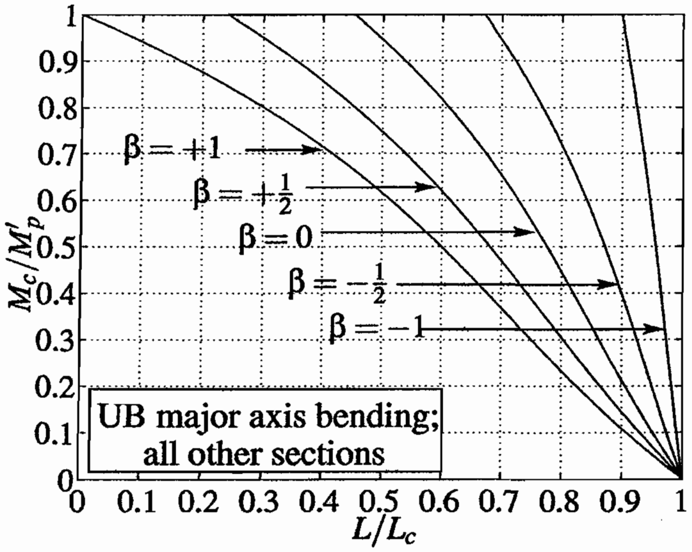
note 2: for stability, $M_u < M_c$.

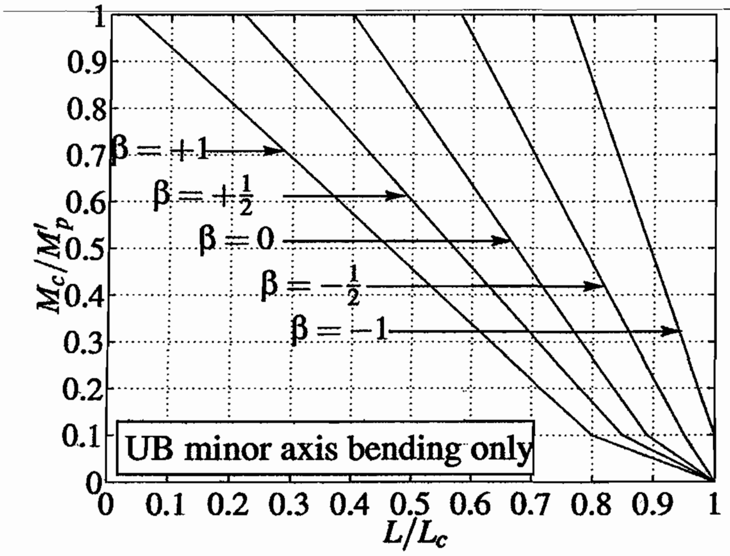
note 3: for strength, $m < M_p$

note 4: if the shear force, V, is larger than $V_c/2$, where $V_c = A_{\mathrm{web}}\tau_y$, M_p in $\bar{M}_c$ and λ_{LT} is replaced by M_y, equal to $Z_e\sigma_y$.

DS3: Beam Columns; Limiting M_c Under Axial Load, P

a. Column Deflection Curves.





note 1: M'_p is the reduced plastic moment; β as in DS2; L_c is the length of a pin-ended column buckling under P alone (found with DS1); only use CDC method if $\lambda_{\text{web}} \leq 56$.

