ENGINEERING TRIPOS PART IIB

Monday 20 April 2009 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, the given loads in all questions 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
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

1 A composite floor is to be designed to carry a uniformly distributed imposed load of 6 kN/m^2, permanent services of 1 kN/m^2, and its self-weight. The partial safety factors for imposed and dead loads are 1.6 and 1.4, respectively. The floor consists of a concrete slab of maximum thickness, 125 mm, and minimum thickness, 75 mm, which has been cast onto a uniform profiled decking. It acts compositely with the set of 457 × 191 × 89 grade S355 UB's, each of span 14 m and placed 3.5 m apart and simply supported at their ends. The concrete has a design strength given by $f_{cd} = 30$ MPa and a density of 2400 kg/m^3. The beams are parallel to the direction of troughs in the decking.

(a) Show that the floor can carry the specified loading. [45%]

(b) How many 65 mm × 13 mm shear studs are needed for each beam, in order to achieve a full composite action? [20%]

(c) Estimate the central deflection of the beams caused by short-term action of the imposed load. [35%]

2 (a) Describe briefly, without calculation, why the axial capacity of a practical column is less than Euler's buckling prediction. [20%]

(b) A *circular* hollow section has an outside diameter of 200 mm and a wall thickness of 10 mm. It is fabricated from S275 steel by welding, in order to form a column of length 15 m.

(i) Determine the maximum axial force before buckling occurs if both ends are pinned. [30%]

(ii) Deflections in the middle of the column are now restrained. By what margin does the load in (i) increase, and how does this compare to Euler's prediction? [30%]

(iii) Calculate the minimum stiffness of the central support used in (ii). [20%]

3 A $457 \times 152 \times 82$ UB, made from grade S355 steel, is simply supported at both ends, which are free to warp but restrained against lateral deflection and twist. The beam is 15 m long and a pair of equal and opposite moments, M, are applied to the ends, causing the beam to bend about the major axis of cross-section.

(a) Determine the maximum value of M that can just be safely carried by the beam. [50%]

(b) One end of the beam is now fully clamped against all rotations but remains free to warp. Determine the change in the maximum safe value of M. [50%]

4 A $356 \times 171 \times 67$ UB, made from grade S355 steel, forms a pin-ended beam-column of length 15 m to which is applied an axial compressive force of 1000 kN and a single end moment, M, about the major axis. Assuming that the beam-column does not deform out of plane and that minor axis buckling is prevented, determine the maximum value of M that can be safely carried by using the methods of:

(a) Column Deflections Curves (CDC); [50%]

(b) Interaction Equations (IE). [50%]

