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CIVIL ENGINEERING LEVEL 6

CON/OS/CET/CR/05/6

Design Engineering Structures

March/April 2026

TVET CURRICULUM DEVELOPMENT, ASSESSMENT AND CERTIFICATION COUNCIL (TVET CDACC)

WRITTEN ASSESSMENT

Time: 3 HOURS

INSTRUCTIONS TO CANDIDATE

1. This paper consists of **TWO** sections: **A** and **B**.
2. Answer **ALL** questions in section A and **ANY THREE** (3) questions in section B.
3. Marks for each question are indicated in the brackets.
4. Candidates are provided with a separate answer booklet
5. Do not write on the question paper.

This paper consists of EIGHT (8) printed pages

Candidates should check the question paper to ascertain that all pages are printed as indicated and that no questions are missing.

SECTION A (40 MARKS)

Answer ALL the questions in this section.

1. Structural drawings are produced using different software tools. List THREE software programs that are widely used in structural design. (3 Marks)
2. Structural design layouts are made up of several essential components that ensure the stability and functionality of a structure. Name THREE of these components (3 Marks)
3. Structural design is a key factor in ensuring safe and efficient construction of buildings. Outline FOUR important roles that structural design plays in building construction. (4 Marks)
4. A simply supported beam is subjected to a dead load (gk) = 6 k N/m and an imposed load (qk) = 4 k N/m. Using BS 8110 partial safety factors for dead + imposed loading, determine the ultimate design load per meter run. (4 Marks)
5. In structural design, a structure is governed by limit states to ensure effective and safe design. Explain the following limit states.
    a. Ultimate Limit State (ULS) (3 Marks)
    b. Serviceability Limit State (SLS) (3 Marks)
6. Figure 1 shows a simply supported rectangular beam of 7 m span carries characteristic dead (including self-weight of beam) gk, and imposed qk, loads of 12 kNm^{-1} and 8 kNm^{-1} respective. The beam dimensions are breadth b, 275 mm and effective depth d, 450 mm. Assuming the following material strengths, calculate the area of reinforcement required.

$fcu = 30\ Nmm^{-2}$

$fy = 500\ Nmm^{-2}$

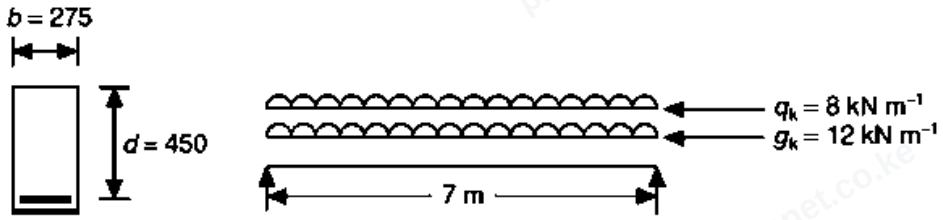


Figure 1

(6 Marks)

7. In structural design, different members are designed to carry loads safely. Name FOUR structural members commonly used in construction. (4 Marks)
8. Figure 2 shows a cross section of a column, determine whether the reinforced concrete would be suitable to resist an axial load of 1500 KN. Assume that the design compressive strengths of the concrete and steel reinforcement are 14 and 375 N mm^{-2} respectively.

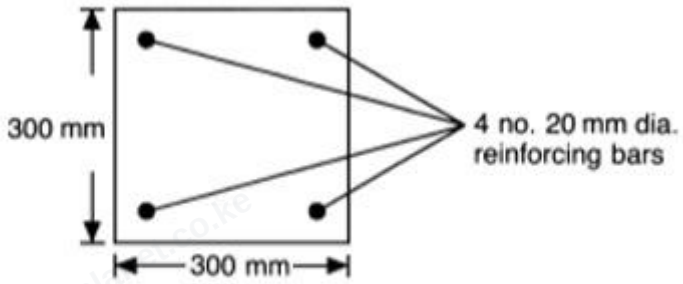


Figure 2

(5 Marks)

