UNIVERSITY OF RUHUNA

Faculty of Engineering

End Semester 5 Examination in Engineering: March 2026

Module Number: CE5251 **Module Name: Design of Timber and Masonry Structures (C-23)**

[Three Hours]

[Answer **all questions,** marks are given as indicated]

Note: Code of practice BS EN 1995-1-1: 2004+A1:2008 and BS EN 1996-1-1: 2005 are provided.

Q1. A Gerber system is a type of beam arrangement in which internal hinges are introduced within a continuous beam. These hinges divide the beam into several segments and allow the internal hinges to reduce bending moments and make the structure statically determinate, which simplifies structural analysis and design. In timber structures, these beam segments are often connected using mechanical fasteners such as nails, bolts, or screws. In this problem, the connection at the hinge region is formed using nailed timber plates, and the nails must be designed to safely transfer forces between the timber members. The Gerber connection is always placed where the moment is (theoretically) zero, which means that the shear force is relatively large. Consequently, the connection must be designed to ensure no moment is transferred. A *skarv* is the joint location that connects two structural members to act as a single continuous element. You may consider the timber member dimensions near the skarv location for the design. A principal sketch is shown in Figure Q1 (a). The possible nailing pattern is shown in Figure Q1 (b). Neglect the steel design.

The Gerber connection is placed in the outer bay of a solid timber beam with a span of 23 m. The beam is a part of a system equally spaced Gerber beams and is loaded with a uniformly distributed design load of 34.3 kN/m. The connection will be a single shear connection steel-timber *(Clause 8.2.3, Eurocode 5)*. The smooth round nails are assumed to have a fixed support in the steel plate. Spacing and edge distances for the nails are assumed to be adequate. Use the following additional data to answer the questions, including all references to the provided code of practice.

Design data

Load duration class	= Medium term
Service class	= 3
Tensile strength of nails	= 600 MPa
Timber class	= C30
Material dimensions, b × h	= 215 × 1305 mm
Nail diameter	= 4 mm
Nail head diameter	= 6 mm

Nail length = 40 mm
Thickness of the steel plate = 5 mm

(a) State how to classify whether the steel plate in the connection is thin or thick with reference to Eurocode 5. Hence, state the type of steel plate used in the above connection.

[1 Mark]

(b) Check the adequacy of the timber sections used to form the connection in resisting the designed tensile stresses under given load conditions.

[2 Marks]

(c) For the outer bay Gerber connection, the shear force at the hinge can be approximately taken as $V \approx 0.44\, qL$ (q = UDL, L = span). Hence compute the shear force to be transferred in the connection.

[1 Mark]

(d) Compute the axial load carrying capacity ($F_{ax,Rd}$) of the nail.

[4 Marks]

(e) Find the rope effect.

[1 Mark]

(f) Find the characteristic yield moment ($M_{y,Rk}$) of the nail and characteristic embedment strength ($f_{h,k}$) in the timber member.

[2 Marks]

(g) Calculate the lateral load carrying capacity ($F_{v,Rd}$) of the nail.

[3 Marks]

(h) Hence, determine the minimum number of nails required for each side of the steel plate connection to successfully transfer the shear force.

[1 Mark]

