ENGINEERING TRIPOS PART IIB

Monday 19 April 2010 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.

Attachments: Special datasheets (9 pages).

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS
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

KAS03

1 The continuous beam, ABCD, in Fig. 1 has a uniform cross-section and is simply-supported at both A and C. The support at D freely enables vertical movement but prevents rotation of the beam end. AC and CD each have length L, and the beam is initially free of stresses. A vertical load W is applied midway along AC at B, as indicated.

(a) Show that the magnitude of the resulting bending moment at D is $3WL/64$ and determine the bending moment profile along the beam in terms of W and L. [35%]

(b) The beam is a 457 × 152 × 82 kg/m grade S275 Universal Beam, and the total length of AD is 20 m. At the supports and at B, the beam is restrained against both lateral deflection and twist, but is free to warp. By consideration of stability, calculate the maximum value of W for which the beam will be *everywhere* safe. [65%]

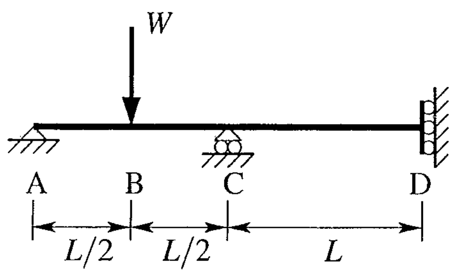


Fig. 1

2 A 254 × 254 × 107 kg/m grade S275 Universal Column has a length of 17.5 m. An axial load of 720 kN is applied to this column on the line of the minor axis but with eccentricities relative to, and beneath, the major axis line of 120 mm and 60 mm at the top and bottom of the column, respectively. The column is simply supported at both ends with respect to major axis bending, and lateral torsional buckling and minor axis flexural buckling are prevented. Determine whether the column can safely carry the load by:

(a) the CDC method; [65%]

(b) the Interaction Equation approach. [35%]

3 A box girder bridge is fabricated by welding together grade S275 plates, of thickness 20 mm, to form a trapezoidal cross-section whose top and bottom flanges have widths of 10 m and 6 m, respectively; the webs are inclined at 45° to the flanges. Longitudinal stiffeners are added to the top flange, and placed equally across its width at 2 m centres; vertical cross-frames are spaced 2 m apart along the length of the bridge. A longitudinal stiffener is added to the middle of each web. All stiffeners are identical with a geometry of 100 mm $\times$ 10 mm. At a given cross-section, the bridge carries a bending moment of 50 MNm, which induces compression in the top flange, and an axial compressive force of 1 MN.

(a) Check the adequacy of the compressive flange as an effective column. [30%]

(b) Check the adequacy of the most heavily stressed web panel. [40%]

(c) The designer thinks it may be possible to remove the web stiffeners. Is this advisable? Justify your advice by calculation. [30%]

4 A composite floor carries 5.5 kN/m^2 of imposed load in addition to 1.0 kN/m^2 of permanent services, where the respective load factors are 1.6 and 1.4. The floor consists of a concrete slab, which has been cast onto profiled decking: the slab has a minimum thickness of 100 mm and a maximum thickness of 150 mm. The floor acts compositely with 406 × 178 × 60 kg/m grade S355 Universal Beams, each of span 14 m and placed at 3 m spacing, and simply supported at their ends. The concrete has design strength, $f_{cd} = 30$ N/mm^2, and a density of 24 kN/m^3. The beams are perpendicular to the direction of troughs in the profiled 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%]