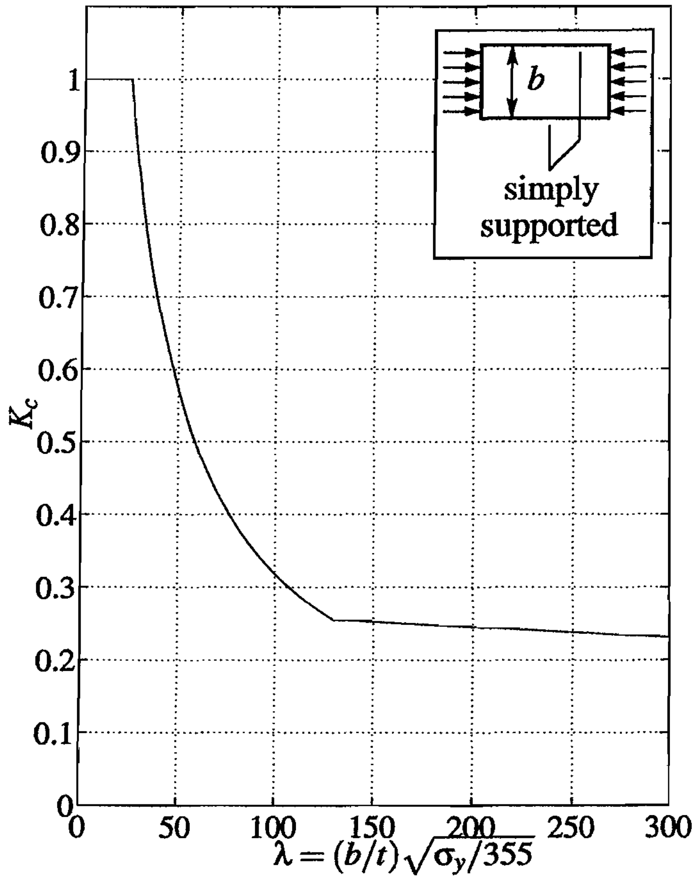
b. Interaction Equations.

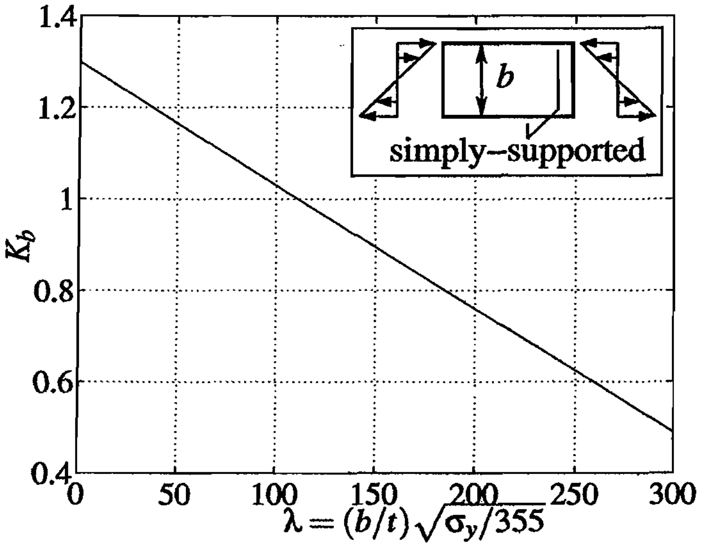
for strength: $\dfrac{P}{P_p} + \dfrac{M_{\max}}{M_p} \leq 1$ (or find M'_p directly)