END OF PAPER

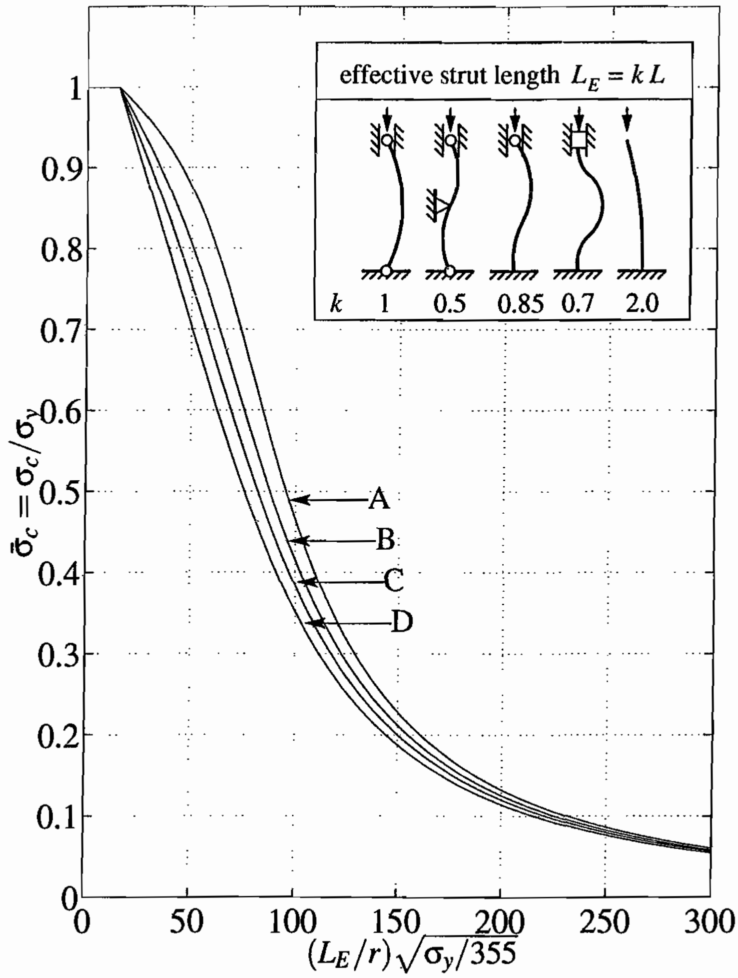
4D10 Structural Steelwork 2008/09

Data Sheets

DO NOT USE FOR ACTUAL DESIGN OF STRUCTURAL STEELWORK

KAS, August 20, 2008

DS1: Column Buckling Capacity σ_c

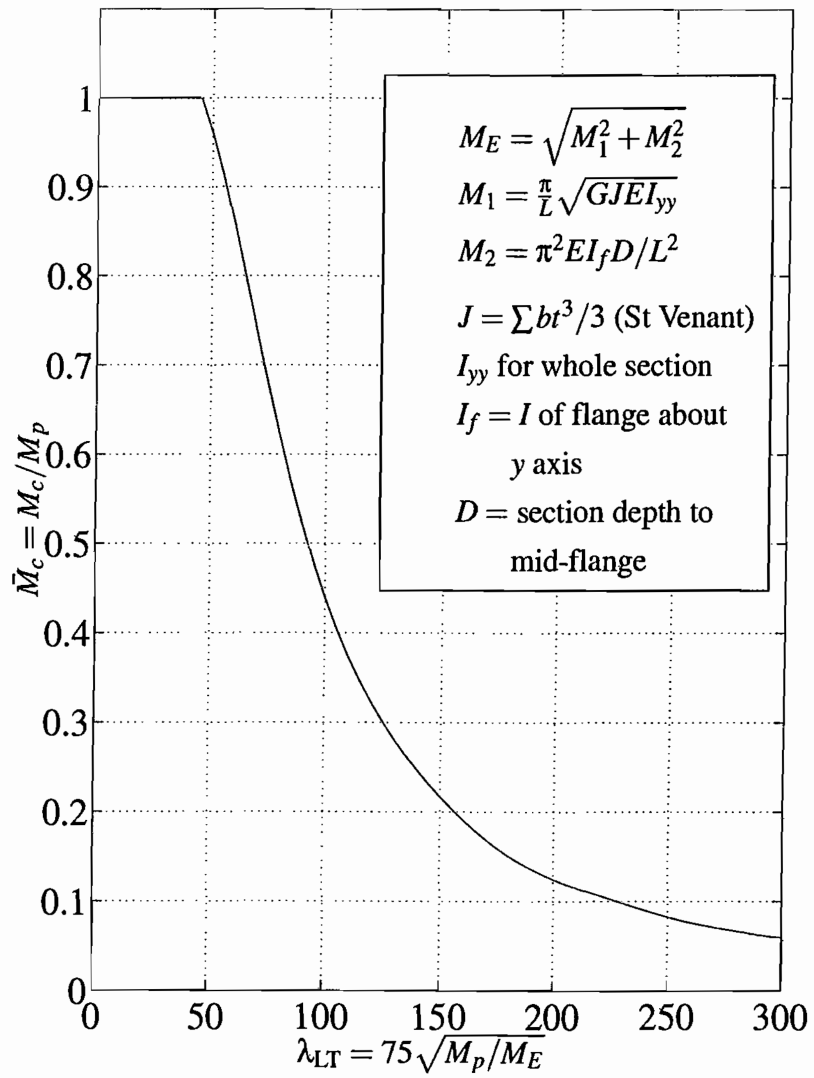


note 1: σ_y in N/mm^2; r is the radius of gyration about centroid of cross-section; curves are selected as follows (linear interpolation used for intermediate r/y values.)

