THE OPEN UNIVERSITY OF SRI LANKA
Department of Civil Engineering
Bachelor of Technology (Civil) - Level 6

**CEX6332 – Structural Design**

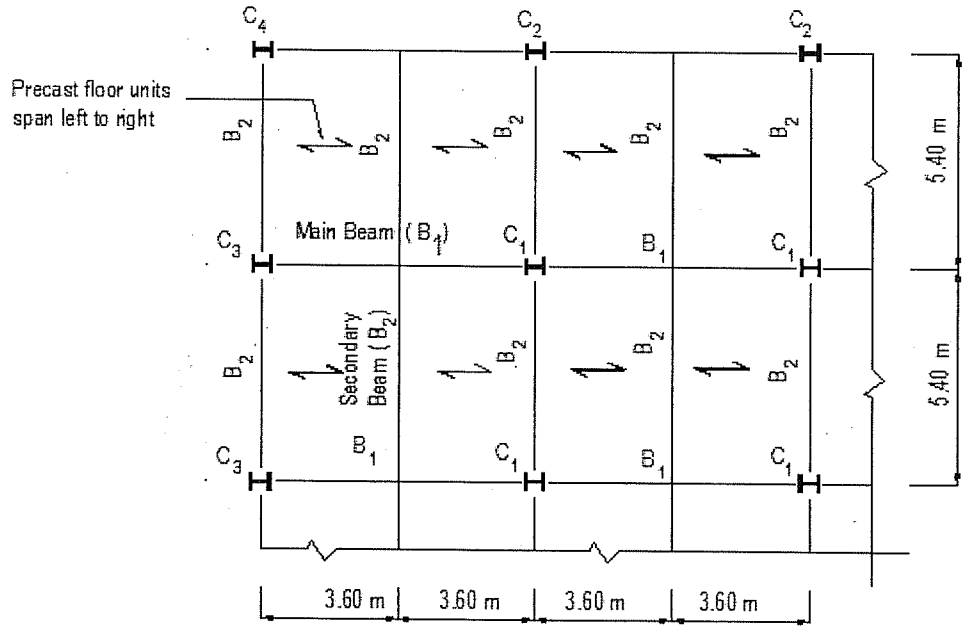
*FINAL EXAMINATION – 2015/2016*

Time Allowed: Four (04) Hours

Date: 2016 - 12 - 17 (Saturday) Time: 0930 - 1330 hrs.

Paper consists of five (05) questions. Answer any four (04) questions.
You may use the booklet named "Extracts From Relevant Standards" provided to you with the course material, which also contain concrete design charts & steel sectional properties
You may assume and state reasonable values for any factors not provided.

**Q1.** A part structural plan of a typical floor in a multi-storied office building constructed using structural steel is shown in Figure Q1, indicating the general arrangement of beams and columns. The floor consists of precast concrete units which are supported on the secondary beams (B2). The dead weight of the floor slab including finishes is 4.0 kN/m² and the imposed load is 3.0 kN/m². Both the secondary (B2) and main beams (B1) may be assumed as laterally restrained and have simple end connections. The height of each storey of the building is 3.8 m. Conduct the following steps using Grade S-275 structural steel in accordance with BS5950-1:2000. Modulus of elasticity of steel = 205 x $10^3$ N/mm².




**General Arrangement - Plan**

**Figure Q1**

i.) Evaluate the service loads acting on a secondary beam B2. (02 Marks)

ii.) Determine the most economical size of the I section beam that can be used as secondary beams satisfying all code requirements. (08 Marks)

iii.) Evaluate the service loads acting on a main beam B1. (02 Marks)

iv.) Determine the most economical size of the I section beam that can be used as main beams satisfying all code requirements. (08 Marks)

v.) Evaluate the maximum axial load that can be carried by a Rolled I section 457x152x82 provided for column C1. Assume the column to be held in position at both ends with no restraint in direction at either end. (05 Marks)