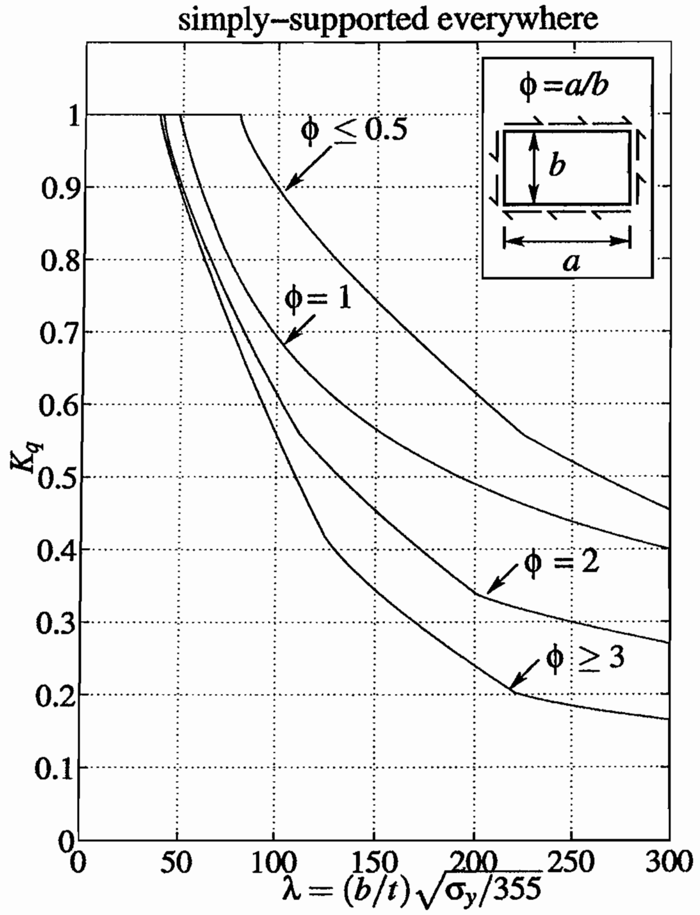
for stability: $\dfrac{P}{P_c} + \dfrac{M_u}{M_c} \leq 1$ (P_c from DS1, M_u and M_c via DS2: all **notes** apply)

DS4: Panel Strength and Plate Compactness

a. Panel strength: use the following three figures in the expressions overleaf.







$$\text{panel stability:} \quad \frac{\sigma_c}{\sigma_{cc}} + \left(\frac{\sigma_b}{\sigma_{bc}}\right)^2 + \left(\frac{\tau}{\tau_c}\right)^2 \leq 1$$

note 1: $\sigma_{cc} = K_c\sigma_y$; $\sigma_{bc} = K_b\sigma_y$; $\tau_c = K_q\tau_y$ $(K_q\sigma_y/\sqrt{3})$.

note 2: τ is the shear stress on the panel, σ_c is the average compressive stress and σ_b is the maximum bending stress.

$$\text{panel local strength:} \quad \sigma \leq \sqrt{\sigma_y^2 - 3\tau^2}$$

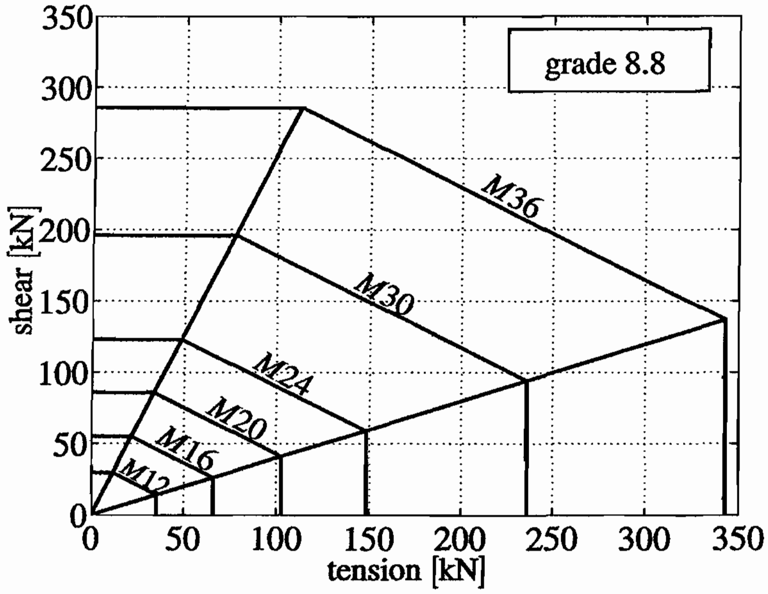
note 3: effective width, b_e, of compression flange with stiffener spacing, b, is $K_c b$.

