هيئة تقويم التعليم والتدريب
Education & Training Evaluation Commission

الهيئة السعودية للمهندسين
SAUDI COUNCIL OF ENGINEERS

Professional Engineering Exam

Structural Engineering

Study Guide

Education and Training Evaluation Commission (ETEC)
National Center for Assessment (NCA)

www.etec.gov.sa

May 2019

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Table of Contents

1. Aim:

The objective of this Instruction Manual is to provide guidelines for the NCA proposed Professional Engineers Exam. These guidelines cover the eligibility conditions, the grading and passing conditions, the structure of the exam and the distribution of exam questions among various areas. In essence, this Instruction Manual represents a “bridge” between the developed exam standards and the actual phrased questions. It is designed to help item writers to prepare questions for the Structural Engineering Discipline Exam as well as a study guide for the examinees.

2. Exam Structure:

2.1 Exam Type

The exam is initially paper-based with questions being a combination of multiple- choice questions (MCQ) and essays.

2.2 Exam Organization

The exam will be conducted in two sessions during one day. The duration of the first session is 2.5 hours while the second section is 4 hours long. There is one-hour break between the two sessions.

2.2.1. Session #1

The first session is the common part to be taken by all the examinees from all disciplines. This part includes seven topics: (Ethics – Professionalism - Laws for Professional Practice, Professional Laws and Regulation - Environment and Natural Resources - Engineering Management - Engineering Economics - Health, Safety & Security (HSS)).

The total duration of this session is 2.5 hours and the total number of questions is 30 MCQ and 2 essays.

2.2.2. Session #2

The second session is the Discipline Part. The following engineering disciplines are considered:

Code	Discipline
STE	Structural Engineering
GTE	Geotechnical Engineering
TRE	Transportation Engineering
WREE	Water Resources and Environmental Engineering
PE	Power Engineering
HVAC	Heating, Ventilation, and Air Conditioning (HVAC) and Refrigeration Engineering
TFSE	Thermal and Fluids Systems Engineering
CHE	Chemical Engineering
FPE	Fire Protection Engineering
ARCH	Architecture

The total duration of this session is 4 hours and the total number of questions is 30 MCQs and 4 essays. The examinee must answer all the MCQs and two essays (one essay is compulsory and one to be chosen out of 3).

2.3 Eligibility for the Exam

The eligibility to register for the Exam is according to the Saudi Council of Engineers (SCE) conditions and requirements.

2.4 Grades

Each part (common part and discipline part) carries a total grade of 100. The MCQs carry a grade of 60% while the essays carry a grade of 40%. Each MCQ has 4 choices for the answer. There is no negative marking for wrong answers.

2.5 Passing Rules

- The eligible candidate must take in his/her first sitting the two exam parts (common part and discipline part).
- In order to pass the exam, the candidate must obtain a grade of 60% or above in each part of the exam.
- If the candidate fails both parts of the exam (by receiving in each part a grade less than 60%), he/she can take two parts of the exam but only when one full year has passed.
- If the candidate fails only one part of the exam (common part or discipline part), he/she must repeat only the part he/she failed, but he/she must pass this part within one year.
- If a year passed and the candidate did not succeed in passing the part he/she failed, then he/she has to take both parts of the exam.

2.6 Exam Rules

- No printed or electronic material is allowed during the exam. All necessary reference materials will be provided by NCA
- Calculators approved by NCA are allowed.
- Comprehensive exam rules will be provided by the examination authority, NCA, in a separate manual.

3. Table of Specifications for Structural Engineering Exam:

Major Area	Multiple Choice Questions (MCQs)		Essay Questions	Engineering Standard
	% of Test	# Q		
1. Structural Analysis	13.33	4	1	STE-T1
2. Structural Materials	13.33	4	1	STE-T2
3. Reinforced Concrete Design	20	6	1 (Compulsory)	STE-T3
4. Prestressed/Post-Tension and Precast Concrete Design	10	3		STE-T4
5. Design of Steel Structures	10	3	1	STE-T5
6. Foundation Design	6.66	2	-	STE-T6
7. Seismic Analysis and Design	6.66	2	-	STE-T7
8. Masonry Structures	6.66	2	-	STE-T8
9. Evaluating, Rehabilitation and Strengthening of Existing Structures	3.33	1	-	STE-T9
10. Temporary Structures	3.33	1	-	STE-T10
11. Quality Assurance and Quality Control	3.33	1	-	STE-T11
12. Codes, Standards and Construction	3.33	1	-	STE-T12
Total	100%	30	One Compulsory and Choose 1 out of 3	

