JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY

SCHOOL OF ENGINEERING AND TECHNOLOGY

UNIVERSITY EXAMINATIONS FOR THE DEGREE IN SCIENCE IN CONSTRUCTION MANAGEMENT

3RD YEAR 2ND SEMESTER 2019/2020 ACADEMIC YEAR

CENTRE: MAIN CAMPUS

COURSE CODE: TCM 3321

COURSE TITLE: STRUCTURES III

EXAM VENUE: **STREAM: BSc CONSTRUCTION MGT**

DATE:1/12//2020 **EXAM SESSION:9-12 NOON**

DURATION: 3 HOURS

Instructions

1. **Answer question 1 (Compulsory) and ANY other two questions**

2. Candidates are advised to write on the text editor provided, or to write on a foolscap, scan and upload alongside the question.

3 Candidates must ensure that they submit their work by clicking 'FINISH AND SUBMIT ATTEMPT' button at the end.

NB: The design tables are provided below, after the questions.

QUESTION ONE (30 Marks)

a. There are ten separate Structural Eurocodes: Each Eurocode is comprised of a number of Parts, which are published as separate documents. Each Part consists of Three (3) parts, name them? (6 Marks)

b. The National Annex, where allowed in the Eurocode, will assist in Four (4) areas. Name these areas? (4 Marks)

c. Why is Structural Eurocode EN 1990 Basis of structural design considered the ‘core’ document of the structural Eurocode system? (6 Marks)

d. Name the four (4) design situations considered by the Eurocodes under Limit State Design with examples? (8 Marks)

e. Two limit states are considered during the design process: ultimate and serviceability. List three (3) criteria that are considered for each of these states? (6 Marks)

QUESTION TWO (20 Marks)

Timber Column with Solid Cross-Section, under Compression parallel to grain has the following specifications:

- Simply supported timber beam with cross-section 110 x 110 mm.
- Buckling length ℓ = 2600 mm.
- Timber of strength class C35 according to EN 338
- Design compressive force N_d = 25 kN (short - term). Service class 1.

   a. Design the compressive strength? (4 Marks)

   b. Design the compressive stress and establish if the expression $\boldsymbol{\sigma_{c.0.d} < fc.o.d}$ is satisfied? (5 Marks)

   c. Calculate the slenderness ratio? (3 Marks)

   d. Determine the instability factors? (6 Marks)

   e. Verify the failure condition? (2 Marks)

QUESTION THREE (20 Marks)

a. Name and describe two (2) main biological agencies responsible for timber degradation? (4 Marks)

b. Show and explain the expressions for the combinations of actions (Characteristic, Frequent and Quasi-permanent combinations) given in BS EN 1990 for serviceability limit state design? (4 Marks)

c. List six (6) steps that should be followed when designing a steel frame structure? (6 Marks)

d. When designing orthodox steel framed buildings, list six (6) key parts of BS EN 1993-1 that will be required? (6 Marks)

QUESTION FOUR (20 Marks)

Consider a Simply supported fully restrained steel beam uniform loading in a truss frame. The steel beam is horizontal and because the concrete slabs are fully grouted and covered with a structural screed, the compression (top) flange is fully restrained. The compression (top) flange is fully restrained.

The combination factor (ψ_0) is not required as the only variable action is the imposed floor load. The wind has no impact on the design of this member.

Partial factor for permanent actions	$\gamma_G = 1.35$
Partial factor for variable actions	$\gamma_Q = 1.5$
Reduction factor	$\xi = 0.925$
Combination factor	$\psi_0 = 0$

$\gamma_{MO} = 1.0$

Beam span, L = 7.0 m

Bay width, = 5.0 m

Total Permanent Actions $G_k = 3.4$kN/m

Total Variable Actions $Q_k = 3.1$kN/m

Apply the expression for the combinations of actions given in BS EN 1990 for ultimate limit state design for Persistent or transient design situation equation 6.10b

Assume a Class 1 section

a. Determine the Ultimate Limit State (ULS) design load, F_d? (5 Marks)
b. Design the Maximum bending moment at mid-span? (5 Marks)
c. Design the Maximum design shear force at the end supports? (5 Marks)
d. Design the shear resistance is: $V_{c.Rd}$? (Assume the shear area Av = 4700mm^2) (5 Marks)

