ENGINEERING TRIPOS PART IIB

Monday 2 May 2005 9 to 10.30am

Module 4D10

STRUCTURAL STEELWORK

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

All questions carry the same number of marks.

The ***approximate*** *number 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 (i) 4D10 data sheets (9 pages)

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 $300 \times 100 \times 10$ rectangular hollow section is fabricated by welding S275 steel plates, to form a column of length 5 m.

(a) For major axis bending, one end is fully built-in, and all other points are free from restraint. Determine the maximum axial force before buckling occurs. [40%]

(b) For minor axis bending, both ends are pinned, and deflections in the middle of the column are restrained. Determine the maximum axial force before buckling occurs. [40%]

(c) Compute the minimum stiffness of the central support required in part (b). [20%]

2 A $533 \times 210 \times 122$ Universal Beam, made from S355 grade steel, is simply supported on both ends, which are free to warp but restrained against lateral deflection and twist. The beam is 20 m long and a pair of moments, M, are applied to either end, in the *same* direction, about the major axis of cross-section.

(a) Determine the maximum value of M that can just be safely carried by the beam. [60%]

(b) A point 3/4 along the beam is now restrained in the same fashion as either end of the beam. Calculate the factor by which M can be ultimately increased. [40%]

3 A 356 × 368 × 202 Universal Column, made from grade S355 steel, is 15 m long and pinned at both ends in both directions of bending.

(a) Calculate the maximum value of axial force, P just before buckling occurs. [30%]

(b) The value of P in part (a) is reduced by 50% whilst a pair of equal and opposite moments, M, are applied to both ends of the column, to cause extra bending about the major axis. Bending about the minor axis is fully restrained.

(i) Compute the reduced plastic moment under this new value of P. [10%]

(ii) Determine the maximum value of M that can be safely carried, along with this new value of P. [60%]

4 The novel T-beam cross-section shown in Fig. 1 overleaf is made by welding grade S275 plates of thickness 10 mm; all dimensions are indicated in mm, but the figure is not drawn to scale. Distributed in the cross-section are fully effective 100 mm × 10 mm stiffeners, placed at 250 mm centres. The loading is such that, on the given cross-section, there is a bending moment of 5000 kNm, producing tension in the top fibre, an axially compressive force of 2000 kN, and a vertical shear force of 2000 kN.

(a) Verify that all panels in the cross-section can adequately carry the loads from both strength and stability viewpoints. Do not perform an isolated T-section check for buckling capacity of the compressive flange. [70%]

(b) A new loading modifies the stress resultants, to increase the moment by 25%, to increase the axial force by 50 %, but not to change the shear force. Now check whether or not these loads can be safely carried in all panels. [30%]