4. Standards for Structural Engineering:

The Engineering Standards for the Structural Engineering Discipline are structured around twelve major areas:

T1. Structural Analysis

T2. Structural Materials

T3. Reinforced Concrete Design

T4. Prestressed/Post-Tension and Precast Concrete Design

T5. Design of Steel Structures

T6. Foundation Design

T7. Seismic Analysis and Design

T8. Masonry Structures

T9. Evaluating, Rehabilitation and Strengthening of Existing Structures

T10. Temporary Structures

T11. Quality Assurance and Quality Control

T12. Codes, Standards and Construction.

Practicing structural engineers are applying above mentioned topics in their field practice during their engineering career. Each of these topics has a number of indicators to ensure that the engineer has the necessary experiences to work as a structural engineering area.

Structural Engineers are expected to possess and demonstrate command of the following Structural Engineering skills:

STE-T1: Structural Analysis

STE-T1-1 Calculate different types of loads (dead, live, wind, and hydrostatic loads) and its effects on various structures according to relevant codes.

STE-T1-2 Identify critical load combinations, and loads patterns for different structural systems for both ultimate and serviceability limits conditions.

STE-T1-3 Identify the maximum effects of moving loads (vehicular and crane loads) on different structural systems using influence lines.

STE-T1-4 Compute the internal forces in determinate beams, frames and trusses subjected to various loading conditions.

STE-T1-5 Evaluate stresses and strains resulted from different loading conditions (axial, shear, flexural, temperature) in various cross sections.

STE-T1-6 Compute combined and principle stresses and their planes at different locations in cross section resulted from different loading conditions.

STE-T1-7 Analyze buckling of columns under application of different end conditions.

STE-T1-8 Calculate displacements and slopes for beams, frames and trusses using numerical and energy methods.

STE-T1-9 Analyze indeterminate structures (beams, frames and trusses) using different methods including both classical and numerical methods.

STE-T2: Structural Materials

STE-T2-1 Recognize the mechanical properties of plain concrete, steel, timber, masonry, and other structural materials.

STE-T2-2 Analyze and interpret test results of steel, concrete, timber and other construction materials.

STE-T2-3 Identify different non-destructive testing methods for evaluating location and size of reinforcement, corrosion issues, location of studs, void and crack locations, etc.

STE-T2-4 Design required concrete mixtures to satisfy design criteria related to strength, durability, required performance and economic constraints.

STE-T2-5 Recognize various factors that affect material strength and durability in a given environment and conditions.

STE-T2-6 Monitor quality control for mixing, handling, placing and curing of concrete.

STE-T2-7 Develop and interpret a coring plan, location of cores, number of cores.

STE-T3: Reinforced Concrete Design

STE-T3-1 Analyze and design of continuous beams for shear and flexure to satisfy both strength and serviceability limit states according to code provisions.

STE-T3-2 Design deep beams and corbels for shear and flexure.

STE-T3-3 Design reinforced concrete short column and slender column with eccentric loading under uniaxial and bi-axial conditions.

STE-T3-4 Design braced and unbraced walls, bearing walls and shear walls.

STE-T3-5 Analyze and design different continuous slab systems (one-way and two-way solid slabs as well as joist slabs) satisfying code provisions for both ultimate and serviceability limit states.

STE-T3-6 Analyze and design different types of stairs and staircases according to code provisions.

STE-T3-7 Analyze and design for splices, bond, anchorage, development length and laps for various structural elements in accordance to code provisions.

STE-T3-8 Analyze and design of water tanks and water sections.

STE-T3-9 Analyze and design of beam-column and slab-support connections.

STE-T3-10 Calculate short and long term beam deflections.

STE-T4: Pre-Tension /Post-Tension and Precast Concrete Design

STE-T4-1 Recognize the different methods for prestressing concrete and its processes.