QUESTION FIVE (20 Marks)

Timber beam with solid cross-section has the following specifications:

- Simply supported solid timber beam with cross-section 50 x 210 mm,

- Clear span l = 3300 mm.
- Timber of strength class C24 according to EN 338
- Design uniformly distributed load of $1.5kNm^{-1}$ (short - term). Service class 1

a. Design bending strength? (5 Marks)

b. Design shear strength? (5 Marks)

c. Verification of failure condition for **bending**, assuming the beam is laterally restrained throughout the Length of its compression edge? (5 Marks)

d. Verification of failure condition for **bending**, assuming the beam is not laterally restrained throughout the Length of its compression edge? (5 Marks)

END

Table 2.0 Values of k_{mod}

Material	Standard		Service class	Load-duration class				
				Permanent action	Long term action	Medium term action	Short term action	Instantaneous action
Solid timber	EN 14081-1		1	0.60	0.70	0.80	0.90	1.10
			2	0.60	0.70	0.80	0.90	1.10
			3	0.50	0.55	0.65	0.70	0.90
Glued laminated timber	EN 14080		1	0.60	0.70	0.80	0.90	1.10
			2	0.60	0.70	0.80	0.90	1.10
			3	0.50	0.55	0.65	0.70	0.90
LVL	EN 14374, EN 14279		1	0.60	0.70	0.80	0.90	1.10
			2	0.60	0.70	0.80	0.90	1.10
			3	0.50	0.55	0.65	0.70	0.90
Plywood	EN 636	Part 1, 2, 3	1	0.60	0.70	0.80	0.90	1.10
		Part 2, 3	2	0.60	0.70	0.80	0.90	1.10
		Part 3	3	0.50	0.55	0.65	0.70	0.90
OSB	EN 300	OSB/2	1	0.30	0.45	0.65	0.85	1.10
		OSB/3, OSB/4	1	0.40	0.50	0.70	0.90	1.10
		OSB/3, OSB/4	3	0.30	0.40	0.55	0.70	0.90
Particle-board	EN 312	Part 4, 5	1	0.30	0.45	0.65	0.85	1.10
		Part 5	2	0.20	0.30	0.45	0.60	0.80
		Part 6, 7	1	0.40	0.50	0.70	0.90	1.10
		Part 7	2	0.30	0.40	0.55	0.70	0.90
Fiberboard, hard	EN 622-2	HB.LA, HB.HLA 1 or 2	1	0.30	0.45	0.65	0.85	1.10
		HB.HLA1 or 2	2	0.20	0.30	0.45	0.60	0.80
Fiberboard, medium	EN 622-3	MBH.LA1 or 2	1	0.20	0.40	0.60	0,80	1.10
		MBH.HLS1 or 2	1	0.20	0.40	0,60	0.80	1.10
		MBH.HLS1 or 2	2	-	-	-	0.45	0.80
Fiberboard, MDF	EN 622-5	MDF.LA	1	0.20	0.40	0.60	0.80	1.10
		MDF.HLS	2	-	-	-	0.45	0.80

Table 3.0 Recommended partial factors γ_M for material properties and resistances

Fundamental combinations:	
Solid timber	1.3
Glued laminated timber	1.25
LVL, plywood, OSB	1.2
Particleboards	1.3
Fiberboards, hard	1.3
Fiberboards, medium	1.3
Fiberboards, MDF	1.3
Fiberboards, soft	1.3
Connections	1.3
Punched metal plate fasteners	1.25
Accidental combinations	1.0

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} \le 1 \tag{6.19}$$

$$\left(\frac{\sigma_{c,0,d}}{f_{c,0,d}}\right)^2 + k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \le 1 \tag{6.20}$$

(2)P The values of k_m given in 6.1.6 apply.

NOTE: To check the instability condition, a method is given in 6.3.

6.3 Stability of members

6.3.1 General

(1)P The bending stresses due to initial curvature, eccentricities and induced deflection shall be taken into account, in addition to those due to any lateral load.