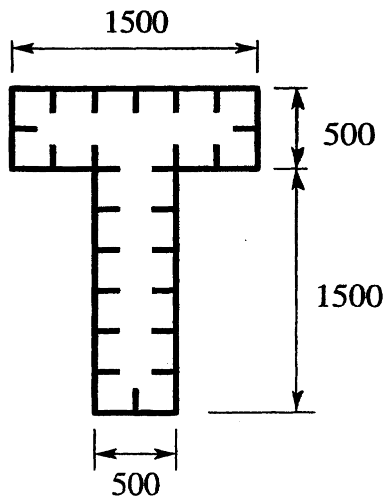


Fig. 1

END OF PAPER

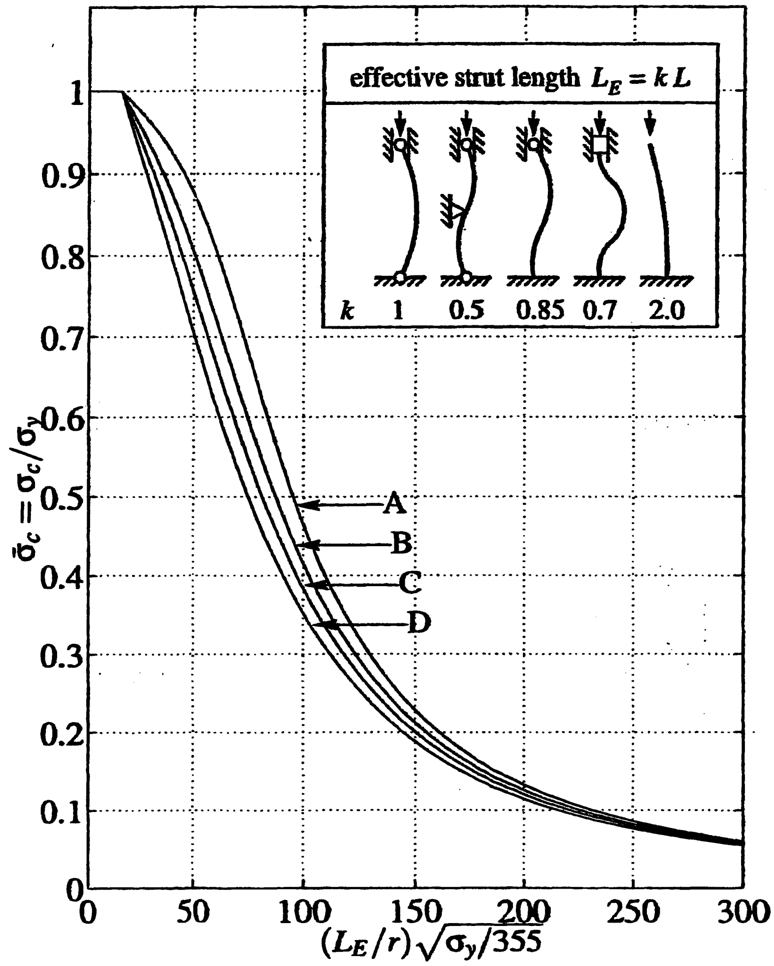
4D10 Structural Steelwork 2004/05

Data Sheets

DO NOT USE FOR ACTUAL DESIGN OF STRUCTURAL STEELWORK

KAS, September 21, 2004

DS1: Column Buckling Capacity σ_c

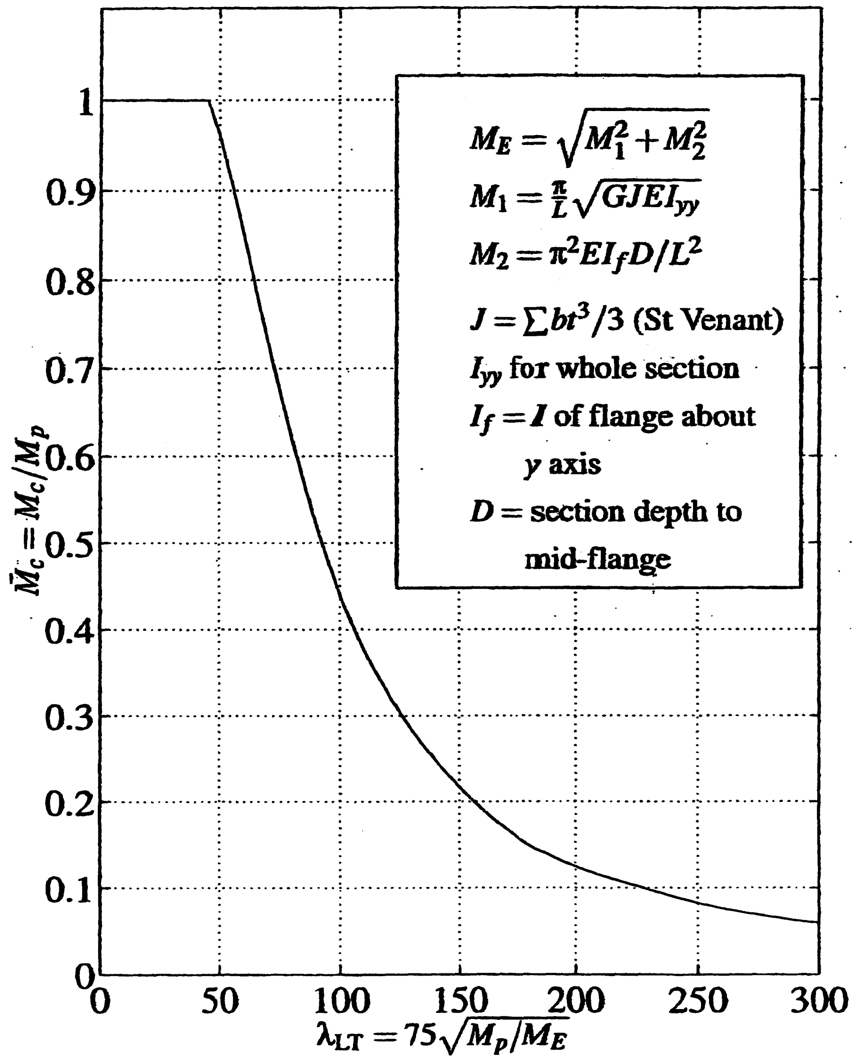


note 1: σ_y in N/mm^2; r is the radius of gyration about centroid of cross-section; curves are selected as follows (linear interpolation used for intermediate r/y values.)

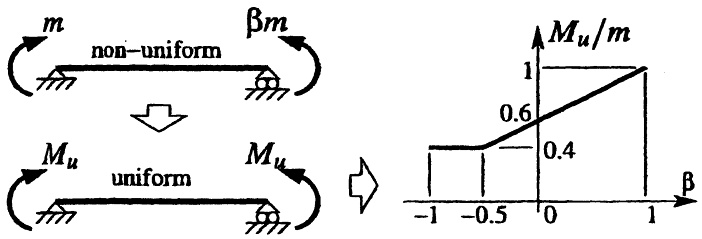
	members fabricated by welding	all other members including stress-relieved welded members