STE-T4-2 Analyze and design different types of prestressed concrete beams for shear and flexure in buildings and bridges satisfying code provisions.

STE-T4-3 Analyze and design the support systems for prestressed bridge girders.

STE-T4-4 Compute creep, shrinkage, frictional losses, and curvature in prestressed concrete elements.

STE-T4-5 Design of hollow-core slabs.

STE-T4-6 Recognize the importance of connections in precast building constructions and design of connections.

STE-T5: Design of Steel Structures

STE-T5-1 Estimate the strength of different steel elements; beams, columns, beam-columns, compression and tension members according to LRFD concept and code provisions.

STE-T5-2 Evaluate buckling and stability effects of columns and braces in steel design according to code provisions.

STE-T5-3 Design steel beams, and steel columns under different types of loading according to LRFD concept and code provisions.

STE-T5-4 Design and evaluate different types of welded and bolted connections including; shear, moment and bracket connections.

STE-T5-5 Design steel composite beams and columns, as well as evaluate their serviceability requirements according to code provisions.

STE-T5-6 Design base plates for pin and moment conditions.

STE-T6: Foundation Design

STE-T6-1 Recognize soil and rock classifications and boring logs to determine design parameters required in the estimate of ultimate bearing capacity and potential settlements for different supporting grounds.

STE-T6-2 Identify constructionable and economical foundation system for certain ground and structure conditions.

STE-T6-3 Design the various types of shallow foundation, including isolated, combined, and strap footings, and raft foundations.

STE-T6-4 Design of different types of deep foundations involving single piles and pile groups, bridge piers, and drilled shafts.

STE-T6-5 Design of earth retaining and water retaining walls, sheet pile and basement walls according to the site and structure characteristics.

STE-T7: Seismic Analysis and Design

STE-T7-1 Evaluate the dynamic properties of structures using simple classical methods.

STE-T7-2 Evaluate seismic forces, and its distributions in design of buildings and structures according to code provisions.

STE-T7-3 Identify the different factors that affect the earthquake loading on buildings.

STE-T7-4 Recognize the different structural systems and favorable arrangement of structural elements for resisting earthquake loading in different seismic regions and soil conditions according to code provisions.

STE-T7-5 Evaluate the effects of vertical seismic and seismic orthogonal components, and recognize its applications.

STE-T7-6 Recognize the concept and design procedure for earthquake resistant structural members according to code provisions.

STE-T8: Masonry Structures

STE-T8-1 Analyze and design unreinforced bearing walls according to code provisions.

STE-T8-2 Analyze and design reinforced bearing walls including all reinforcement and grouting details according to code provisions.

STE-T8-3 Analyze and design of wall-ties to accommodate differential tolerance differences and movements caused by loads applied on frame and floor elements.

STE-T8-4 Evaluate empirical design of masonry walls.

STE-T8-5 Analyze and design anchorage of masonry walls.

STE-T8-6 Monitor the Quality Control Program for insure grout and reinforcement placement as per specifications.

STE-T8-7 Design reinforced walls under shear and bending conditions.

STE-T8-8 Design of lintels and arches.

STE-T9: Evaluating, Rehabilitation and Strengthening Existing Structures

STE-T9-1	Review the processes and methods used in evaluating existing buildings and evaluate different structural elements that might require rehabilitation, with any needed in-situ testing, measurements and documentation.
STE-T9-2	Identify different materials used in strengthening different structural elements, including properties and range of applications.
STE-T9-3	Identify different types of cracks in different concrete elements (Slabs, beams, columns, walls, and foundation) with their causes based on the available information.
STE-T9-4	Identify the appropriate method of strengthening for different concrete structural elements based on available information and constraints.
STE-T9-5	Review the process and methods of strengthening and rehabilitate different structural elements with any required safety measures.
STE-T9-6	Review the safety requirements of a structure or a portion satisfying the Code provisions.

STE-T10: Temporary Structures

STE-T10-1	Conduct and report special site inspections, follow-up deadlines and deliverables submittals.
STE-T10-2	Review safety and design of scaffolding, formwork, and non-permissible works.
STE-T10-3	Monitor shoring of structures including multi-story construction and reshoring safely.
STE-T10-4	Review and monitor bracing and anchorage in the structural systems.
STE-T10-5	Implement safety management system in place including required fire and safety measures.
STE-T10-6	Identify the load factors and combinations for temporary structures.