(2)P Column stability and lateral torsional stability shall be verified using the characteristic properties, e.g. $E_{0,05}$

(3) The stability of columns subjected to either compression or combined compression and bending should be verified in accordance with 6.3.2.

(4) The lateral torsional stability of beams subjected to either bending or combined bending and compression should be verified in accordance with 6.3.3.

6.3.2 Columns subjected to either compression or combined compression and bending

(1) The relative slenderness ratios should be taken as:

$$\lambda_{rel,y} = \frac{\lambda_y}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} \tag{6.21}$$

and

$$\lambda_{rel,z} = \frac{\lambda_z}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0,05}}} \tag{6.22}$$

where:

λ_y and $\lambda_{rel,y}$ are slenderness ratios corresponding to bending about the *y*-axis (deflection in the *z*-direction);

λ_z and $\lambda_{rel,z}$ are slenderness ratios corresponding to bending about the *z*-axis (deflection in the *y*-direction);

$E_{0,05}$ is the fifth percentile value of the modulus of elasticity parallel to the grain.

(2) Where both $\lambda_{rel,z} \le 0{,}3$ and $\lambda_{rel,y} \le 0{,}3$ the stresses should satisfy the expressions (6.19) and (6.20) in 6.2.4.

(3) In all other cases the stresses, which will be increased due to deflection, should satisfy the following expressions:

$$\frac{\sigma_{c,0,d}}{k_{c,y} f_{c,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1 \tag{6.23}$$

$$\frac{\sigma_{c,0,d}}{k_{c,z} f_{c,0,d}} + k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1 \tag{6.24}$$

where the symbols are defined as follows:

$$k_{c,y} = \frac{1}{k_y + \sqrt{k_y^2 - \lambda_{rel,y}^2}} \tag{6.25}$$

$$k_{c,z} = \frac{1}{k_z + \sqrt{k_z^2 - \lambda_{rel,z}^2}} \tag{6.26}$$

$$k_y = 0,5 \left(1 + \beta_c \left(\lambda_{rel,y} - 0,3\right) + \lambda_{rel,y}^2\right) \tag{6.27}$$

$$k_z = 0,5 \left(1 + \beta_c \left(\lambda_{rel,z} - 0,3\right) + \lambda_{rel,z}^2\right) \tag{6.28}$$

where:

β_c is a factor for members within the straightness limits defined in Section 10:

$$\beta_c = \begin{cases} 0,2 & \text{for solid timber} \\ 0,1 & \text{for glued laminated timber and LVL} \end{cases} \tag{6.29}$$

k_m as given in 6.1.6.

6.3.3 Beams subjected to either bending or combined bending and compression

(1)P Lateral torsional stability shall be verified both in the case where only a moment M_y exists about the strong axis *y* and where a combination of moment M_y and compressive force N_c exists.

(2) The relative slenderness for bending should be taken as:

$$\lambda_{rel,m} = \sqrt{\frac{f_{m,k}}{\sigma_{m,crit}}} \tag{6.30}$$

where $\sigma_{m,crit}$ is the critical bending stress calculated according to the classical theory of stability, using 5-percentile stiffness values.

The critical bending stress should be taken as:

$$\sigma_{m,crit} = \frac{M_{y,crit}}{W_y} = \frac{\pi\sqrt{E_{0,05} I_z G_{0,05} I_{tor}}}{\ell_{ef} W_y} \tag{6.31}$$

where:

$E_{0,05}$ is the fifth percentile value of modulus of elasticity parallel to grain;

$G_{0,05}$ is the fifth percentile value of shear modulus parallel to grain;

I_z is the second moment of area about the weak axis *z*.

I_{tor} is the torsional moment of inertia;

ℓ_{ef} is the effective length of the beam, depending on the support conditions and the load configuration, acccording to Table 6.1;

W_y is the section modulus about the strong axis *y*.

For softwood with solid rectangular cross-section, $\sigma_{m,crit}$ should be taken as:

$$\sigma_{m,crit} = \frac{0,78 b^2}{h \ell_{ef}} E_{0,05} \tag{6.32}$$

where:

b is the width of the beam;

h is the depth of the beam.