$r/y \geq 0.7$	curve B	curve A
$r/y = 0.6$	curve C	curve B
$r/y = 0.5$	curve C	curve B
$r/y \leq 0.45$	curve C	curve C
all rolled sections with flange thickness > 40 *mm*	curve D	curve D
hot-finished hollow sections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



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

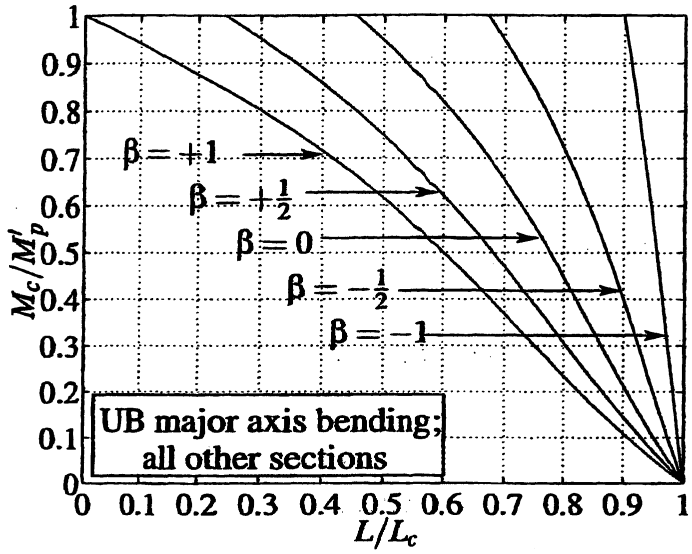
note 2: for stability, $M_u < M_c$.

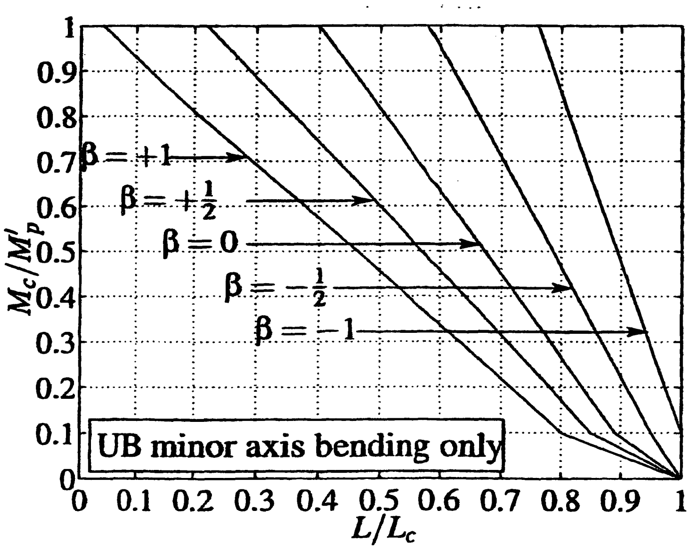
note 3: for strength, $m < M_p$

note 4: if the shear force, V, is larger than $V_c/2$, where $V_c = A_{web}\tau_y$, 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 $\lambda_{web} \leq 56$.