STE-T11: Quality Assurance and Quality Control

STE-T11-1	Demonstrate quality assurance and control of data, drawings and designs.
STE-T11-2	Establish material's quality assurance and control in accordance to the standard specifications.
STE-T11-3	Maintain sampling, analysis and test methods as per recommended specifications.
STE-T11-4	Recognize acceptable criteria within the limits of tolerance as per specifications.

STE-T11-5 Establish procedures to make sure handling non –conformance works and methods have been properly addressed.

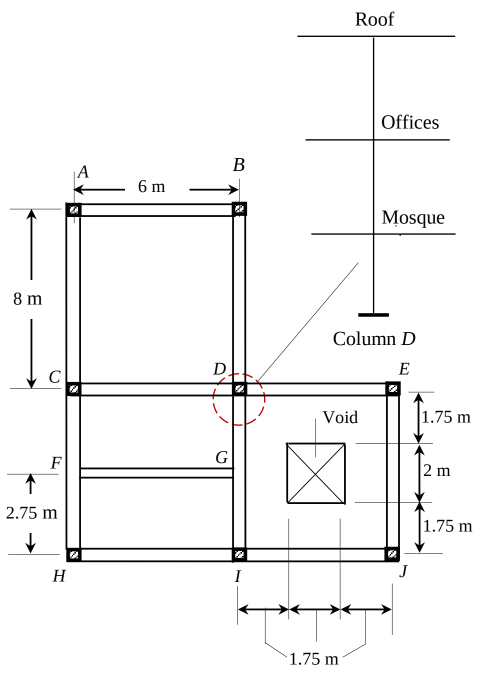
STE-T12: Codes, Standards and Construction

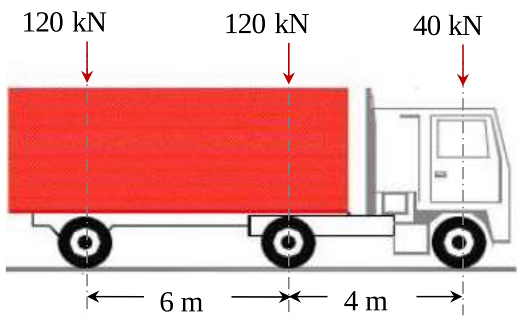
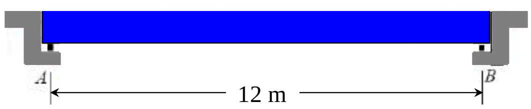
STE-T12-1 Recognize the importance of building codes, specifications, requirements and limitations, especially SBC and ACI Codes, in the RC design process and related areas.

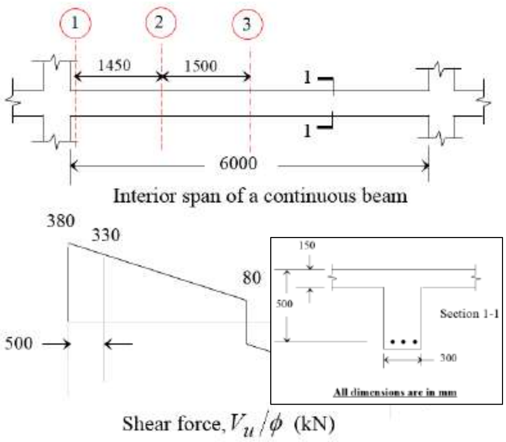
STE-T12-2 Recognize codes, standards and guidance documents:

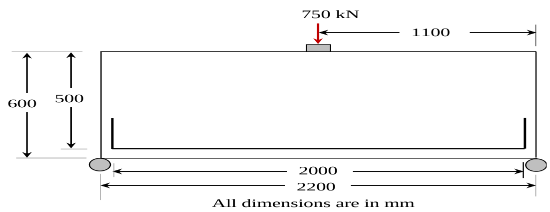
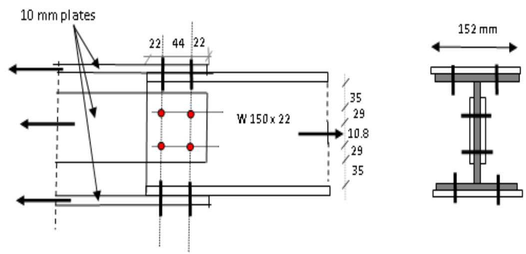
- SBC 201 - Saudi Building Code - General (Equivalent to International Building Code – IBC 2015).
- SBC 301 - Loading (Equivalent to Minimum Design Loads for Buildings and Other Structures (ASCE 7-14).
- SBC 302 – Construction (Equivalent to various ACI Technical Specifications and covering part of Occupational Safety and Health Administration (OSHAA) Regulations - OSHA 1926 Construction Safety Standards).
- SBC 303 – Soils and Foundations (Equivalent to IBC2015)
- SBC 304 - Concrete Structures (Equivalent to American Concrete Institute (ACI 318-14).
- SBC 305 - Saudi Masonry Code (Equivalent to Joint Committee TMS 402/ACI 530/ASCE 5 Building Code Requirements for Masonry Structures 2013).
- SBC 306 - Steel (Equivalent to AISC 360 Specification for Structural Steel Buildings and AISC 341 Seismic Provisions for Structural Steel Buildings – 15th Edition).
- Ministry of Municipal and Rural Affairs (MOMRA) Bridges Design Specifications (Equivalent to LRFD Bridge Design Specifications (AASHTO)).
- SBC not available for the following
- Precast/Prestressed Concrete Institute (PCI Design Handbook – 8th Edition).
- AISC Manual –Steel Construction Manual – 15th Edition.

5. Sample Questions Table

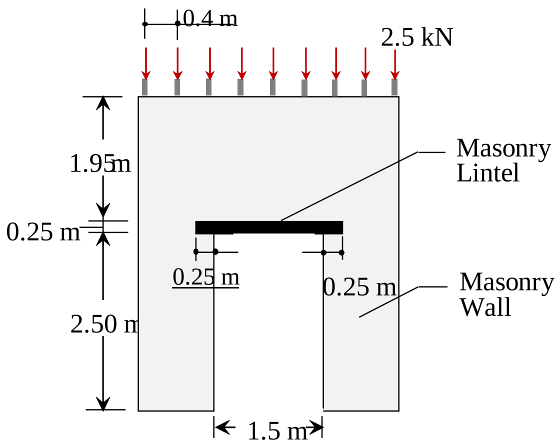
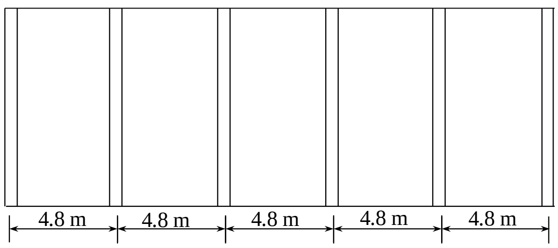
Q. No.	Major Area	EA Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
1	**Structural Analysis**	STE-T1-1	The floor plan shown in figure is a typical plan for a three-story building (the use of its various floors are as indicated). Using the guidelines of SBC 301-18 considering the roof live load is 1.0 kN/m^2, and only the floor's live uniform loads are considered, the total reduced live load on column D (in kN) at ground floor is most nearly: A) 267 B) 246 C) 228 D) 206 Note: 1- No live load reduction for roof. 2- Take KLL= 4 	(D)	4 - 5	Reference Sheet # 1

Q. No.	Major Area	EA Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
2	**Structural Analysis**	STE-T1-3	The standard truck shown in figure moves from left to right direction over the shown simply supported girder. Loads of the intermediate and back axles of the truck are 120 kN, and the load of the front axle is 40 kN. Assume weight of girder is negligible, the absolute maximum moment (in kNm) of the bridge girder is most nearly: A) 400 B) 425 C) 450 D) 475   	(B)	6 - 8	None
3	**Structural Materials**	STE-T2-4	A reinforced concrete loading dock is to be casted against existing soil which is directly in contact with the Sea bed. The geotechnical report states that the sub-soil contains water-soluble sulfate (SO_4^{2-}) of 0.9% (by mass). The minimum required concrete compressive strength (in MPa), maximum allowed water to cementitious material (w/cm) ratio and the type of cement that is required, respectively, for this concrete shall be: A) 28 MPa, 0.50 and Cement Type V. B) 31 MPa, 0.45 and Cement Type V. C) 31 MPa, 0.45 and Cement Type V + pozzolan or slag cement. D) 35 MPa, 0.40 and Cement Type I + pozzolan or slag cement.	(D)	4 - 5	Reference Sheet # 2