**Q2.**

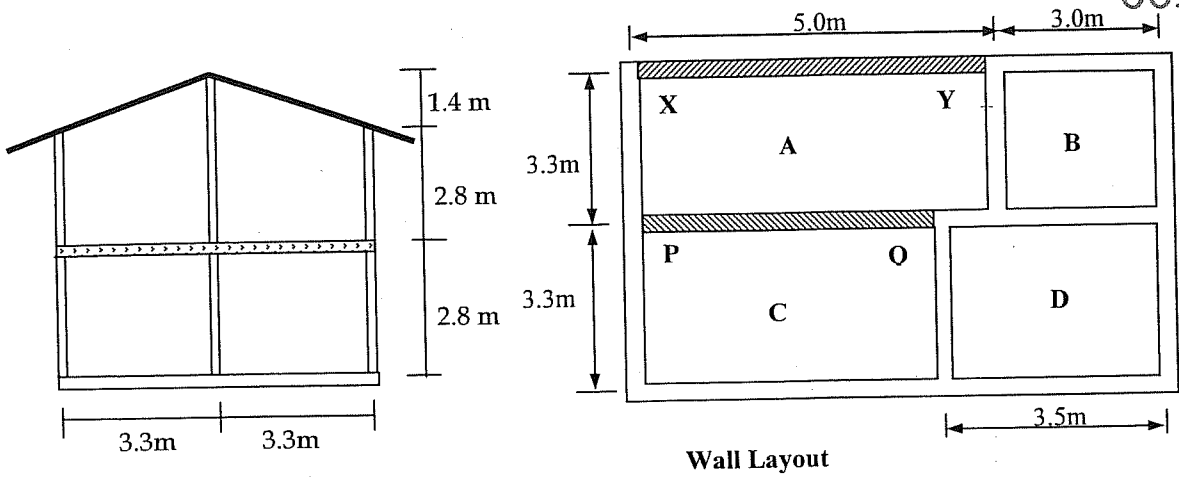



**Figure Q2:** Proposed masonry building

A two storied community building has been proposed to be constructed in a certain place in Batticoloa district under a foreign funded community development project. It is a load bearing masonry wall construction. The plan of and elevation of the building is shown in Figure Q2. A and C are community gathering rooms. B and D are office room and wash room, respectively.
Walls are constructed with locally made high quality bricks and their dimensions are 200mm*100mm*50mm, length, breath, height, respectively. Half brick wall construction is 100mm, one brick wall construction is 210 mm, one and half brick wall construction is 320mm. Further, external and internal wall thicknesses are 350 mm and 240mm, respectively.

**Loads**

| | |
|---|---|
| Dead load of the roof (Plan area) | = 0.5 kN/m² |
| Imposed load on the roof | = 0.25 kN/m² |
| Imposed load on the floor | = 3.0 kN/m² |
| Dead load by 125mm slab | = 3.0 kN/m² |
| Dead load due to finishes on slab | = 0.5 kN/m² |

**Geometry**

| | |
|---|---|
| Thickness of floor slab | = 125mm |
| Floor to floor clear height | = 2.8m |
| Eave of the roof | = 1.0m |

**Weights of Materials**

| | |
|---|---|
| Unit weight of RC | = 24.0 kN/m² |
| Unit weight of masonry | = 18.0 kN/m² |
| Mortar Designation | = IV |
| Compressive Strength of Brick | = 5.0 N/mm² |
| $\gamma_m$ | = 3.5 |
| Water absorption | >12% |

I. Evaluate characteristic dead and live loads acting on the internal wall **P-Q** in the first floor level. (04 Marks)

II. Find different load combinations and corresponding design loads and eccentricities. (04 Marks)

III. Determine the slenderness ratio of the wall and compare with its permissible value. (03 Marks)

IV. Check whether the internal wall is able to carry the design compressive load considering vertical load resistance of the wall. (03 Marks)

V. Draw a figure showing boundary conditions for the external wall panel **X-Y** (1st floor to roof office area). (04 Marks)

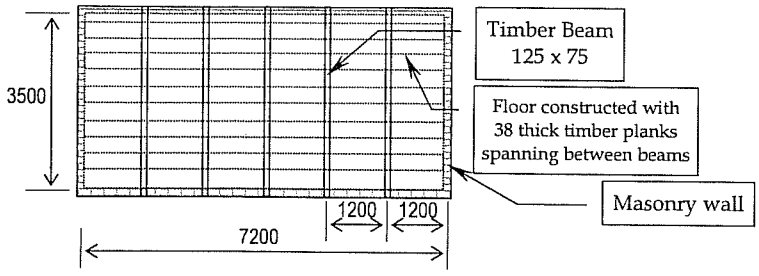
VI. Determine the moments parallel and perpendicular to the bed joint if it is subjected a wind load of 3.0 kN/m². (04 Marks)

VII. Check the safety of the external wall panel under the given wind load. (03 Marks)

Indicate whatever assumptions used clearly.