(3) In the case where only a moment M_y exists about the strong axis *y*, the stresses should satisfy the following expression:

$$\sigma_{m,d} \leq k_{crit} f_{m,d} \tag{6.33}$$

where:

$\sigma_{m,d}$ is the design bending stress;

$f_{m,d}$ is the design bending strength;

k_{crit} is a factor which takes into account the reduced bending strength due to lateral buckling.

Table 6.1 – Effective length as a ratio of the span

Beam type	**Loading type**	ℓ_{ef}/ℓ [a]
Simply supported	Constant moment Uniformly distributed load Concentrated force at the middle of the span	1,0 0,9 0,8
Cantilever	Uniformly distributed load Concentrated force at the free end	0,5 0,8
[a] The ratio between the effective length ℓ_{ef} and the span ℓ is valid for a beam with torsionally restrained supports and loaded at the centre of gravity. If the load is applied at the compression edge of the beam, ℓ_{ef} should be increased by 2*h* and may be decreased by 0,5*h* for a load at the tension edge of the beam.		

(4) For beams with an initial lateral deviation from straightness within the limits defined in Section 10, k_{crit} may be determined from expression (6.34)

$$k_{crit} = \begin{cases} 1 & \text{for } \lambda_{rel,m} \leq 0,75 \\ 1,56 - 0,75\lambda_{rel,m} & \text{for } 0,75 < \lambda_{rel,m} \leq 1,4 \\ \dfrac{1}{\lambda_{rel,m}^2} & \text{for } 1,4 < \lambda_{rel,m} \end{cases} \tag{6.34}$$

(4)P Where the results of a verification are very sensitive to variations of the magnitude of a permanent action from place to place in the structure, the unfavourable and the favourable parts of this action shall be considered as individual actions.

NOTE This applies in particular to the verification of static equilibrium and analogous limit states, see 6.4.2(2).

(5) Where several effects of one action (*e.g.* bending moment and normal force due to self-weight) are not fully correlated, the partial factor applied to any favourable component may be reduced.

NOTE For further guidance on this topic see the clauses on vectorial effects in EN 1992 to EN 1999.

(6) Imposed deformations should be taken into account where relevant.

NOTE For further guidance, see 5.1.2.4(P) and EN 1992 to EN 1999.

6.4.3.2 Combinations of actions for persistent or transient design situations (fundamental combinations)

(1) The general format of effects of actions should be :

$$E_d = \gamma_{Sd} E\left\{\gamma_{g,j} G_{k,j} \,;\, \gamma_p P \,;\, \gamma_{q,1} Q_{k,1} \,;\, \gamma_{q,i} \psi_{0,i} Q_{k,i}\right\} \quad j \geq 1 \,;\, i > 1 \qquad (6.9a)$$

(2) The combination of effects of actions to be considered should be based on
- the design value of the leading variable action, and
- the design combination values of accompanying variable actions :

NOTE See also 6.4.3.2(4).

$$E_d = E\left\{\gamma_{G,j} G_{k,j} \,;\, \gamma_P P \,;\, \gamma_{Q,1} Q_{k,1} \,;\, \gamma_{Q,i} \psi_{0,i} Q_{k,i}\right\} \quad j \geq 1 \,;\, i > 1 \qquad (6.9b)$$

(3) The combination of actions in brackets { }, in (6.9b) may either be expressed as :

$$\sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{"+"} \gamma_P P \text{"+"} \gamma_{Q,1} Q_{k,1} \text{"+"} \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} \qquad (6.10)$$

or, alternatively for STR and GEO limit states, the less favourable of the two following expressions:

$$\begin{cases} \sum_{j\geq 1} \gamma_{G,j} G_{k,j} \text{"+"} \gamma_P P \text{"+"} \gamma_{Q,1} \psi_{0,1} Q_{k,1} \text{"+"} \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} & (6.10a) \\ \sum_{j\geq 1} \xi_j \gamma_{G,j} G_{k,j} \text{"+"} \gamma_P P \text{"+"} \gamma_{Q,1} Q_{k,1} \text{"+"} \sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} & (6.10b) \end{cases}$$

Where :

"+ " implies "to be combined with"
Σ implies "the combined effect of"
ξ is a reduction factor for unfavourable permanent actions G

6.2.5 Bending moment

[AC1) (1)P The design value of the bending moment M_{Ed} at each cross-section shall satisfy: (AC1]

$$\frac{M_{Ed}}{M_{c,Rd}} \leq 1,0 \qquad (6.12)$$

where $M_{c,Rd}$ is determined considering fastener holes, see (4) to (6).