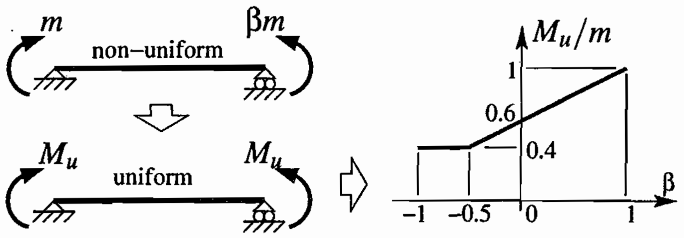
	members fabricated by welding	all other members including stress-relieved welded members
$r/y \geq 0.7$	curve B	curve A
$r/y = 0.6$	curve C	curve B
$r/y = 0.5$	curve C	curve B
$r/y \leq 0.45$	curve C	curve C
all rolled sections with flange thickness > 40 mm	curve D	curve D
hot-finished hollow sections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

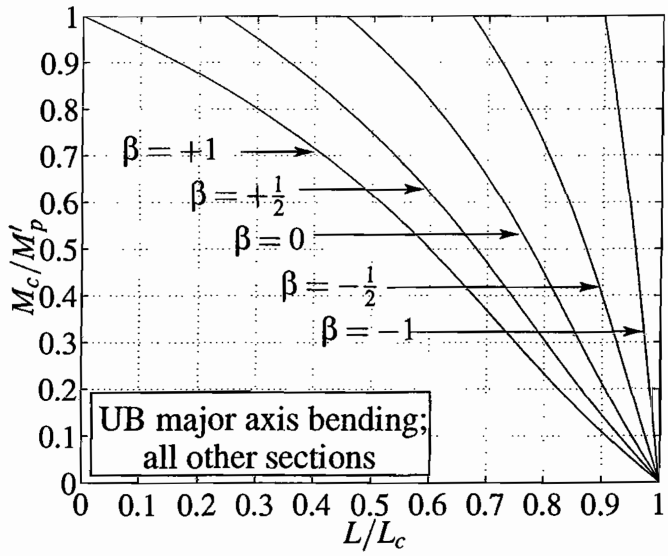


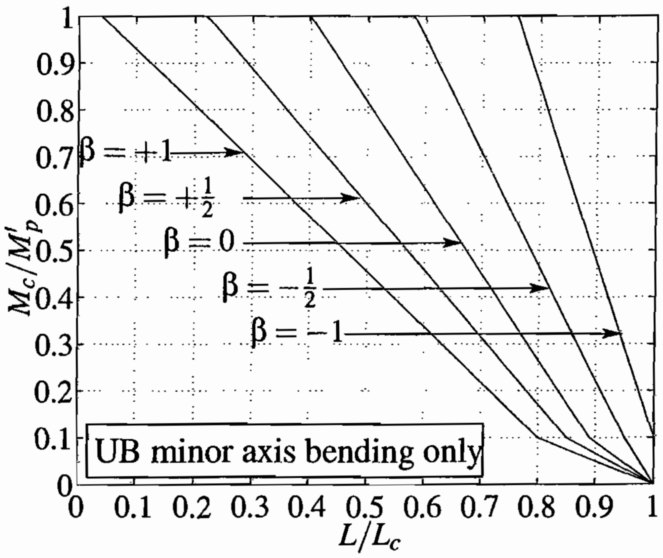
$$M_u = (0.6 + 0.4\beta)m, \quad -0.5 \leq \beta \leq 1;$$
$$M_u = 0.4m, \quad -1 \leq \beta \leq -0.5$$

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 $\lambda_{\text{web}} \leq 56$.