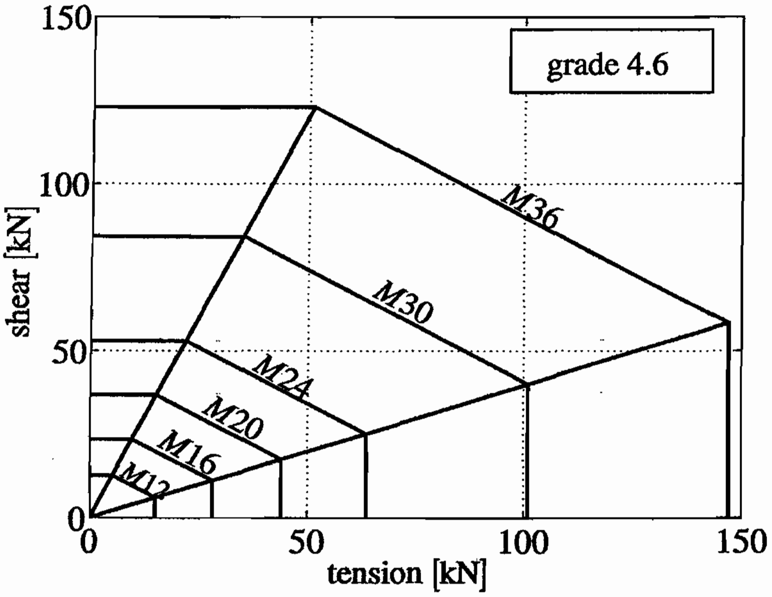
b. Plate compactness.

member and action	compact if λ $(= (b/t)\sqrt{\sigma_y/355})$
internal plate in compression	≤ 24
external plate in compression	≤ 8
internal plate in bending (no axial load)	≤ 56

DS5 Connector Capacity and Fatigue Life

a. Bolt strength in combined tension and shear.





b. Bolt placement.

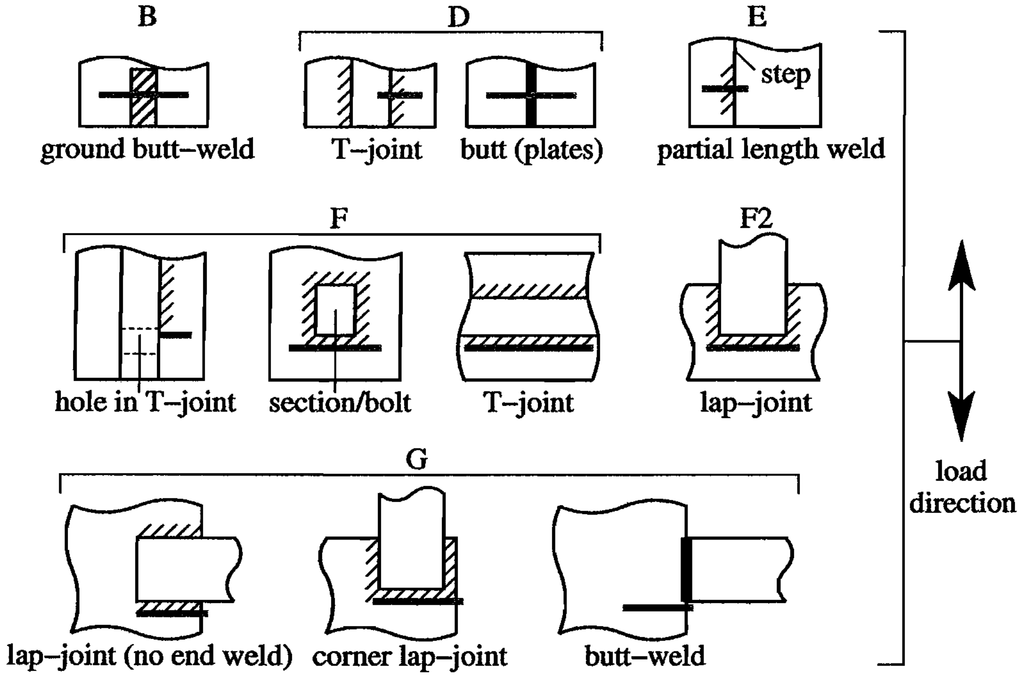
edge and end distances: $\geq 2.5\phi$

spacing between bolt axes: $\leq 32t$ and $\geq 2.5\phi$

note 1: **ϕ is the bolt hole diameter; t is the total thickness of joint plates.**

c. Weld capacity. Shear force transmitted across weld $\leq$ throat area $\times$ τ_y.