**Q3.**

**Part A -** A Driver's room with a timber floor is to be constructed over a vehicle garage formed with 225 thick masonry walls, as shown below.




Plan of the proposed timber floor

| | |
|---|---|
| Timber | - Balau |
| Strength Class | - D70 |
| Dead loads on the floor: | |
| Weight of finishes | - 0.3 kN/m² |
| Unit weight of planks | - 8.0 kN/m³ |
| Unit weight of Balau | - 10.8 kN/m³ |
| Imposed loads on the floor: | |
| under normal service | - 1.5 kN/m² |

**Assume:**
* Exposure condition is could be wet.
* lateral support at the ends of the beams due to embedment in the masonry walls.
* Loads are medium term.
* Wane is permitted.

Maximum allowable deflection for the beam is 30 mm at mid span.

**All dimensions are in 'mm'**

The floor layout consists of timber planks supported by timber beams which are simply supported on existing masonry walls as shown .Effective span of a timber beam is 4.0 m and they are spaced at 1.2 m.

i.) Evaluate the loading on the beam due to **live and dead** loads.

(02 marks)

ii.) Check the proposed beam against **lateral stability** criteria.

(02 marks)

iii.) Compute the applied **bending stress** at the critical section and check whether this is within the permissible limit.

(02 marks)

iv.) Check whether the **maximum allowable deflection** is within the permissible limit.
*You may use the following deflection values at mid span of a simply supported beam loaded with an udl;*
*Deflection due to Bending* $= 5wL^4 / (384EI)$
*Deflection due to Shear* $= 3wL^2 / (20GA)$

(03 marks)

v.) Check whether the beam is safe against failure due to **shear.**

(03 marks)

vi.) Check whether applied **bearing stress** is within the permissible limit. Assume that wane is permitted at bearing area.

(03 marks)

**Part B**

The table given below shows the description of two elements; AB and BE of a cantilevering Timber truss supporting an out-door canopy. The two elements can be assumed to only deflect in the plane of the truss.

| Element | Length (m) | Magnitude of force (kN) | Magnitude of Moment (kNm) |
|---|---|---|---|
| AB | 2.5 | 22 (tensile) | 3.2 |
| BE | 2.8 | 28 (compressive) | 3.8 |

Timber members of strength class D70 with cross sectional dimensions of 150 mm x 75 mm are proposed for both elements. The frame is subject to wet exposure conditions. All loads acting on the frame are of medium term duration.

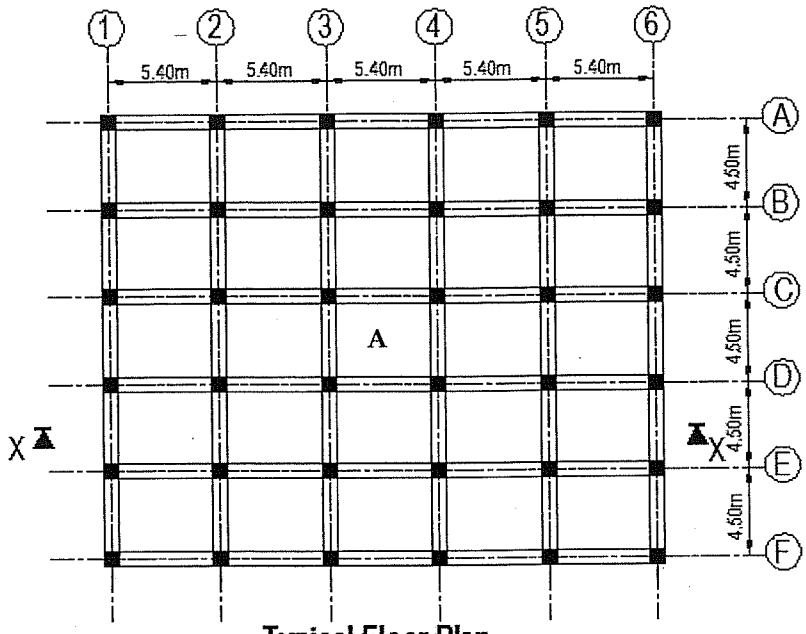
i.) Determine the adequacy of member AB to carry the combined tensile force and moment.