END OF PAPER

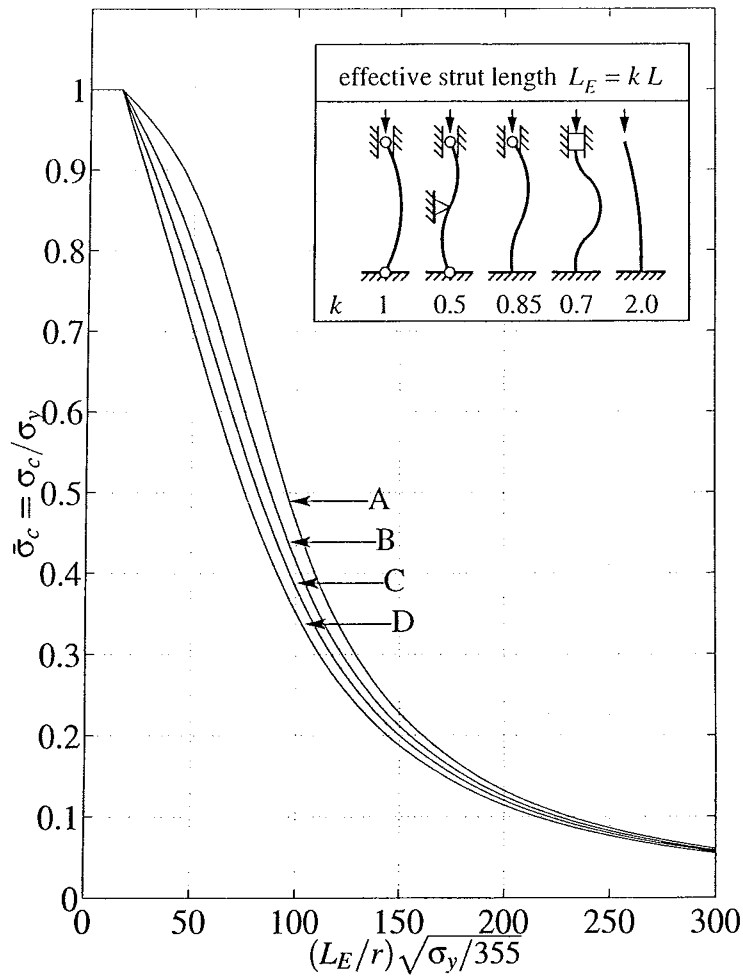
4D10 Structural Steelwork 2009/10

Data Sheets

DO NOT USE FOR ACTUAL DESIGN OF STRUCTURAL STEELWORK

KAS & FAM, September 8, 2009

DS1: Column Buckling Capacity σ_c

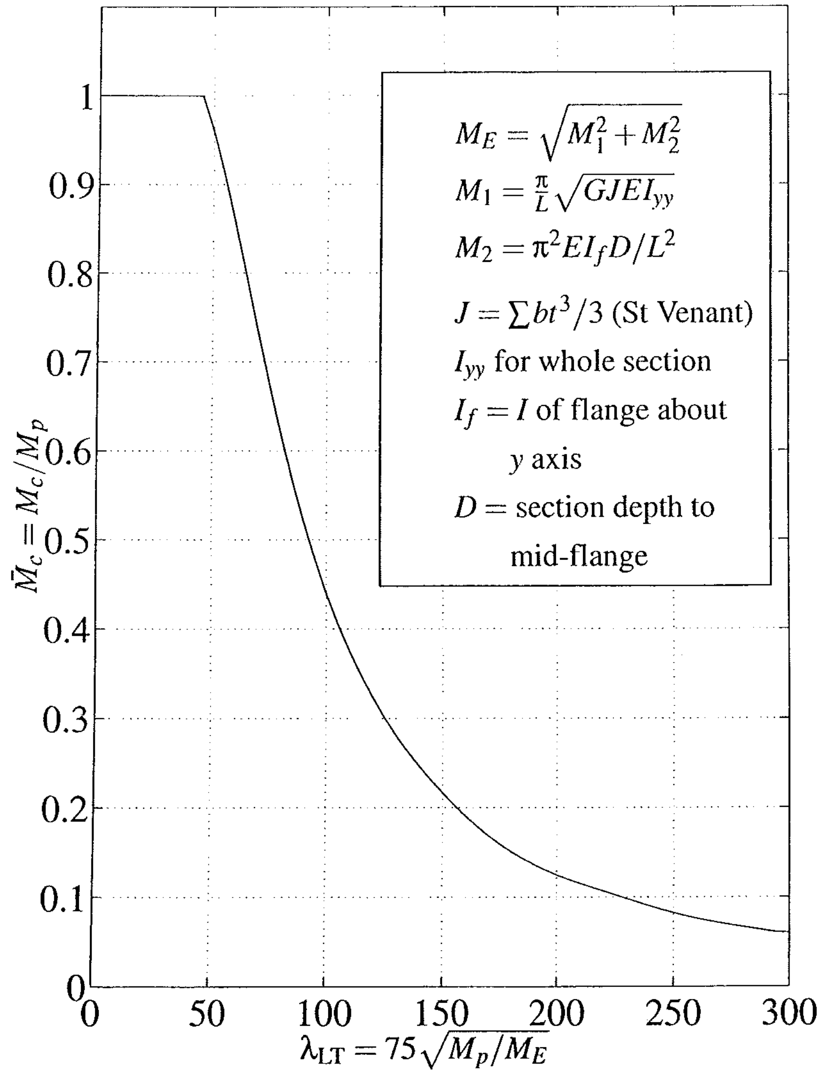


note 1: σ_y in MPa; r is the radius of gyration about centroid of cross-section; curves are selected as follows (linear interpolation used for intermediate r/y values.)

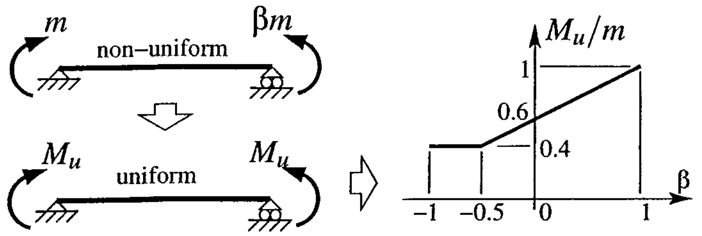
	members fabricated by welding	all other members including stress-relieved welded members
$r/y \geq 0.7$	curve B	curve A