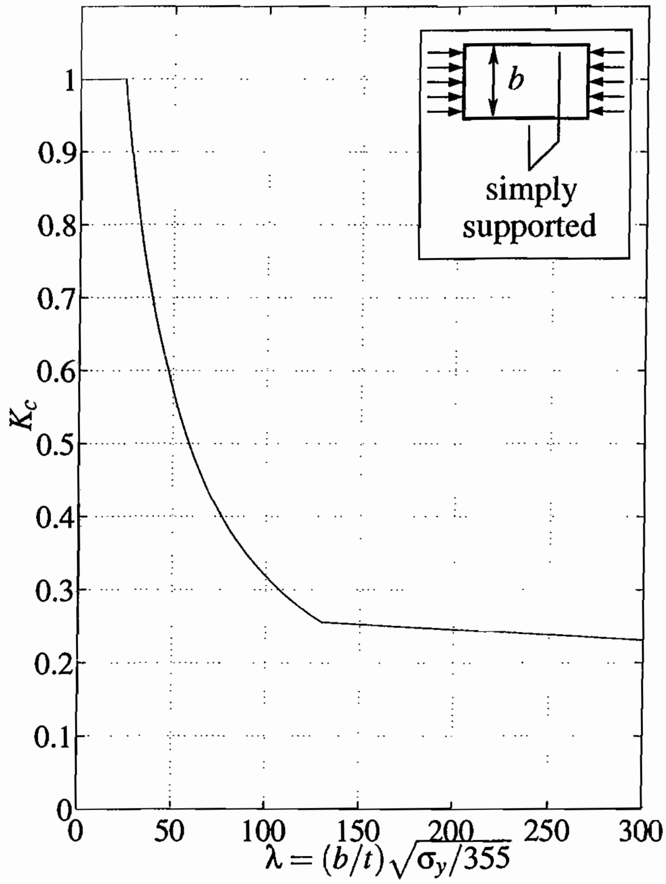
b. Interaction Equations.

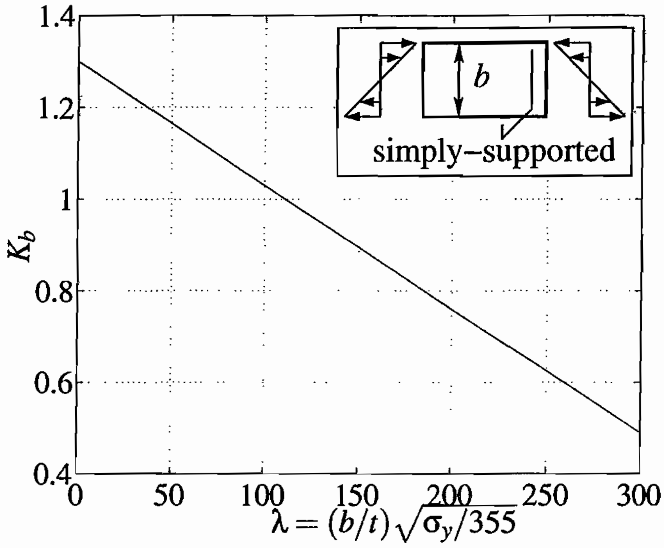
for strength: $\dfrac{P}{P_p} + \dfrac{M_{\max}}{M_p} \leq 1$ (or find M'_p directly)

