SOLUTIONS MANUAL FOR
Design of Structural Elements,
3rd edition

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This manual has been prepared for use in conjunction with the textbook *Design of Structural Elements, Third edition*, covering the problems in chapters 2-6, particularly for use by course instructors.

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CHAPTER 2

Question 1

Beam 1

Beam 1: (a) bending moment and (b) shear force diagrams

Beam 2: (a) bending moment and (b) shear force diagrams
Beam 3: (a) bending moment and (b) shear force diagrams

Beam 4: (a) bending moment and (b) shear force diagrams
Question 2

Load Case 1

\[ \omega_{\text{max}} = 1.4g_k + 1.6q_k \]

Load case 1: (a) bending moment and (b) shear force diagrams

Dead, \( g_k = 20 \text{ kNm}^{-1} \)
Imposed load, \( q_k = 10 \text{ kNm}^{-1} \)

\[ V_{x=0} = 117.3 \text{ kN} \]

\( \ell_1 = 6 \text{ m} \)
\( \ell_2 = 2 \text{ m} \)
By inspection,
design sagging moment = 178.4 kNm (Load Case 2)
design hogging moment = 88.0 kNm (Load Cases 1 & 3)
design shear force at A = 125.3 kN (Load Case 2)
design shear force at B (towards A) = 146.7 kN (Load Case 1)
design shear force at B (towards C) = 88 kN (Load Cases 1 & 3)
**Question 3**

(a) Cross-sectional area, \( A = 6432 \text{ mm}^2 \)

Moment of inertia about major axis, \( I_{xx} = 14,570 \times 10^6 \text{ mm}^4 \)

Elastic section modulus about major axis, \( Z_{xx} = 808,459 \text{ mm}^3 \)

Plastic section modulus about major axis, \( S_{xx} = 907,488 \text{ mm}^3 \)

Radius of gyration about major axis, \( r_x = 150.5 \text{ mm} \)

(b) Working load, \( \omega_{wl} = 49.4 \text{ kNm}^{-1} \)

Collapse load, \( \omega_{cl} = 55.5 \text{ kNm}^{-1} \)

**Question 5**

Load Case 1
- Maximum tensile force (in leg L) = 96 kN
- Maximum compression force (in leg R) = 348 kN

Load Case 2
- Maximum tensile force (in leg L) = 194 kN
- Maximum compressive force (in leg R) = 434 kN
CHAPTER 3

**Question 2**

(a) Bending reinforcement

\[ b = 400 \text{ mm} \]
\[ d = 650 \text{ mm} \]
\[ f_{cu} = 40 \text{ Nmm}^{-2} \]
\[ f_y = 500 \text{ Nmm}^{-2} \]

Area of bending reinforcement required, \( A_{s,req} = 2845 \text{ mm}^2 \). Provide 4H32 (\( A_{s,prov} = 3220 \text{ mm}^2 \))

(b) New moment capacity

\[ d' = 50 \text{ mm} \]
\[ d = 650 \text{ mm} \]

New moment capacity = 822.9 kNm

**Question 3 (b)**

\[ g_k = 20 \text{ kNm}^{-1} \]
\[ q_k = 10 \text{ kNm}^{-1} \]

\[ \ell = 7 \text{ m} \]

Bending reinforcement

Area of bending reinforcement required, \( A_{s,req} = 1431 \text{ mm}^2 \). Provide 3H25 (\( A_{s,prov} = 1470 \text{ mm}^2 \)).
Shear reinforcement

\[ \frac{A_{sv}}{s_v} = 0.552 \]. Hence provide R10@275 \((A_{sv}/s_v = 0.571)\)

**Question 5**

![Diagram of a beam with dimensions b = 900 mm, d = 600 mm, h_f = 200 mm, b_w = 300 mm, and 2H25]

(a)(i) Factors influencing the shear resistance of concrete beams
- Tensile strength of concrete.
- Longitudinal reinforcement ratio.
- Concrete in the compression zone.
- Aggregate interlock across flexural cracks.