(05 marks)

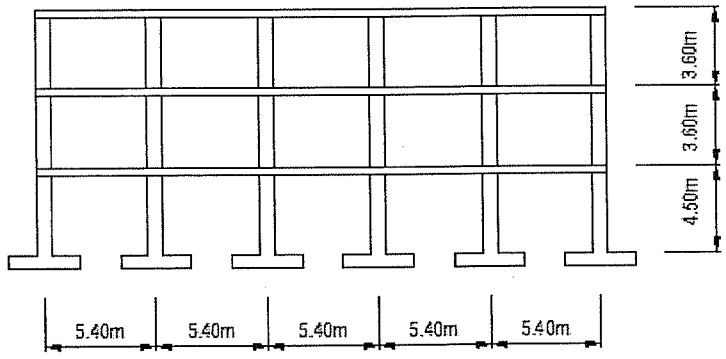
ii.) Determine the adequacy of member BE to carry the combined compressive force and moment.

(05 marks)

**Q4.** A typical floor plan and a sectional view of a three storied commercial building is shown in Figure Q4. The beams are cast monolithically with the floor slab.




Typical Floor Plan




Section X-X

**Strength of materials;**
Grade of concrete = 25
Characteristic strength of steel
Main r/f = 460 N/mm²
Shear r/f = 250 N/mm²

Nominal cover for reinforcement = 20 mm

**Order of floors – Ground, 1st , 2nd , Roof**

* Required design charts are provided *

**Loads on the structure;**
Dead load by finishes on floors & roof = 1.5 kN/m²
Imposed load on floors & roof = 3.0 kN/m²
** You may neglect the effects of Wind

Thickness of floor & roof slabs = 125 mm

**Weights of materials**
Unit weight of RC = 24.0 kN/m³

Figure Q4

i.) Evaluate the design ultimate load acting on the 1st floor slab. Considering the slab panel "A", compute the bending moments acting at critical locations of the panel using the bending moment coefficients from the BS8110-1:1997 and design reinforcements for this panel to satisfy code requirements. Draw a typical plan showing the reinforcement detail of slab panel "A". Indicate curtailment of reinforcements without dimensions. (06 Marks)

ii.) Evaluate the design ultimate load acting on the beam (400x300 mm) on grid C. (you may assume that the loads transferred to the beam are uniformly distributed along its span) and calculate the ultimate bending moments at critical locations using the design formula given in BS8110-1:1997 for uniformly loaded continuous beams. (04 Marks)

iii.) Draw the bending moment diagram for the beam on grid C using the bending moments computed above. Design the required reinforcements for the span 3-4 to resist bending at critical locations of the span and indicate how you would curtail reinforcements within span 3-4 in the bending moment diagram. (05 Marks)

iv.) Assuming the column at C-3 (300x300 mm) is unbraced and no bending moments are transferred from beams framing into the column, evaluate the design ultimate axial load on the column at ground floor level and the slenderness condition of the column segment between ground and first floor.(05 Marks)

v.) Evaluate the generated bending moments (if any) and design required reinforcements for the same column segment. (05 Marks)

**Q5.**

A pre tensioned concrete beam (Figure Q5), having an unsymmetrical I – Section is proposed to use for supporting a roof of a pavilion of a school playground. The beam is simply supported at both ends and the effective span is 10 m. The beam carries only its own weight at transfer. The beam has to be of type 1

Proposed section of the pre stressed beam, material properties and the loading on the beam are as follows.