$r/y = 0.6$	curve C	curve B
$r/y = 0.5$	curve C	curve B
$r/y \leq 0.45$	curve C	curve C
all rolled sections with flange thickness > 40 mm	curve D	curve D
hot-finished hollow sections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

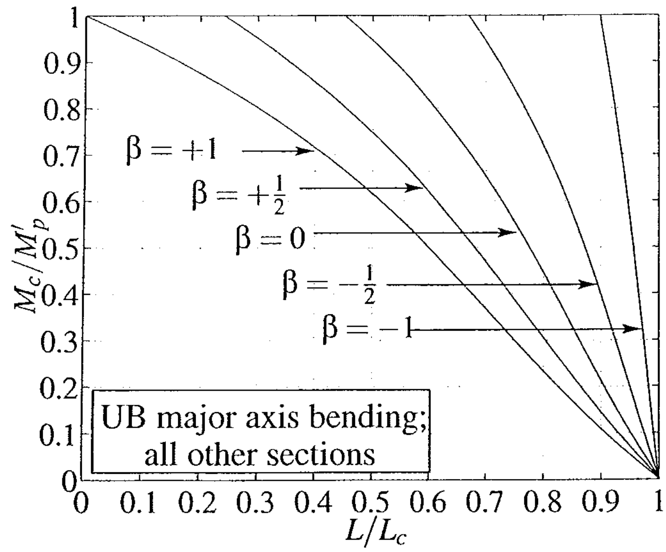


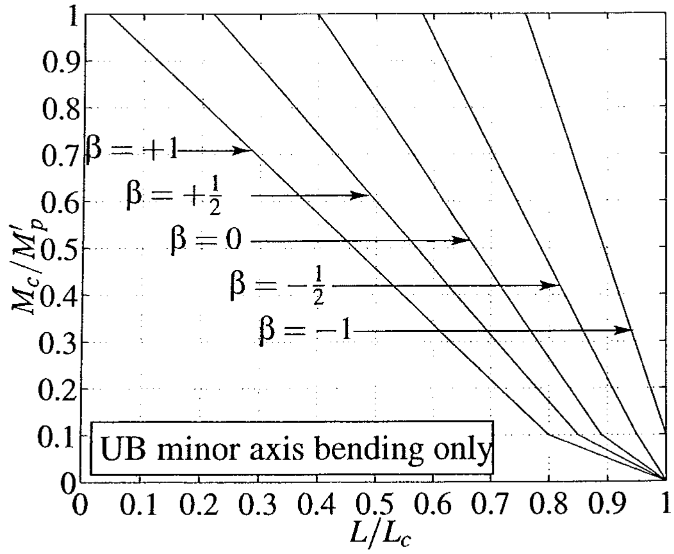
$$M_u = (0.6 + 0.4\beta)m, \quad -0.5 \le \beta \le 1;$$
$$M_u = 0.4m, \quad -1 \le \beta \le -0.5$$

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 $V_c = A_{\text{web}}\tau_y$, 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 $\lambda_{\text{web}} \leq 56$.