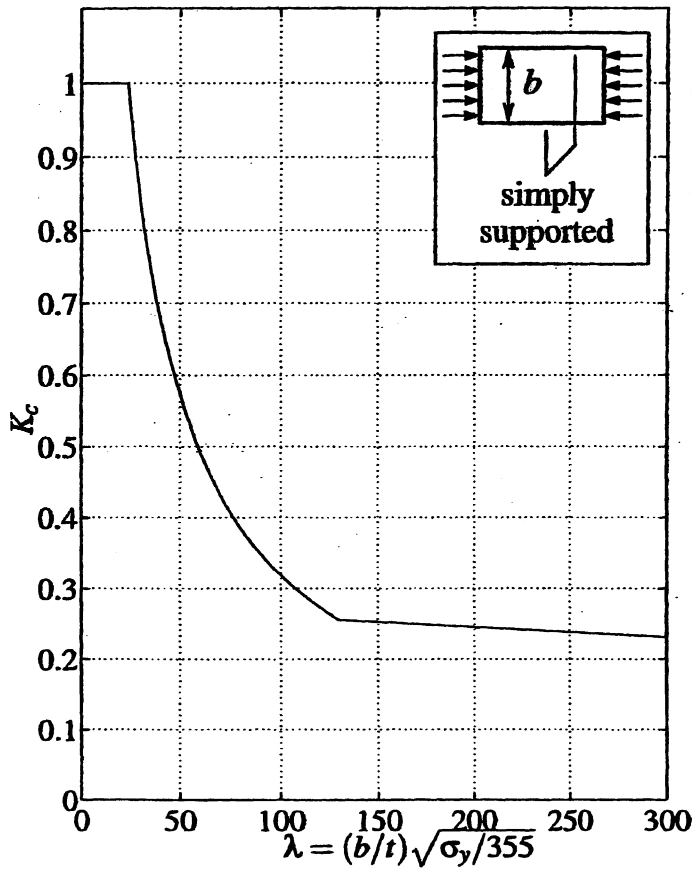
b. Interaction Equations.

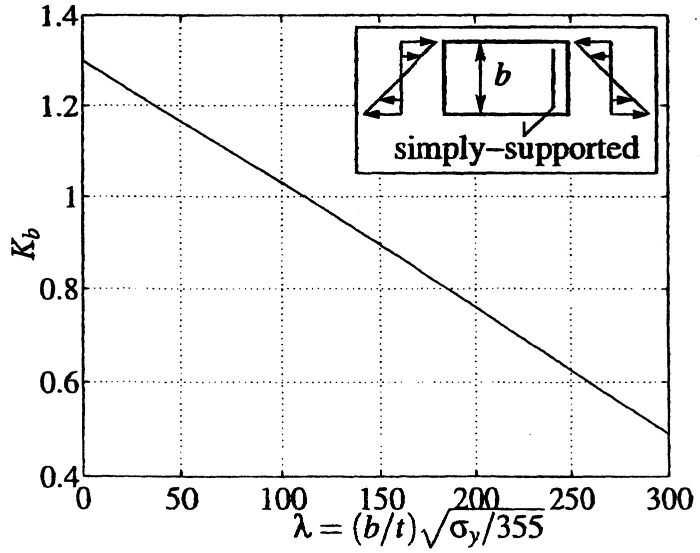
for strength: $\frac{P}{P_p} + \frac{M_{max}}{M_p} \leq 1$ (or find M'_p directly)