(2) The design resistance for bending about one principal axis of a cross-section is determined as follows:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl}\, f_y}{\gamma_{M0}} \quad \text{for class 1 or 2 cross sections} \qquad (6.13)$$

$$M_{c,Rd} = M_{el,Rd} = \frac{W_{el,min}\, f_y}{\gamma_{M0}} \quad \text{for class 3 cross sections} \qquad (6.14)$$

$$M_{c,Rd} = \frac{W_{eff,min}\, f_y}{\gamma_{M0}} \quad \text{for class 4 cross sections} \qquad (6.15)$$

where $W_{el,min}$ and $W_{eff,min}$ corresponds to the fibre with the maximum elastic stress.

(3) For bending about both axes, the methods given in 6.2.9 should be used.

(4) Fastener holes in the tension flange may be ignored provided that for the tension flange:

$$\frac{A_{f,net}\, 0{,}9\, f_u}{\gamma_{M2}} \geq \frac{A_f\, f_y}{\gamma_{M0}} \qquad (6.16)$$

where A_f is the area of the tension flange.

NOTE The criterion in (4) provides capacity design (see 1.5.8) [AC2) *text deleted* (AC2].

(5) Fastener holes in tension zone of the web need not be allowed for, provided that the limit given in (4) is satisfied for the complete tension zone comprising the tension flange plus the tension zone of the web.

(6) Fastener holes except for oversize and slotted holes in compression zone of the cross-section need not be allowed for, provided that they are filled by fasteners.

6.2.6 Shear

[AC1) (1)P The design value of the shear force V_{Ed} at each cross section shall satisfy: (AC1]

$$\frac{V_{Ed}}{V_{c,Rd}} \leq 1,0 \qquad (6.17)$$

where $V_{c,Rd}$ is the design shear resistance. For plastic design $V_{c,Rd}$ is the design plastic shear resistance $V_{pl,Rd}$ as given in (2). For elastic design $V_{c,Rd}$ is the design elastic shear resistance calculated using (4) and (5).

(2) In the absence of torsion the design plastic shear resistance is given by:

$$V_{pl,Rd} = \frac{A_v \left(f_y / \sqrt{3}\right)}{\gamma_{M0}} \qquad (6.18)$$

where A_v is the shear area.

Table 1.0 Strength classes and characteristic values according to EN 338

		Coniferous species and Poplar												Deciduous species					
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	D30	D35	D40	D50	D60	D70
Strength properties in N/mm^2																			
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50	30	35	40	50	60	70
Tension parallel to grain	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	30	18	21	24	30	36	42
Tension perpendicular to grain	$f_{t,90,k}$	0,4	0,5	0,5	0,5	0,5	0,5	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Compression parallel to grain	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29	23	25	26	29	32	34
Compression perpendicular to grain	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2	8,0	8,4	8,8	9,7	10,5	13,5
Shear	$f_{v,k}$	1,7	1,8	2,0	2,2	2,4	2,5	2,8	3,0	3,4	3,8	3,8	3,8	3,0	3,4	3,8	4,6	5,3	6,0
Stiffness properties in kN/mm^2																			
Mean value of modulus of elasticity parallel to grain	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16	10	10	11	14	17	20
5% value of modulus of elasticity parallel to grain	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7	8,0	8,7	9,4	11,8	14,3	16,8
Mean value of modulus of elasticity perpendicular to grain	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53	0,64	0,69	0,75	0,93	1,13	1,33
Mean value of shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00	0,60	0,65	0,70	0,88	1,06	1,25
Density in kg/m^3																			
Density	ρ_k	290	310	320	330	340	350	370	380	400	420	440	460	530	560	590	650	700	900
Mean value of density	ρ_{mean}	350	370	380	390	410	420	450	460	480	500	520	550	640	670	700	780	840	1080

END