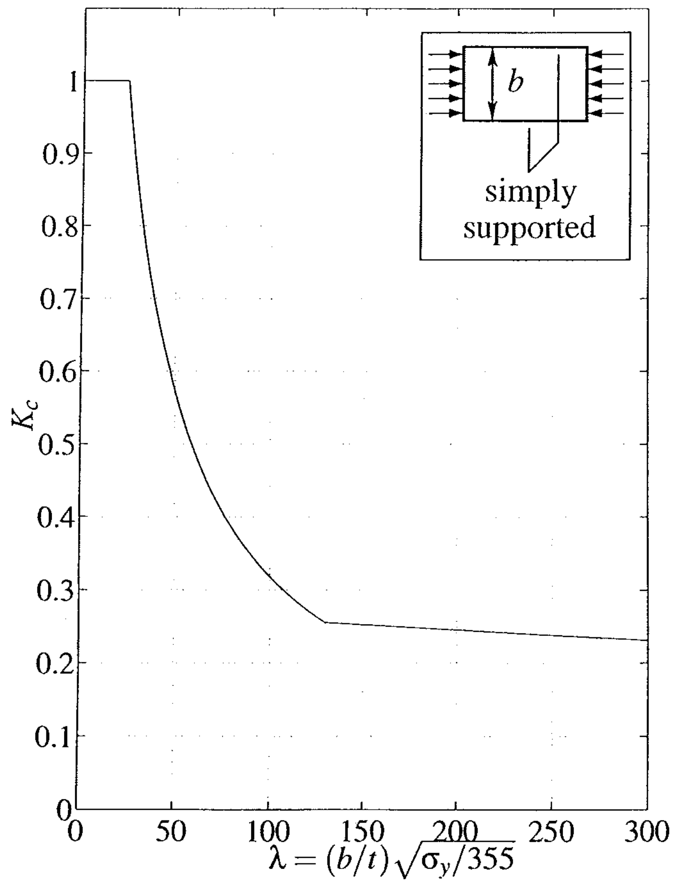
b. Interaction Equations.

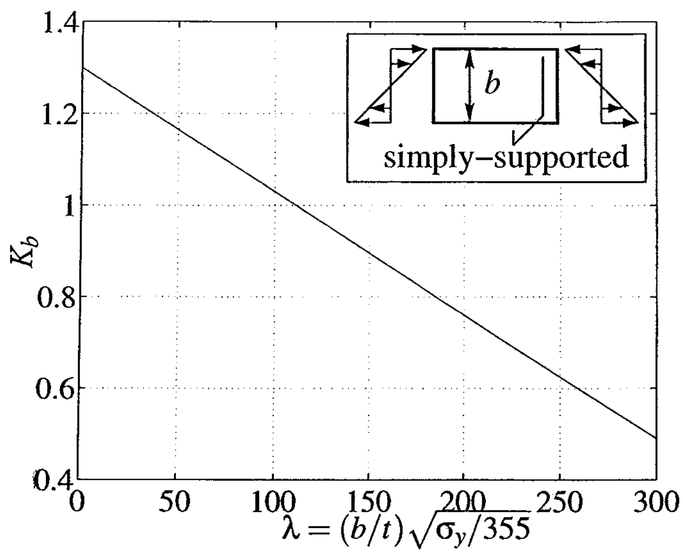
for strength: $\dfrac{P}{P_p} + \dfrac{M_{\max}}{M_p} \leq 1$ (or find M'_p directly)