d. Weld classification. Plan-views of typical crack locations, which are shown in grey for clarity. Where a crack is shown to overlap with a step or T-joint edge, it has become vertical.



e. Weld fatigue life. The number of repetitions, N, to failure under stress amplitude, σ_r, is

$$N\sigma_r^m = K_2 \quad (\sigma_r \text{ in N/mm}^2)$$

where the constants m and K_2 take different values for each class of weld from the following table.

detail class	m	K_2	σ_o [N/mm^2]
G	3	0.25×10^{12}	29
F2	3	0.43×10^{12}	35
F	3	0.63×10^{12}	40
E	3	1.04×10^{12}	47
D	3	1.52×10^{12}	53
B	4	1.01×10^{15}	100

note 2: the number of repetitions of each stress range, σ_r, less than σ_o —the non-propagating stress—, should be reduced by a factor $(\sigma_r/\sigma_o)^2$.

note 3: for complex variations, use Miner's Law

$$\frac{n_1}{N_1}+\frac{n_2}{N_2}+\cdots+\frac{n_i}{N_i}+\cdots\leq 1$$

n_i is the number of *applied* cycles under σ_{ri}; N_i is the *total* number of possible cycles under σ_{ri}. Each σ_{ri} is given by application of the *Reservoir Method* described in the notes.

DS6: Composite Construction

a. Headed shear stud capacity.

headed studs		f_{cd} [N/mm^2]			
diameter [mm]	height [mm]	20	30	40	50
		stud shear strength [kN]			
25	100	139	154	168	183
19	100	90	100	109	119
13	65	42	47	52	57

note 1: for sheeting ribs orthogonal to the supporting beam, single studs have full strength but paired studs each have 80% strength.

b. Transformed section data.

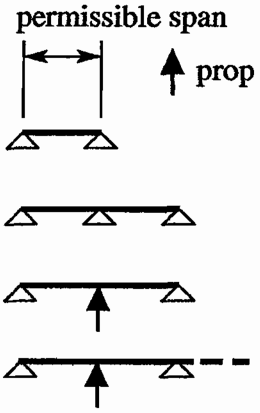
Young's modulus for grade 30 concrete, E_c, depends on duration of loading as:

short term: $E_c = 28\ \text{kN/mm}^2$
long term: $E_c = 14\ \text{kN/mm}^2$

Effective width of slab, b_e, is equal to $0.25 \times$ span but less than b, the beam spacing.

The maximum deflection must be less than the total span/250.

c. Profiled decking capacity.



		$t = 0.9$ mm			$t = 1.2$ mm		
support condition	total slab depth [mm]	imposed loading [kN/m^2]					
		2.5	5	7.5	2.5	5	7.5
		permissible spans [m]					
single span (no props)	100	2.3	2.3	2.3	2.8	2.8	2.8
	150	2.0	2.0	2.0	2.4	2.4	2.4
multiple span (no props)	100	2.3	2.3	2.3	2.7	2.7	2.7
	150	2.0	2.0	2.0	2.4	2.4	2.4
single span (one prop)	100	4.5	3.9	3.3	5.1	4.1	3.6
	150	4.0	4.0	4.0	4.7	4.7	3.7
multiple span (with props)	100	4.6	4.0	3.4	5.1	4.1	3.6
	150	4.1	4.1	4.1	4.8	4.8	4.8

note 2: table above only applies to 50 mm deep troughs; thickness of sheeting is t.