9. A multi-story building is being constructed in an area prone to strong winds. As a structural engineer, list THREE ways you would use to ensure columns and beams are designed to resist both vertical and lateral loads. (3 Marks)
10. Retaining walls are structural members that resist lateral pressure from soil. List TWO common modes of failure in retaining walls. (2 Marks)

SECTION B (60 MARKS)

Answer Any THREE Questions in This Section

11. Figure 3 shows a reinforced concrete beam which is 300 mm wide and 600 mm deep is required to span 6.0 m between the centers of supporting piers 300 mm wide. The beam carries dead and imposed loads of 25 kNm^{-1} and 19 kNm^{-1} respectively. Assuming fcu = 30 Nmm^{-2}, $fy = fyv$ = 500 Nmm^{-2} and the exposure class is XC1, design the beam.

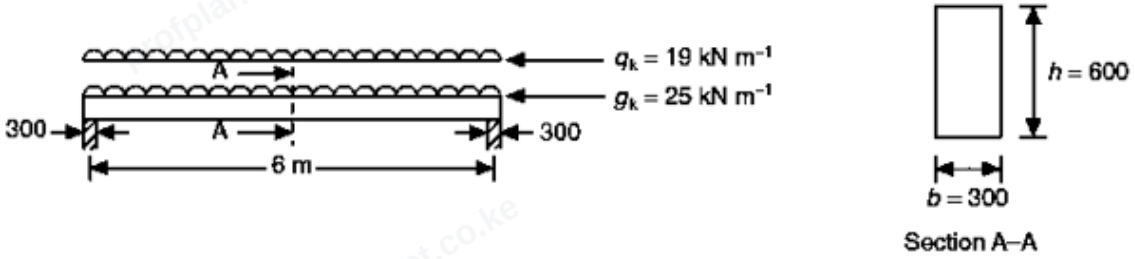


Figure 3

(20 Marks)

12. Columns are vertical structural members that transfer loads from beams and slabs to the foundation. Their design is critical for the safety and stability of a structure.
    a. A reinforced concrete column carries a factored axial load of 800 kN**.** The column is square with a side of 400 mm and uses M20 concrete and Fe500 steel**.** Calculate the area of steel reinforcement required for the column. (4 Marks)
    b. According to BS 8110, short braced columns are classified into different categories depending on the loads and moments they carry. Describe the THREE categories of short braced columns. (6 Marks)
    c. Figure 4 shows a column. Using table 3.19, determine if the column is classified as a short column. (10 Marks)

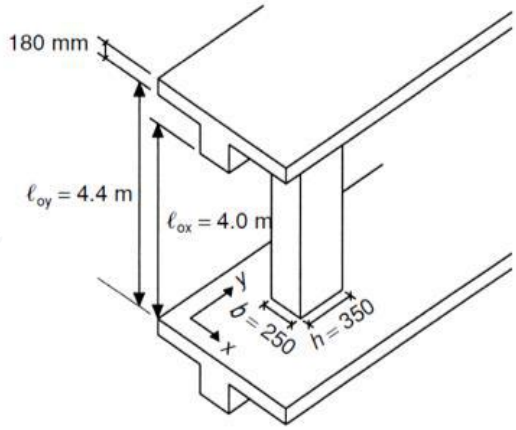


Figure 4

13. Figure 5 shows a 400 mm square column carries a dead load (*Q*k) of 1050 kN and imposed load (*G*k) of 300 kN. The safe bearing capacity of the soil is 170 kNm^2. Design a square pad footing to resist the loads assuming the following material strengths.

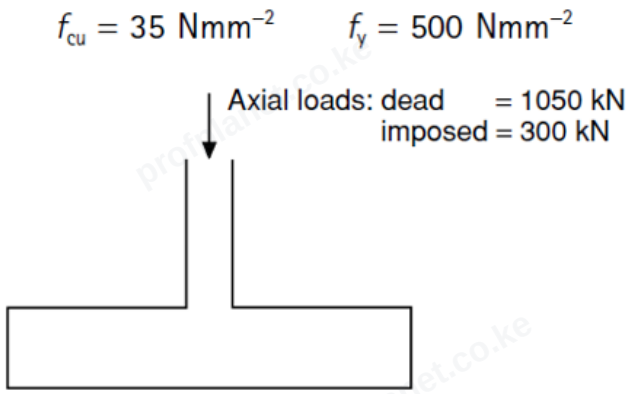


Figure 5

(20 Marks)