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

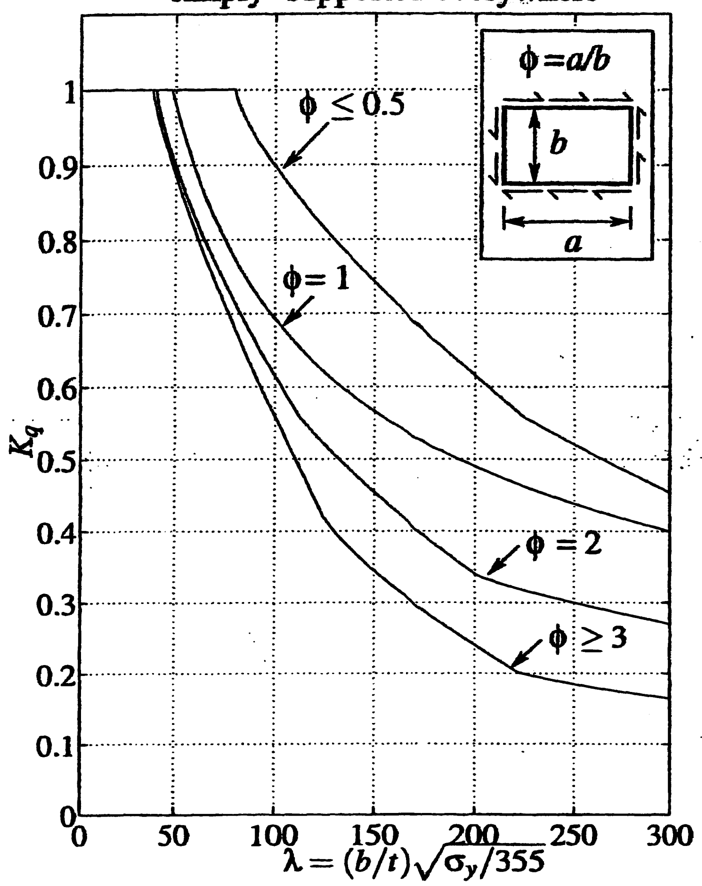
DS4: Panel Strength and Plate Compactness

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





simply–supported everywhere



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

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.

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

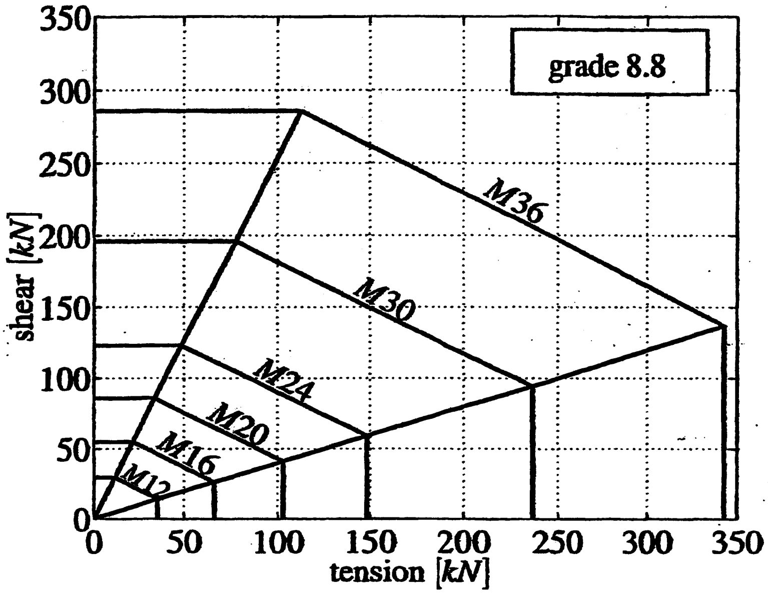
note 3: effective width, b_e, of compression flange with stiffener spacing, b, is $K_c b$.