Shear resistance of concrete

Design concrete shear resistance, \(v_c = 0.54 \text{ N mm}^{-2}\)

(ii) Shear reinforcement

\[ \frac{A_{sv}}{s_v} = 0.276 \]. Hence provide H8@300 \((A_{sv}/s_v = 0.335)\)

(b) Deflection

Permissible span/effective depth ratio = 23.7 > actual span/effective depth ratio = 11.7
Hence deflection is not a problem.
**Question 6**

![Diagram of a rectangular slab with dimensions 4.5 m by 150 mm]

**Summary of Output**

- **Nominal cover**
  From Table A4 of BS8500-1 (Table 3.6, p39 of Design of Structural Elements), cover to all reinforcement = 25 mm

- **Depth of slab**
  Overall depth, $h = 170$ mm

- **Bending reinforcement**
  Required area of *main* steel, $A_{s,req} = 1085 \text{ mm}^2 \text{ m}^{-1}$. Provide R16@150 ($A_{s,prov} = 1340 \text{ mm}^2 \text{ m}^{-1}$)

  Required area of *secondary* steel = R10@150 ($A_s = 523 \text{ mm}^2 \text{ m}^{-1} > \text{minimum area of reinforcement, } A_{s,\text{min}} = 408 \text{ mm}^2 \text{ m}^{-1}$)

- **Shear reinforcement**
  None required.

**Comment on Output**

Areas of both the main and secondary steel are greater but the thickness of slab is smaller using mild steel reinforcement.

**Question 7**

(b) **Axial load capacity and shear reinforcement**

Ultimate axial load capacity of column, $N = 4305.7$ kN

A possible arrangement of links is shown in the column section below. Note that the inner bars are more than 150 mm from the corner bars.
Question 8

(a) Column classification

\[
\frac{\ell_{ex}}{h} = \frac{\ell_{ey}}{b} = \frac{4500}{300} = 15
\]

Hence column is “slender”. However it can be treated as “short” for design purposes as its slenderness ratio is at the short/slender interface.

(b) Longitudinal and shear reinforcement

Assuming diameter of longitudinal bars = 32 mm and diameter of shear reinforcement is 8 mm, \(d = 300 - 32/2 - 8 - 35 = 241\) mm and \(d/h = 241/300 = 0.8\). Using the procedure outlined in Example 3.19 construct a column design chart assuming the longitudinal steel is symmetrically placed at a \(d/h\) ratio of 0.8, \(f_{cu} = 40\) Nmm\(^{-2}\) and \(f_y = 500\) Nmm\(^{-2}\) (see below).

(i) \(N = 500\) kN and \(M = 200\) kNm

Longitudinal reinforcement

From design chart \(\frac{\%A_{sc}}{bh} = 4.3\)  \(\Rightarrow A_{sc} = \frac{4.3 \times 300 \times 300}{100} = 3870\) mm\(^2\)

Provide 4H32 + 2H25 (\(A_{sc} = 3220 + 1260 = 4480\) mm\(^2\))

Shear reinforcement

Provide H8 links at 300 mm centres.

Cross-section through column showing the arrangement of longitudinal and shear reinforcement
(ii) \( N = 800 \text{ kN}, M_x = 75 \text{ kNm and } M_y = 50 \text{ kNm} \)

**Longitudinal reinforcement**

From design chart  \( \frac{\%A_s}{bh} = 1.7 \quad \Rightarrow A_s = \frac{1.7 \times 300 \times 300}{100} = 1530 \text{ mm}^2 \)

Provide 4H25 (\( A_s = 1960 \text{ mm}^2 \))

**Shear reinforcement**

Provide H8 links at 300 mm centres.

Cross-section through column showing the arrangement of longitudinal and shear reinforcement.
Question 9

Cross-section

300 × 300 mm column section is suitable.

Longitudinal reinforcement

Provide 4H32 ($A_{sc} = 3220 \text{ mm}^2$).

Shear reinforcement

Provide H8 links at 300 mm centers.
CHAPTER 4

**Question 1**

\[ G_k = 200 \text{ kN} \]
\[ Q_k = 100 \text{ kN} \]

(a) 610 × 229 × 125 UB in S275 steel

(b) 533 × 210 × 82 UB in S460 steel

**Question 2**

\[ G_k = 20 \text{ kNm}^{-1} \]
\[ Q_k = 10 \text{ kNm}^{-1} \]

(a) 406 × 178 × 67 UB in S275 steel

(b) 533 × 210 × 82 UB in S460 steel

**Question 3**

\[ Q_k = 12 \text{ kN} \]
\[ g_k = 40 \text{ kNm}^{-1} \]
\[ q_k = 32 \text{ kNm}^{-1} \]

610 × 229 × 125 UB in S275 steel
**Question 4**

356 × 406 × 235 UB in S275 steel

**Question 5**

356 × 368 × 177 UB in S275 steel

**Question 6**

The calculations assume that Beams 1-4 are fully laterally restrained and there is notional torsional restraint at supports.