Q. No.	Major Area	EA Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
4	**Reinforced Concrete Design**	STE-T3-1	An Interior span of a continuous beam is as shown in figure. If the clear span of the beam is 6 m, design shear force ($V_u/\emptyset$) at the face of support is 380 kN and effective depth of the beam is 500 mm. The required spacing of stirrups (in mm) for beam interval between section 1 and 2 is: A) 250 B) 200 C) 150 D) 100 Given: Concrete is normal-weight and having a compressive strength, f_c', of 30 MPa. Use 10 mm double leg vertical stirrups, and f_{yt} = 280 MPa (Yield strength of stirrups). 	(D)	6 - 8	Reference Sheet # 3
5	**Reinforced Concrete Design**	STE-T3-2	The figure below shows a simply supported reinforced concrete beam with a span of 2.2 m, effective depth of 0.5 m and the overall depth of 0.6 m. The beam is subjected to a concentrated factored load including it's self-weight of 750 kN applied at it's mid-span. The area of tension reinforcement (in mm^2) is nearly: A) 2380 B) 2360 C) 2280 D) 2260 Given: Reinforcing steel is grade 420 (f_y=420 MPa)	(A)	4 - 5	Reference Sheet # 4

Q. No.	Major Area	EA Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
						
6	**Prestressed and Precast Concrete Design**	STE-T4-4	A pre-tensioned prestressed concrete beam is expected to have ultimate shrinkage strain $\varepsilon_{sh,u}$ of concrete after 5 years as 0.0008. The modulus of elasticity (E_p) of its tendons is 2×10^5 MPa. If the ratio of shrinkage strain ε_{sh} (after 28 days of transfer) to the ultimate shrinkage strain $\varepsilon_{sh,u}$ is 0.6, the loss of prestress (in MPa) due to shrinkage of concrete is: A) 24 B) 48 C) 96 D) 120	(C)	3 - 4	None
7	**Design of Steel Structures**	STE-T5-1	The shown bolted steel connection is connecting W 150 x 22 with two plates at its top and bottom flanges in addition to two plates at web as shown in the figure. All plates are 10 mm thickness and all bolts are 16 mm A325 Bolts. According to SBC 306 , the factored tensile strength (in kN) of the W Shape section based on the fracture at effective area is mostly nearly to: A) 536 B) 638 C) 646 D) 685 	(B)	4 - 5	Reference Sheet # 5

Q. No.	Major Area	EA Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
			Given: The steel grade is A36 (F_y=250 MPa, F_u=400 MPa). For W 150 x 22 A= 2850 mm^2; flange width= 152 mm, flange thickness = 6.6 mm, Depth = 152 mm, Web thickness = 5.80 mm, hole diameter = 19 mm			
8	**Foundation Design**	STE-T6-3	In a rectangular footing, the reinforcement in the short direction is placed in three bands with a closer bar spacing in the band under the column than in the two end bands. If the size of the footing is 2.3 m × 4.6 m and number of bars of 20 mm size needed in the short direction is 21. The number of bars required in the middle strip/band are: A) 5 B) 7 C) 14 D) 21	(C)	3 - 4	Reference Sheet # 6
9	**Masonry Structures**	STE-T8-8	The 200 mm × 250 mm × 2000 mm masonry reinforced lintel shown in the figure is used to support a partition wall for 1.5m door opening. The bearing lengths of the lintel on the wall are 250 mm at each end. The height and thickness of the partition above the lintell are 1.95 m and 200 mm, respectively. The wall supports equally spaced (at 400 mm c/c) purlins with 2.5 kN load for each. Consider the arching action for the wall above the lintel, the maximum service moment (in kN.m) in the lintel is nearly: A) 1.1 B) 1.3 C) 1.5 D) 1.7 Given: The unit weight of the wall = 20 kN/m^3 The unit weight of the reinforced lintel =23 kN/m^3	(B)	4 - 5	None