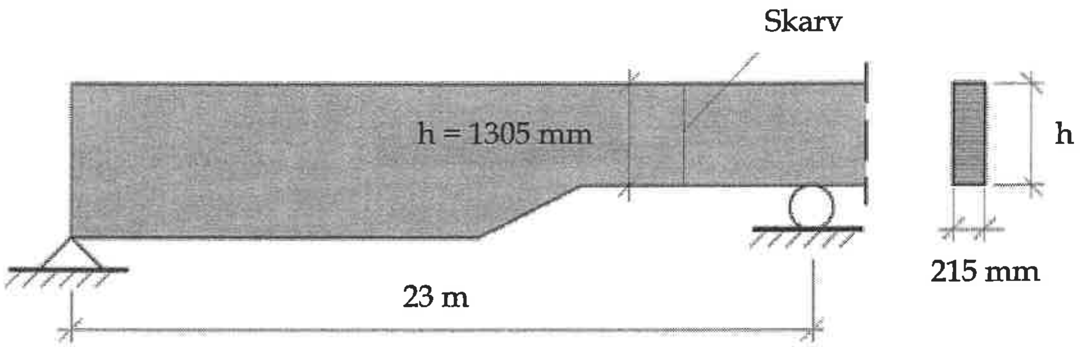

Figure Q1 (a). Geometry of the Geber beam and skarv location

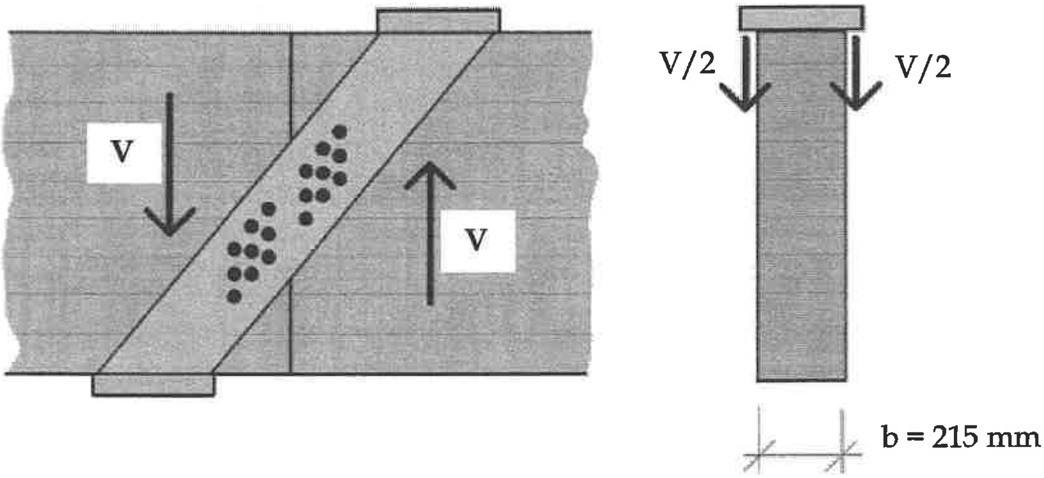

Figure Q1 (b). Possible nailing pattern for the Gerber connection.

Q2. a). You are the Design Engineer for a timber roof structure of a two-storey house under construction in Matara, a coastal region of Sri Lanka. The roof consists of timber rafters, purlins, and ceiling joists fabricated using locally sourced timber obtained from the State Timber Corporation yard. During construction, the following observations were made.

- Some timber planks show surface cracks (shakes) and slight warping.
- A batch of timber has high moisture content due to recent rain exposure.
- The contractor proposes using Coconut timber for rafters without treatment
- No clear grading or seasoning records have been provided.

Based on this situation, answer the following:

(i) Timber shakes were identified in several rafters. State two possible causes for the occurrence of shakes.

[1 Mark]

(ii) The timber was observed to have high moisture content. State two problems this may cause in the roof structure.

[1 Mark]

(iii) The available timber has no seasoning record. Specify two acceptable seasoning methods suitable for Sri Lankan conditions and state one advantage of each.

[1 Mark]

(iv) Before structural use, timber must be graded. State two methods used for timber grading and specific parameters (two per each) checked during each grading method.

[1 Mark]

(v) How would you accept or reject the proposal to use Coconut timber as the rafters? Specify your recommendations.

[1 Mark]

b) A notched timber beam in a building has a simply supported arrangement between the supports as shown in Figure Q2. The beam is made of C30 solid timber, and the cross-section is 90 mm× 315 mm. The design should consider Service class 1 and a medium-term load duration class. The beam carries a dead load of 2 kN/m and an imposed load of 1.6 kN/m. It is assumed that the beam is not subject to lateral buckling. Length of the notch from the centerline of the end support (x) is 150 mm. Based on the given data, answer the following questions. Your answers should include all relevant references to the provided code of practice.

(i) Considering the beam is subjected to uniaxial bending about y-y axis, verify its bending capacity with respect to the ultimate limit state.

[5 Marks]

(ii) Check the shear capacity of the beam with respect to the ultimate limit state.