14. The selection and use of construction materials play a vital role in ensuring structural safety, durability and cost-effectiveness of a building project.
    a. Explain THREE factors that should be considered when selecting construction materials for a building project. (6 Marks)
    b. Discuss the THREE properties of reinforced concrete as a structural material (6 Marks)
    c. Describe FOUR impacts of improper material selection on the safety, durability and maintenance costs of a structure. (8 Marks)

DESIGN TABLES

Design in reinforced concrete to BS 8110

Table 3.5 Exposure classes related to environmental conditions in accordance with BS EN 206 and BS 8500

Class	*Description of the environment*	*Informative examples where exposure classes may occur*
1. No risk of corrosion		
X0	For concrete with reinforcement or embedded metal: very dry	Concrete inside buildings with very low (around 35%) humidity
2. Corrosion induced by carbonation		
XC1	Dry or permanently wet	Concrete inside building with low air humidity Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact; many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high humidity External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
3. Corrosion induced by chlorides		
XD1	Moderate humidity	Concrete exposed to airborne chlorides
XD2	Wet, rarely dry	Concrete totally immersed in water containing chlorides, e.g. swimming pools Concrete exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides Pavements, car park slabs
4. Corrosion induced by chlorides from sea water		
XS1	Exposed to air borne salt but not	Structures near to or on the coast in direct contact with sea water
XS2	Permanently submerged	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures
5. Freeze/thaw attack		
XF1	Moderate water saturation, without deicing agent	Vertical concrete surfaces exposed to rain and freezing
XF2	Moderate water saturation, with deicing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne deicing agents
XF3	High water saturation, without deicing agent	Horizontal surfaces exposed to rain and freezing
XF4	Moderate water saturation, with deicing agent	Road and bridge decks exposed to deicing agents; concrete surfaces exposed to direct spray containing deicing agents and freezing; splash zone of marine structures exposed to freezing
6. Chemical attack		
ACEC	See *Table 3.8*	Reinforced concrete in contact with the ground, e.g. many foundations

Table for calculating area of reinforcement

Bar size (mm)	Number of bars									
	1	2	3	4	5	6	7	8	9	10
6	28.3	56.6	84.9	113	142	170	198	226	255	283
8	50.3	101	151	201	252	302	352	402	453	503
10	78.5	157	236	314	393	471	550	628	707	785
12	113	226	339	452	566	679	792	905	1020	1130
16	201	402	603	804	1010	1210	1410	1610	1810	2010
20	314	628	943	1260	1570	1890	2200	2510	2830	3140
25	491	982	1470	1960	2450	2950	3440	3930	4420	4910
32	804	1610	2410	3220	4020	4830	5630	6430	7240	8040
40	1260	2510	3770	5030	6280	7540	8800	10100	11300	12600

Table 3.11 Values of design concrete shear stress, υ_c (N/mm^2) for f_{cu} = 25 N/mm^2 concrete (Table 3.8, BS 8110)

$\frac{100A_s}{bd}$	Effective depth (d) mm							
	125	150	175	200	225	250	300	≥ 400
≤ 0.15	0.45	0.43	0.41	0.40	0.39	0.38	0.36	0.34
0.25	0.53	0.51	0.49	0.47	0.46	0.45	0.43	0.40
0.50	0.57	0.64	0.62	0.60	0.58	0.56	0.54	0.50
0.75	0.77	0.73	0.71	0.68	0.66	0.65	0.62	0.57
1.00	0.84	0.81	0.78	0.75	0.73	0.71	0.68	0.63
1.50	0.97	0.92	0.89	0.86	0.83	0.81	0.78	0.72
2.00	1.06	1.02	0.98	0.95	0.92	0.89	0.86	0.80
≥ 3.00	1.22	1.16	1.12	1.08	1.05	1.02	0.98	0.91