Q. No.	Major Area	EA Code	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
			 			
10	**Codes, Standards and Construction**	SE-T12-2	A five-span one-way slab is supported on 300 mm wide beams with center-to-center spacing of 4.8 m. Assuming partitions are not sensitive to deflections, the minimum uniform thickness of the slab (in mm) as per SBC 304-18 is: A) 200 B) 180 C) 160 D) 140  Plan	(A)	3 - 4	Reference Sheet # 7

Essay Questions

Essay Question # 1

Topic Area: Reinforced Concrete Design

Expected Time: 25-35 min

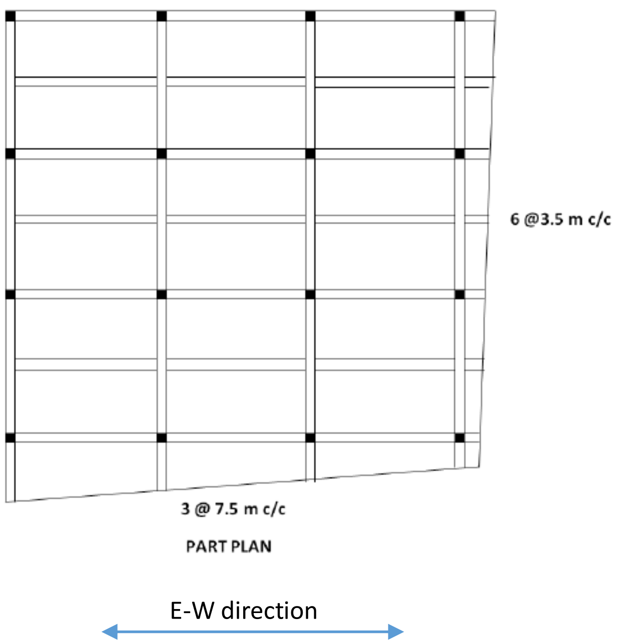
Reference Sheet # 8

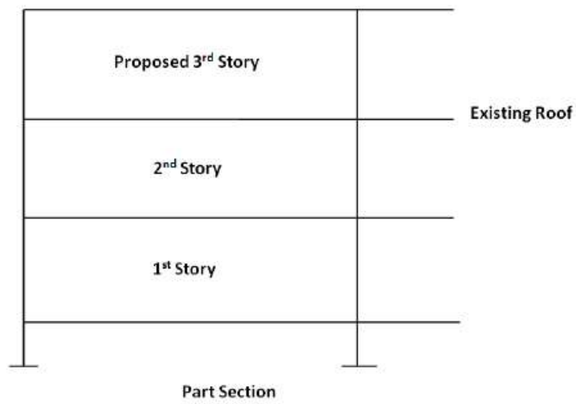
Roof plan of a two-story existing reinforced concrete building is shown in the figure. The Owner wants to add one more story (Third story) and use the existing roof for commercial purpose.

Based on the following data and according to SBC 301, and SBC 304, compute the maximum live load that the Existing Roof can sustain for the following Criteria:

a) Flexural strength of slab by considering only the bottom slab reinforcement.

b) Shear strength of main beams connecting columns in E-W Direction.





Given Data:

Existing Construction:

All Slabs 150 mm thick

All Beams and Girders are 350x700 mm

All Columns are 350x350 mm

f_c' = 21 MPa, f_y = 420 MPa for flexure and 280 MPa for shear reinforcement

Concrete Density = 25 kN/m^3

Superimposed Dead Load = 2.5 kN/m^2

Consider a wall load of 3.0 kN/m^2 and wall height 2.8m on main beams connecting columns.