[5 Marks]

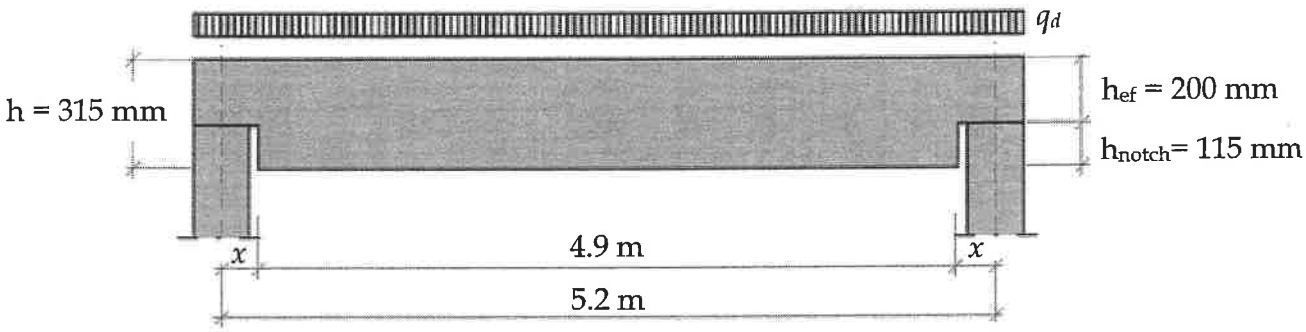

Figure Q2. Notched timber beam arrangement.

Q3 (a) Name four types of masonry units covered under BS EN 1996-1-1: 2005.

[2 Marks]

(b) You are the Design Engineer for a two-storey classroom building under construction in Kurunegala, Sri Lanka. The contractor proposes using a stretcher bond instead of English bond. Name two bond types other than those specified above and state one structural advantage of the English bond over the stretcher bond.

[2 Marks]

(c) In the above project in part (b), the storey height is 3.2 m and the floors consist of RC slabs supported by beams. A 3.0 m long section of an external wall is subjected to a concentrated load of 120 kN from a beam, which is higher than the typical wall loading. Suggest two appropriate modifications to the wall design at the location where a 120 kN beam reaction is applied to safely accommodate and transfer the imposed load.

[2 Marks]

(d) Name four functions of mortar in masonry construction.

[2 Marks]

(e) The actual size of the bricks used in the project specified in part (b) is given as 225 × 112.5 × 75 mm. State what is meant by follows and provide appropriate dimensions:

(i) Coordinating size

(ii) Working size.

[2 Marks]

Q4. Figure Q4 illustrates a three-story building with load bearing masonry. Consider the structure's external walls supporting the roof slab are cavity walls comprising outer leaves of Group 1 standard format clay units (102.5 mm thick). The wall consists of inner leaves of 215 mm high × 140 mm thick Group 1 concrete block units and a cavity width of 50 mm. Assume the walls are part of a braced structure and that lateral forces due to wind loading are not considered. The characteristic load values acting on roofs & floors, characteristic self-weight of masonry and other required data are given below. Given that the masonry wall panel satisfies the design criteria for a vertically loaded masonry wall with eccentricity, answer the following questions based on this wall arrangement.

Design data:

Characteristic permanent load on the roof slab (including self-weight)	= 4.5 kN/m^2
Characteristic variable load on the roof slab	= 1.5 kN/m^2
Characteristic permanent load on all floors	= 5.0 kN/m^2
Characteristic variable load on all floors	= 2.5 kN/m^2
Characteristic self-weight of concrete block units	= 3.0 kN/m^2
Mortar designation (general purpose mortar)	= M6
Manufacturing control of masonry units	= Category I
Execution control for the masonry on site	= Class 1
Modulus of elasticity for the concrete slab	= 34.0 GPa

(a) What is meant by the "Normalized compressive strength of masonry units (f_b)"? How is it determined? You may use the relevant equations and terms to support your answer.

[1.5 Marks]

(b) Check the dimensions of wall A with respect to the basic requirements for masonry structures specified in BS EN 1996-1-1: 2005.