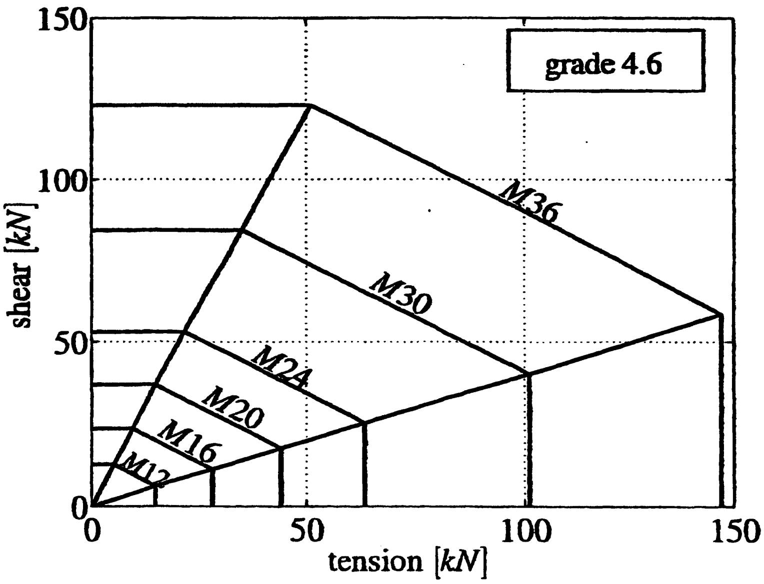
b. Plate compactness.

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.





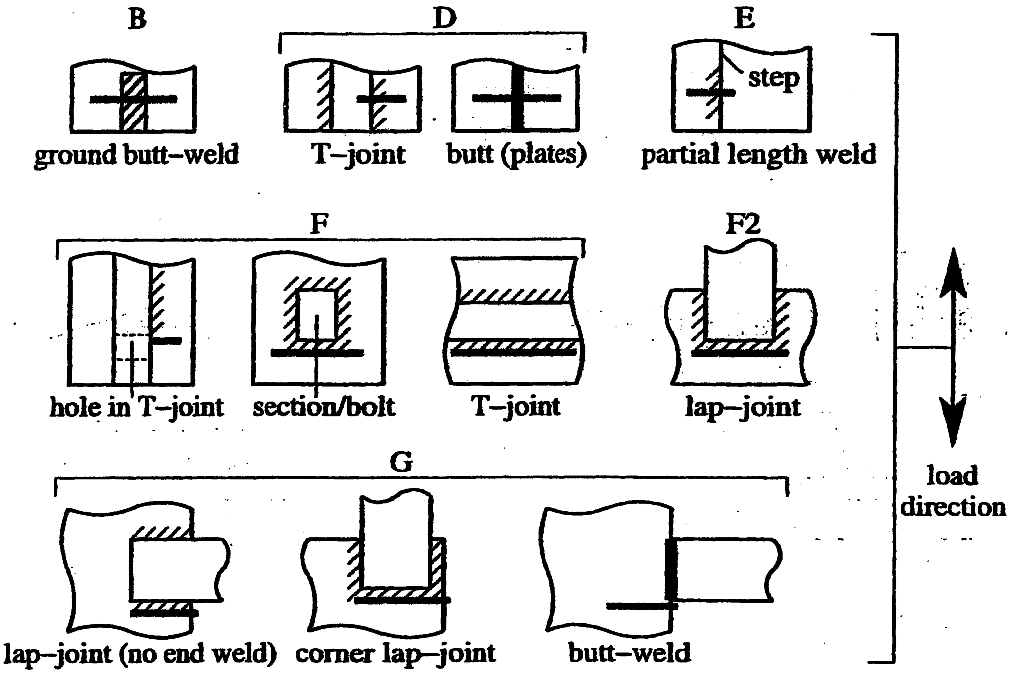
b. Bolt placement.

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 $\times \tau_y$.

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.

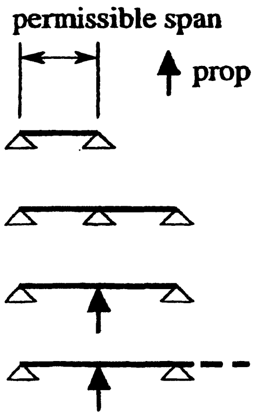
Young's modulus for grade 30 concrete, E_c, depends on duration of loading as:

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

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.



support condition	total slab depth $[mm]$	$t = 0.9\ mm$			$t = 1.2\ mm$		
		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.