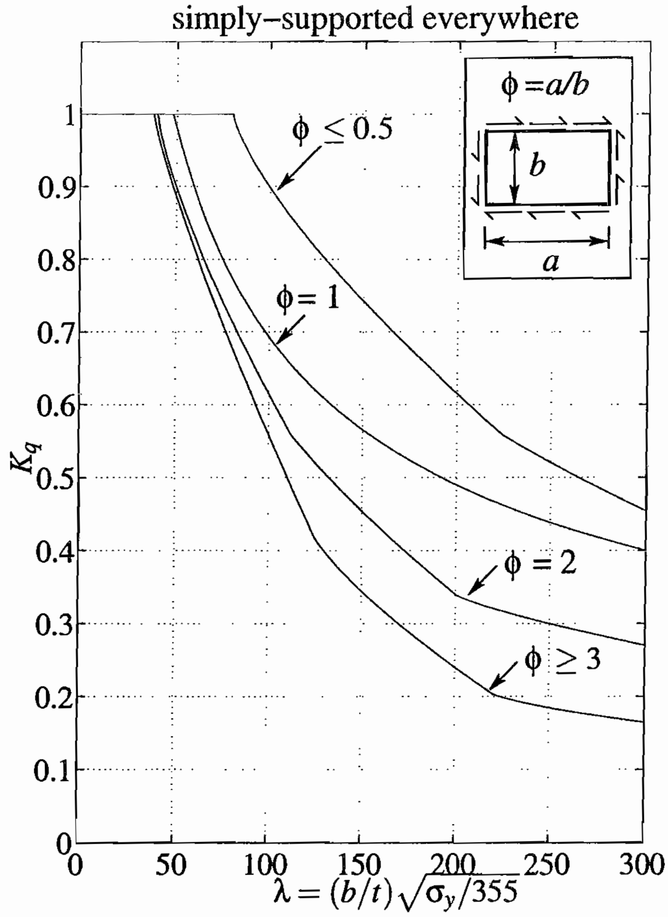
for stability: $\dfrac{P}{P_c} + \dfrac{M_u}{M_c} \leq 1$ (P_c from DS1, M_u and M_c via DS2: all **notes** apply)

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.

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

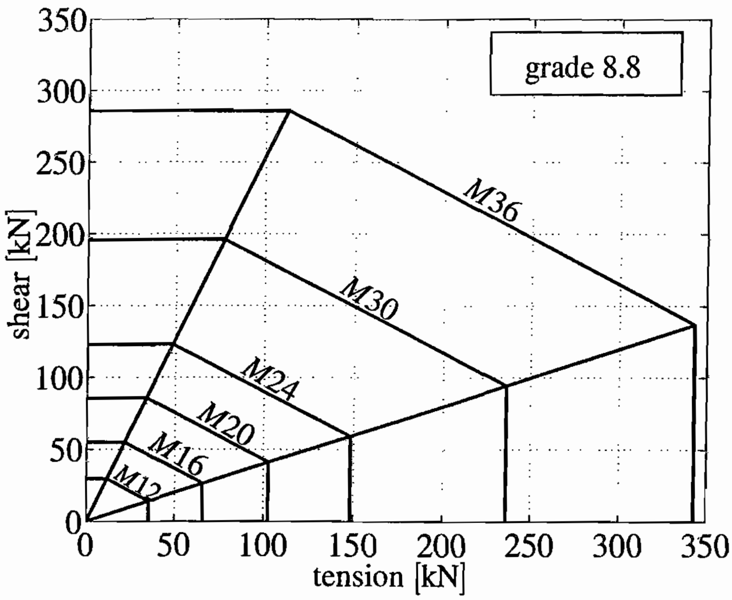
note 3: effective width, b_e, of compression flange with stiffener spacing, b, is $K_c b$.

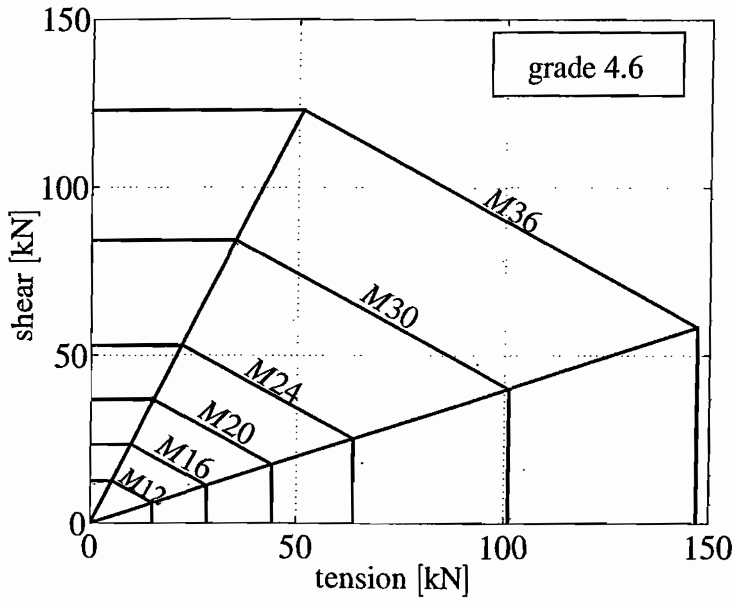
b. Plate compactness.