[1.5 Marks]

(c) Calculate the bending moments at the top, bottom and middle of the wall A. (You can assume Characteristic compressive strength of masonry units as 5.0 MPa for this part only.)

[7 Marks]

(d) Determine the eccentricity at the top, bottom and middle of the wall A.

[7 Marks]

(e) Determine the minimum normalized compressive strength (air dried) of masonry blocks for the inner leaf of the wall A to support the specified loads.

[3 Marks]

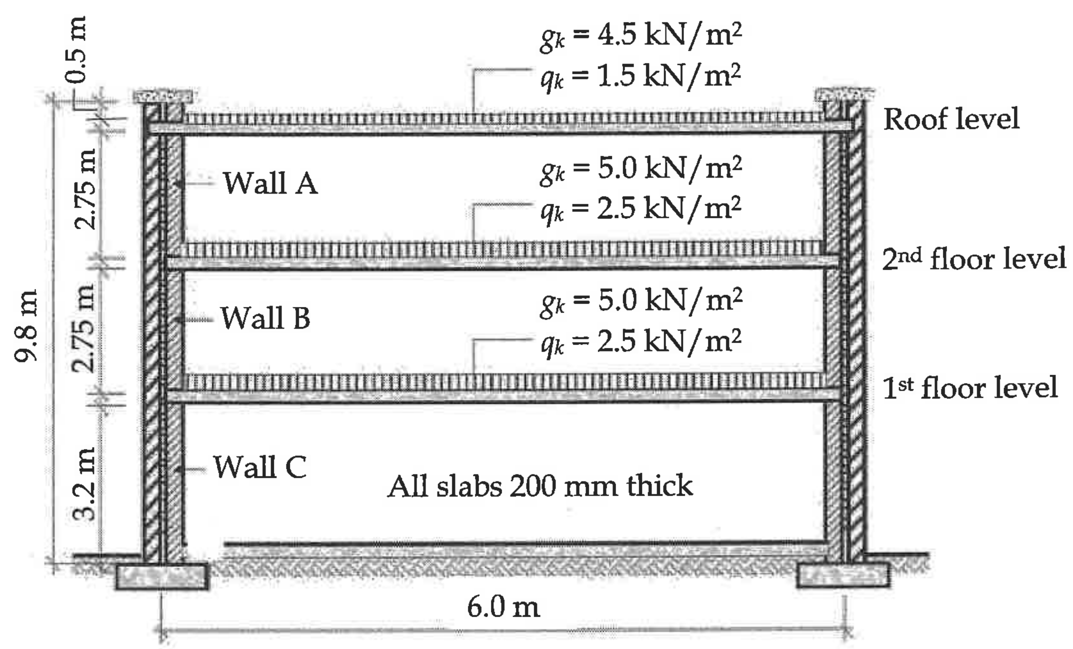

Figure Q4. Masonry wall arrangement in a 3-storey building.

APPENDIX

Table A.1: Characteristic Values for Timber (Extracted from Table 1; EN 338:2009)

		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 pependicular 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

Table A.2: Partial factors for material properties for the ultimate limit state (γ_M) in masonry.

Partial safety factors γ_M (based on the UK NA to EN 1996-1-1: Table NA.1 values)			
Level of manufacturing control		**Class of execution control**	
		Class 1	Class 2
Unreinforced masonry in a state of direct or flexural compression.	Category I	2,3	2,7
	Category II	2,6	3,0
Masonry in a state of direct or flexural tension.	Category I	2,3	2,7
	Category II	2,3	2,7
Unreinforced masonry in a state of shear.	Category I	2,5	2,5
	Category II	2,5	2,5
Reference should be made to notes which are given in **EN 1996-1-1: Table NA.1**			