Table 3.13 Values of A_{sv}/s_v

Diameter (mm)	Spacing of links (mm)										
	85	90	100	125	150	175	200	225	250	275	300
8	1.183	1.118	1.006	0.805	0.671	0.575	0.503	0.447	0.402	0.366	0.335
10	1.847	1.744	1.57	1.256	1.047	0.897	0.785	0.698	0.628	0.571	0.523
12	2.659	2.511	2.26	1.808	1.507	1.291	1.13	1.004	0.904	0.822	0.753
16	4.729	4.467	4.02	3.216	2.68	2.297	2.01	1.787	1.608	1.462	1.34

Table 3.19 — Values of β for braced columns

End condition at top	End condition at bottom		
	1	2	3
1	0.75	0.80	0.90
2	0.80	0.85	0.95
3	0.90	0.95	1.00

Table 3.16 Modification factors for tension reinforcement (based on Table 3.10, BS 8110)

Service stress	*M/bd²*								
	0.50	*0.75*	*1.00*	*1.50*	*2.00*	*3.00*	*4.00*	*5.00*	*6.00*
100	2.00	2.00	2.00	1.86	1.63	1.36	1.19	1.08	1.01
150	2.00	2.00	1.98	1.69	1.49	1.25	1.11	1.01	0.94
(f_y = 250) 167	2.00	2.00	1.91	1.63	1.44	1.21	1.08	0.99	0.92
200	2.00	1.95	1.76	1.51	1.35	1.14	1.02	0.94	0.88
250	1.90	1.70	1.55	1.34	1.20	1.04	0.94	0.87	0.82
300	1.60	1.44	1.33	1.16	1.06	0.93	0.85	0.80	0.76
(f_y = 500) 323	1.41	1.28	1.18	1.05	0.96	0.86	0.79	0.75	0.72

Note 1. The values in the table derive from the equation:

$$\text{Modification factor} = 0.55 + \frac{(477 - f_s)}{120\left(0.9 + \frac{M}{bd^2}\right)} \leq 2.0 \quad \text{(equation 7)}$$

where
f_s is the design service stress in the tension reinforcement
M is the design ultimate moment at the centre of the span or, for a cantilever, at the support.
Note 2. The design service stress in the tension reinforcement may be estimated from the equation:

$$f_s = \frac{5^*}{8} \times \frac{f_y A_{s,req}}{A_{s,prov}} \times \frac{1}{\beta_b} \quad \text{(equation 8)}$$

where β_b is the percentage of moment redistribution, equal to 1 for simply supported beams.
* As pointed out in Reynolds RC Designers Handbook the term 5/8 which is applicable to γ_{ms} = 1.15 is given incorrectly as 2/3 in BS 8110 which is applicable to γ_{ms} = 1.05.

Table 3.22 Cross-sectional area per metre width for various bar spacing (mm²)

Bar size (mm)	*Spacing of bars*								
	50	*75*	*100*	*125*	*150*	*175*	*200*	*250*	*300*
6	566	377	283	226	189	162	142	113	94.3
8	1010	671	503	402	335	287	252	201	168
10	1570	1050	785	628	523	449	393	314	262
12	2260	1510	1130	905	754	646	566	452	377
16	4020	2680	2010	1610	1340	1150	1010	804	670
20	6280	4190	3140	2510	2090	1800	1570	1260	1050
25	9820	6550	4910	3930	3270	2810	2450	1960	1640
32	16100	10700	8040	6430	5360	4600	4020	3220	2680
40	25100	16800	12600	10100	8380	7180	6280	5030	4190

Values of υ (N/mm²)	*Area of shear reinforcement to be provided*
$\upsilon < 0.5\upsilon_c$ throughout the beam	No links required but normal practice to provide nominal links in members of structural importance
$0.5\upsilon_c < \upsilon < (\upsilon_c + 0.4)$	Nominal (or minimum) links for whole length of beam $A_{sv} \geq \frac{0.4bs_v}{0.87f_{yv}}$
$(\upsilon_c + 0.4) < \upsilon < 0.8\sqrt{f_{cu}}$ or 5 N/mm²	Design links $A_{sv} \geq \frac{bs_v(\upsilon - \upsilon_c)}{0.87f_{yv}}$