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.





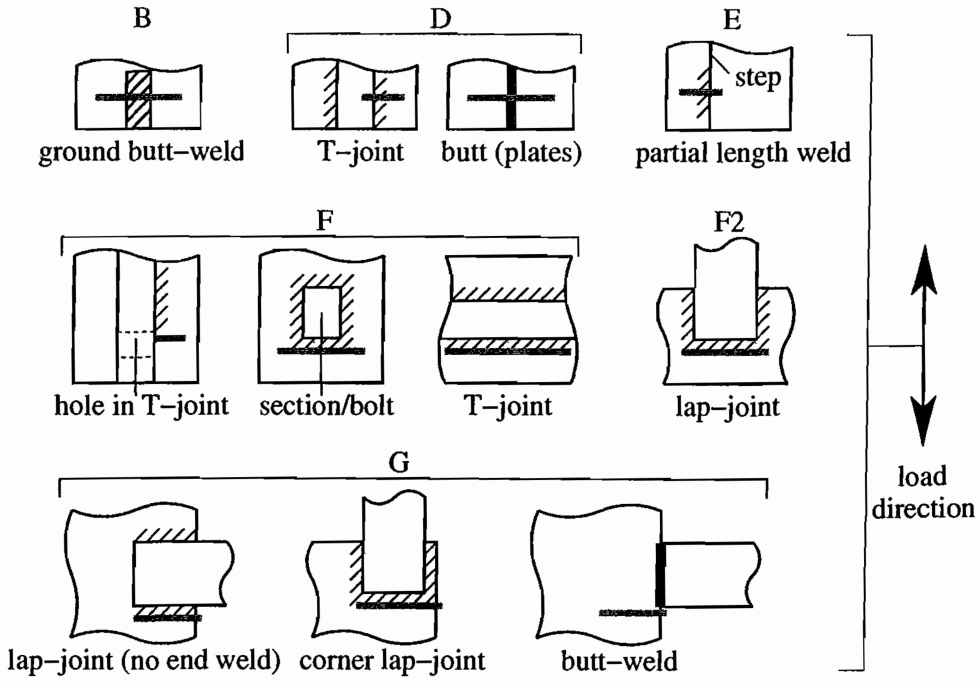
b. Bolt placement.

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.

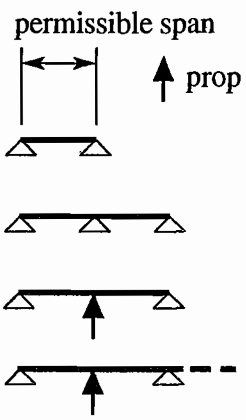
Young's modulus for grade 30 concrete, E_c, depends on duration of loading as:

short term: $E_c = 28$ kN/mm^2
long term: $E_c = 14$ kN/mm^2

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.

ENGINEERING TRIPOS PART IIB 2009

4D10 STRUCTURAL STEELWORK

1a) Moment to be carried at midspan is 1262 kNm; moment capacity of floor is 1313 kNm.

1b) Axial force in concrete is 4047 kN. Use 174 shear studs over entire span.

1c) Imposed short term deflection is 39.2mm; limit on deflection is 56 mm.

2b) (i) Axial capacity without bracing is 213.4 kN. (ii) Axial capacity with bracing is 623.4 kN, giving 2.92 fold increase over (i). (iii) Intermediate bracing stiffness required is 259 kN/m.

3a) Critical LTB moment is 80.4 kNm, stability governs.

3b) $\beta = -0.5$, and critical LTB moment is 201.0 kNm, which governs over strength.

4a) Critical moment capacity, after subtraction of compressive core, is 148.0 kNm.

4b) Interaction equation approach gives maximum moment in strength as 288.3 kNm and a maximum moment for stability as 32.2 kNm, which governs.

K.A.S. May 2009