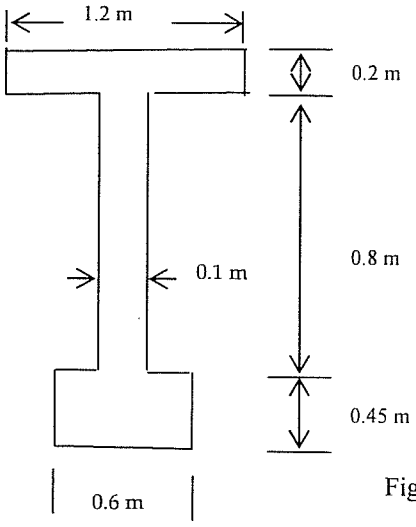



Figure Q5

**Strengths**

$f_{cu}$ at 28 days = 40 N/mm²
$f_{ci}$ at 7 days (transfer) = 32 N/mm²

Transfer is 7 day after casting

$f_{pu}$ Super strand 5.0 mm dia. Wires (assume 70 %effective after losses) = 1600 N/mm²

**Loss of prestress**

at transfer = 10 %
at service = 20 %

**Loads**

Unit weight of concrete = 24 kN/m³
Dead load other than self weight = 10.0 kN/m
Imposed load = 8.0 kN/m
(Assuming loads to be distributed evenly.)

**Allowable concrete stresses for Class 2 members**

at transfer

$f'_{max} = 0.5 f_{ci}$ $f'_{min}$ = - 1.00 N/mm²

at service

$f_{max} = 0.33 f_{cu}$ $f_{min}$ = 0

You may use following inequalities (in standard notation) for your calculations

$Z_t \geq (\alpha M_s - \beta M_i) / (\alpha f_{max} - \beta f'_{min})$
$Z_b \geq (\alpha M_s - \beta M_i) / (\beta f'_{max} - \alpha f_{min})$

$P_i \geq (Z_t f'_{min} - M_i) / \alpha(Z_t/A_c - e)$
$P_i \leq (Z_b f'_{max} + M_i) / \alpha(Z_b/A_c + e)$
$P_i \leq (Z_t f_{max} - M_s) / \beta(Z_t/A_c - e)$
$P_i \geq (Z_b f_{min} + M_s) / \beta(Z_b/A_c + e)$

$e \leq (M_i - Z_t f'_{min}) / \alpha P_i + Z_t/A_c$
$e \leq (M_i + Z_b f'_{max}) / \alpha P_i - Z_b/A_c$
$e \geq (M_s - Z_t f_{max}) / \beta P_i + Z_t/A_c$
$e \geq (M_s + Z_b f_{min}) / \beta P_i - Z_b/A_c$

Using above data, design the beam according to the following steps;

i.) Show that cross sectional area of the given beam is 0.59 m² .Yb = 0.767 m. Using given sectional properties of the beam find the $Z_t$ and $Z_b$ (Take Ixx = 0.171 m⁴) (03 Marks)

ii.) Evaluate the dead and imposed loads on the beam at transfer and in service and calculate the critical bending moments at the two instances. (03 Marks)

iii.) Check the adequacy of the section in carrying the stresses at **transfer** and in **service** for the range of spans. (03 Marks)

iv.) State the four stress conditions applied in the beam for mid span critical section. (03 Marks)

v.) a).By assuming eccentricity, e = 1000 mm find the suitable range for initial Pre stress Force, Pi. (04 Marks)
b). By selecting suitable value for Pre Stress Force, Pi find the range for eccentricity, 'e'. (04 Marks)

vi). By selecting suitable Pi and e give the tendon arrangement with neat sketch. (06 Marks)

vi.) Check whether the proposed tendon arrangement is suitable for the supports of the beam. If not suggest the method to overcome this problem. (03 Marks)

vii). Check the suitability of the section respect to Ultimate Moment capacity and Ultimate Shear Force Capacity. (04 Marks)