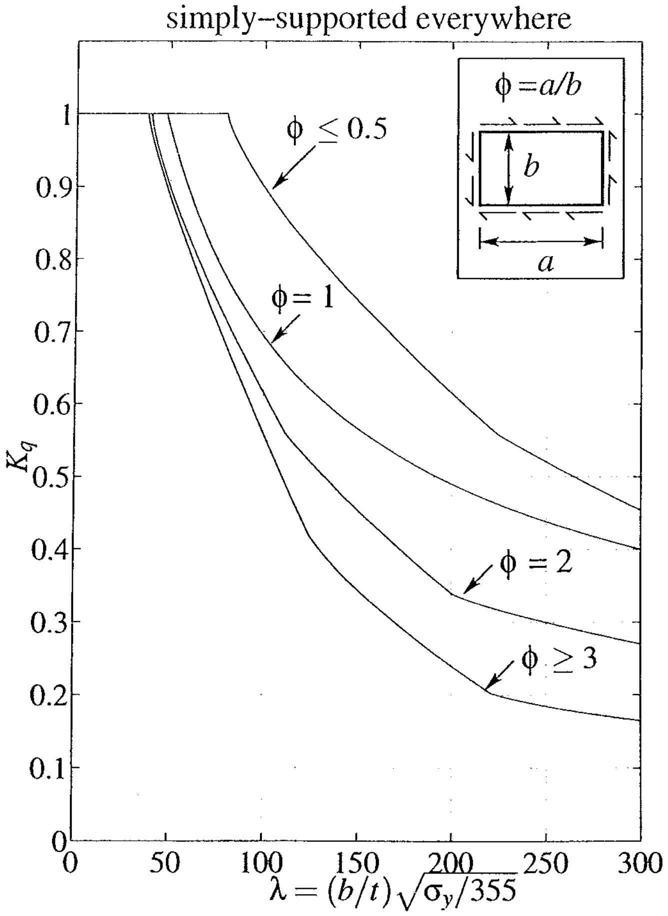
for stability: $\dfrac{P}{P_c} + \dfrac{M_u}{M_c} \leq 1$ (P_c from DS1, M_u and M_c via DS2: all **notes** apply)

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.

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

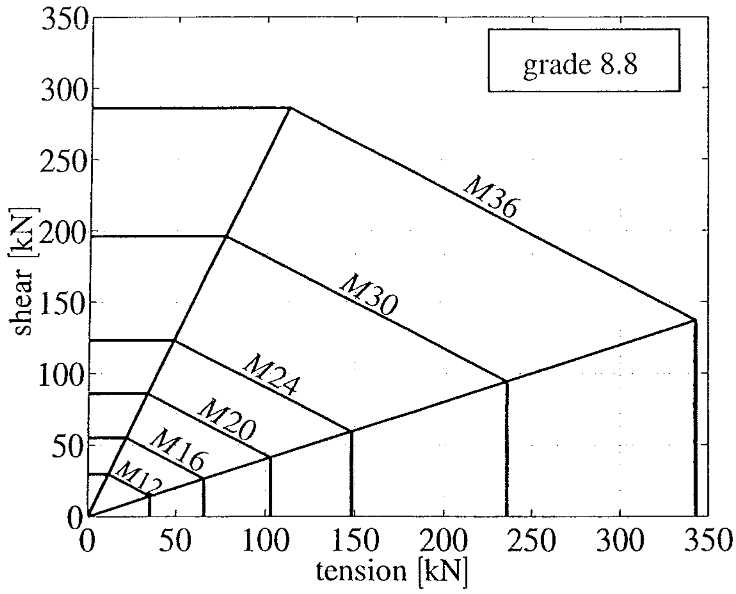
note 3: effective width, b_e, of compression flange with stiffener spacing, b, is $K_c b$.