Table A.3: Values of K according to Table NA.4; UK NA to EC6

Table NA.4 **Values of K to be used with equation 3.1:**

Masonry Unit		**General purpose mortar**	**Thin layer mortar (bed joint $\geqslant$ 0,5 mm and $\leqslant$ 3 mm)**	**Lightweight mortar of density**	
				$600 \leqslant \rho_d \leqslant 800$ kg/m³	**$800 < \rho_d \leqslant 1\,300$ kg/m³**
Clay	Group 1	0,50	0,75	0,30	0,40
	Group 2	0,40	0,70	0,25	0,30
	Group 3	A)	A)	A)	A)
	Group 4	A)	A)	A)	A)
Calcium silicate	Group 1	0,50	0,80	B)	B)
	Group 2	0,40	0,70	B)	B)
Aggregate concrete	Group 1	0,75	0,90	0,45	0,45
	Group 1 C) (units laid flat)	0,50 D)	0,70 D)	0,40 D)	0,40 D)
	Group 2	0,70	0,76	0,45	0,45
	Group 3	A)	A)	A)	A)
	Group 4	A)	A)	A)	A)
Autoclaved aerated concrete	Group 1	0,75	0,90	0,45	0,45
Manufactured stone	Group 1	0,75	0,90	B)	B)
Dimensioned natural stone	Group 1	0,45	B)	B)	B)

A) Group 3 and 4 units have not traditionally been used in the UK, so no values are available.

B) These masonry unit and mortar combinations have not traditionally been used in the UK, so no values are available.

C) If Group 1 aggregate concrete units contain formed vertical voids in the normal direction, multiply K by (100-n) /100, where n is the percentage of voids, maximum 25%.

D) When aggregate concrete masonry units are to be used laid flat, the normalized strength of the unit should be calculated using the width and height of the unit in the upright position along with the compressive strength of the unit tested in the upright position.

Values of α, β for use with Equation 3.1 are as follows:

For general purpose mortar:	$\alpha = 0,7$ and $\beta = 0,3$
For lightweight mortar:	$\alpha = 0,7$ and $\beta = 0,3$
For thin layer mortar (in bed joints of thickness 0,5 mm to 3 mm):	
a) using clay units of Group 1, Calcium silicate and aggregate concrete units of Group 1 and 2 and autoclaved concrete units of Group 1	$\alpha = 0,85$ and $\beta = 0$
b) using clay units of Group 2	$\alpha = 0,7$ and $\beta = 0$

In here conditioning factor which varies with testing conditions takes following values,

- 0.8 for units subjected to oven dry conditions
- 1.0 for units subjected to air dry condition or conditioning to 60% moisture content
- 1.2 for units subjected to conditioning by immersion

Table A.4: Details of masonry mortar according to Table NA.2; UK NA to E

Table NA.2 **Acceptable assumed equivalent mixes for prescribed masonry mortars**

Compressive strength class [A)]	Prescribed mortars (proportion of materials by volume) (see Note)				Mortar designation	[A1) Suitable for use in environmental condition
	Cement [B)] : lime : sand with or without air entrainment	Cement [B)] : sand with or without air entrainment	Masonry cement [C)] : sand	Masonry cement [D)] : sand		
M12	1 : 0 to ¼ : 3	1 : 3	Not suitable	Not suitable	(i)	Severe (S)
M6	1 : ½ : 4 to 4½	1 : 3 to 4	1 : 2½ to 3½	1 : 3	(ii)	Severe (S)
M4	1 : 1 : 5 to 6	1 : 5 to 6	1 : 4 to 5	1 : 3½ to 4	(iii)	Moderate (M)
M2	1 : 2 : 8 to 9	1 : 7 to 8	1 : 5½ to 6½	1 : 4½	(iv)	Passive (P) (A1]

[A)] The number following the M is the compressive strength for the class at 28 days in N/mm^2

[B)] Cement or combinations of cement in accordance with **NA.2.3.2**, except masonry cements

[C)] Masonry cement in accordance with **NA.2.3.2** (inorganic filler other than lime)

[D)] Masonry cement in accordance with **NA.2.3.2** (lime)

NOTE 1 When the sand portion is given as, for example, 5 to 6, the lower figure should be used with sands containing a higher proportion of fines whilst the higher figure should be used with sands containing a lower proportion of fines.

[A1) *NOTE 2 For Class 2 of execution control site compressive strength testing is not required for these traditional mixes and checking of prescribed mortars should only be done by testing the proportions of the constituents.* (A1]