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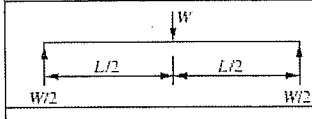
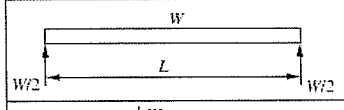
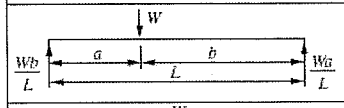
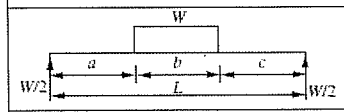
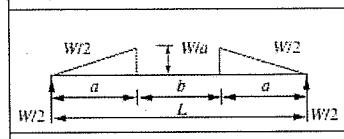
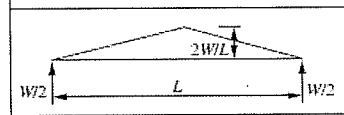
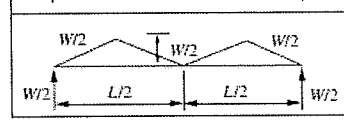
## Supplementary Information

**For question Q1.**

**Simply supported beam maximum moments and deflections**

| Beam and load | Maximum moment | Deflection at centre |
|---|---|---|
|   | $WL/4$ | $\frac{WL^3}{48EI}$ |
|   | $WL/8$ | $\frac{5WL^3}{384EI}$ |
|   | $Wab/L$ | $\frac{WL^3}{48EI}\left[\frac{3a}{L}-4\left(\frac{a}{L}\right)^3\right]$ |
|   | $W(a/2+b/8)$ | $\frac{W}{384EI}[8L^3-4Lb^2+b^3]$ |
|   | $Wa/3$ | $\frac{Wa}{120EI}[16a^2-20ab+5b^2]$ |
|   | $WL/6$ | $\frac{WL^3}{60EI}$ |
|   | $WL/8$ | $\frac{WL^3}{73.14EI}$ |

## ROLLED I SECTIONS

| Designation | | Depth of section D mm | width of section B mm | Thickness | | Ratios For Local Bucking | | Second Mo't of Area | | Radius of Gyration | | Elastic Modulus | | Plastic Modulus | | Area of section A cm² |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Serial size | Mass per m | | | Web t mm | Flange T mm | Flange b/T | Web d/t | Axis x-x cm⁴ | Axis y-y cm⁴ | Axis x-x cm | Axis y-y cm | Axis x-x cm³ | Axis y-y cm³ | Axis x-x cm³ | Axis y-y cm³ | |
| mm | Kg | | | | | | | | | | | | | | | |
| 457x152 | 82 | 465.1 | 153.5 | 10.7 | 18.9 | 4.06 | 38.0 | 36 200 | 1140 | 18.6 | 3.31 | 1560 | 149 | 1800 | 235 | 104 |
| | 74 | 461.3 | 152.7 | 9.9 | 17.0 | 4.49 | 41.1 | 32 400 | 1010 | 18.5 | 3.26 | 1410 | 133 | 1620 | 209 | 95.0 |
| | 67 | 457.2 | 151.9 | 9.1 | 15.0 | 5.06 | 44.7 | 28 600 | 878 | 118.3 | 3.21 | 1250 | 116 | 1440 | 182 | 85.4 |
| | 60 | 454.7 | 152.9 | 8.0 | 13.3 | 5.75 | 51.0 | 25 500 | 794 | 18.3 | 3.23 | 1120 | 104 | 1280 | 163 | 75.9 |
| | 52 | 449.8 | 152.4 | 7.6 | 10.9 | 6.99 | 53.6 | 21 300 | 645 | 17.9 | 3.11 | 949 | 84.6 | 1090 | 133 | 66.5 |
| 305x127 | 48 | 310.4 | 125.2 | 8.9 | 14.0 | 4.47 | 29.7 | 9500 | 460 | 12.5 | 2.75 | 612 | 73.5 | 706 | 116 | 60.8 |
| | 42 | 306.6 | 124.3 | 8.0 | 12.1 | 5.14 | 33.1 | 8140 | 388 | 12.4 | 2.70 | 531 | 62.5 | 610 | 98.2 | 53.2 |
| | 37 | 303.8 | 123.5 | 7.2 | 10.7 | 5.77 | 36.7 | 7160 | 337 | 12.3 | 2.67 | 472 | 54.6 | 540 | 85.7 | 47.5 |
| | | | | | | | | | | | | | | | | |