**Beam 1**

![Beam 1 diagram]

203 × 133 × 30 UB in S275 steel

**Beam 2**

![Beam 2 diagram]

254 × 102 × 25 UB in S275 steel

**Beam 3**

![Beam 3 diagram]

356 × 127 × 39 UB in S275 steel
Beam 4

356 × 171 × 67 UB in S275 steel

**Question 7**

(a) Floor systems for use in conjunction with steel framed structures:

- steel plates
- precast, prestressed concrete slab
- cast in-situ concrete slab
- composite metal deck floor

(b)

(i) 457 × 152 × 60 UB in S355 steel
(ii) 305 × 127 × 37 UB in S355 steel

**Question 8**

(a) Factors influencing the load carrying capacity of steel columns include

- Strength of the material
- Length of column
- End restraint conditions
- Radius of gyration
- Moment capacity of section
- Buckling resistance of section

(b) The proposed 254 × 254 × 132 UC section is suitable.
**Question 9**

(a) Section is plastic in both cases.

(b) Squash load, \( P_c = 4637.5 \) kN

(c) Plastic moment of resistance, \( M_c = 609.5 \) kNm

(d) When axial load is 800 kN, moment capacity of column is 504 kNm

(e) Column is suitable.

**Question 10**

356 × 368 × 153 UC in S275 steel

**Question 11**

356 × 368 × 202 UC in S275 steel

**Question 12**

All bolts are general grade M24 HSFG (parallel shank) bolts in standard clearance holes.
Proposed welding scheme is adequate.
**CHAPTER 5**

**Question 1(b)**

Design strength, \( N_R = 111.6 \text{ kN m}^{-1} \) run of wall

**Question 2(b)**

Internal wall

Required characteristic compressive strength of masonry, \( f_k \geq 4.5 \text{ N mm}^{-2} \)

390 × 190 × 100 solid concrete blocks of compressive strength \( \geq 5.2 \text{ N mm}^{-2} \) laid in mortar designation (iii) would be suitable.

Cavity wall

**Inner leaf:** Required characteristic compressive strength of masonry, \( f_k \geq 1.9 \text{ N mm}^{-2} \)

390 × 190 × 100 solid concrete blocks of compressive strength \( \geq 2.9 \text{ N mm}^{-2} \) laid in mortar designation (iv) would be suitable.

**Outer leaf:** The bricks and mortar for the outer leaf would be selected on the basis of appearance and durability.
**Question 3(b)**

Required characteristic compressive strength of masonry, $f_k \geq 5.1 \text{ N mm}^{-2}$

Standard format brick of compressive strength $\geq 30 \text{ N mm}^{-2}$ laid in mortar designation (iv) would be suitable.

**Question 4(b)**

(A) Required characteristic flexural strength of masonry with the plane of failure perpendicular to bed joint, $f_{kx\text{ perp}} \geq 1.6 \text{ N mm}^{-2}$

Clay bricks having a water absorption content < 7% laid in mortar designation (i) would be suitable.

(B) Required characteristic flexural strength of masonry with the plane of failure perpendicular to bed joint, $f_{kx\text{ perp}} \geq 1.0 \text{ N mm}^{-2}$

Either clay bricks having a water absorption content < 12% laid in mortar designation (iii) or clay bricks having a water absorption content of >12 % laid in mortar designation (i) would be suitable.
Question 5(b)

Maximum wind resistance of outer leaf is 198 N m$^{-2}$
Maximum wind resistance of inner leaf is 118 N m$^{-2}$

Total wind resistance of cavity wall is 316 N m$^{-2}$
CHAPTER 6

Question 1

A 100 × 300 mm deep section would be suitable.

Question 2

Use 47 × 175 mm joists.

Question 3

The maximum imposed load the roof can support is 0.84 kN m⁻²

Question 4

(i) A 100 mm square section of strength class C27 or a 100 × 150 mm rectangular section of strength class C16 would be suitable.

(ii) Assuming the moment acts about x-x, a 100 × 150 mm rectangular section of strength class C16 would be suitable.
**Question 5**

- **Studs**
  Use 47 × 125 mm strength class C16 studs.

- **Sole and top plates**
  Use 75 × 125 mm strength class C16 sections.

- **Noggings**
  Use 47 × 125 mm strength class C16 sections.

- **Covering**
  Use plasterboard and skim.