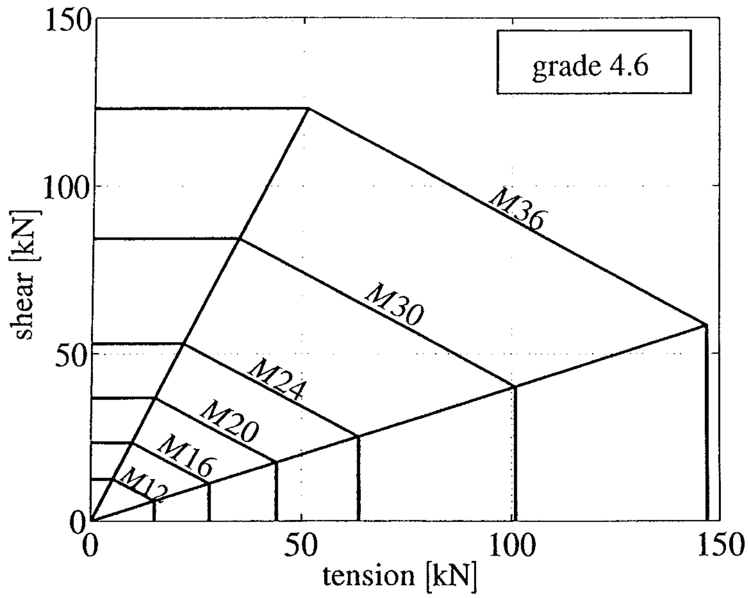
b. Plate compactness.

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.





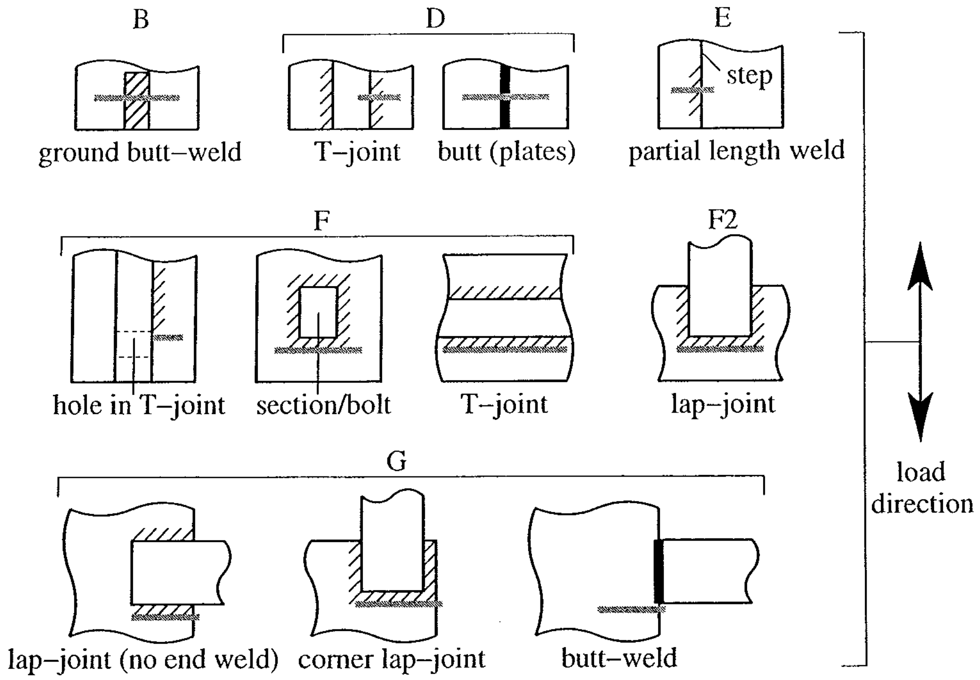
b. Bolt placement.

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

$$N\sigma_r^m = K_2 \quad (\sigma_r \text{ in MPa})$$

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 [MPa]
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} [MPa]			
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.

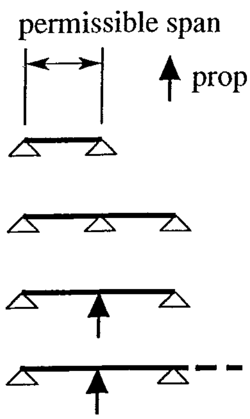
Young's modulus for grade 30 concrete, E_c, depends on duration of loading as:

short term: $E_c = 28$ GPa
long term: $E_c = 14$ GPa

Effective width of slab, b_e, is equal to 0.25 × 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.