Consider the following factored load combination; 1.4D + 1.7 L

Consider the discontinuous ends of slabs are integrally casted with beams

Slab reinforcement	Beam reinforcement (All beams in E-W dir. except peripheral beams)
ϕ 10 at 300 mm on center, bottom	5ϕ 16, bottom
ϕ 10 at 250 mm on center, top at supports	5ϕ 20, top at supports
Clear cover= 20 mm	10ϕ8 per meter (stirrups)
	Clear cover= 40 mm

Essay Question # 2

Topic Area: Design of Steel Structures

Expected Time: 25-30 min

Reference Sheet # 9

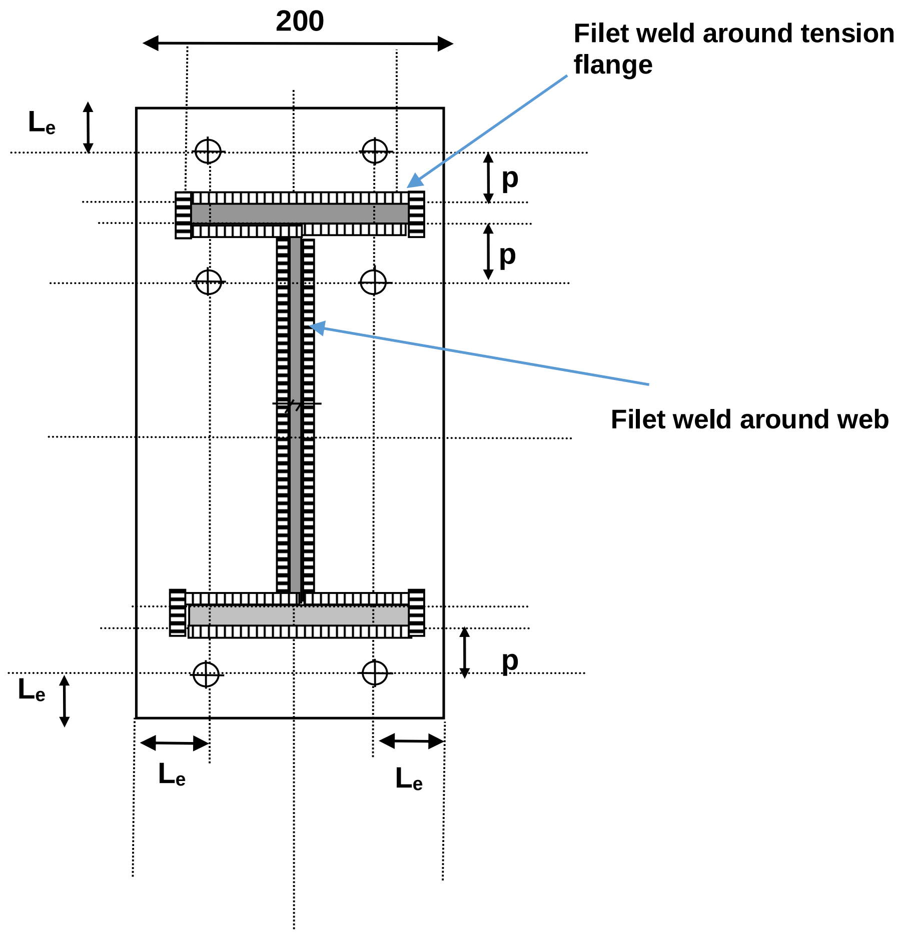
A beam with section W 460x60 needs to be connected to a column with an extended end-plate connection with 4 bolts at tension side and 2 bolts at compression side, as shown in the figure. The connection needs to be slip critical connection with μ=0.50 and using standard holes. The end plate width is taken 200mm, and the edge distance (L_e) = 30mm, and Pitch (p) =50mm. Use A325 bolts with F_{ub} = 620 MPa and F_{vb}= 400 MPa, while the electrode strength F_{EX} = 500 MPa. The end plate is steel grade A36 (Fy =250 MPa)

The splice needs to be designed to resist factored negative moment = 200 kN.m, and factored shear = 300 kN. Use minimum weld size is 6 mm.

a) Determine the A325 bolt diameter used to resist the tension force
b) Check the slip critical strength of the connection
c) Check the shear strength on the bolts
d) Determine the required weld size around the tension flange
e) Determine the weld size around the web to resist the shear (consider the effective length of weld is 214.2 mm)
f) Determine the required end plate thickness.

For W 460 x 60; depth (d) = 455 mm, flange thickness (t_f) = 13.3 mm, web thickness (t_w) = 8.0 mm, Flange width (b_f) = 153 mm

Hint: use even numbers for bolts diameter, weld sizes and plate thicknesses


200
Filet weld around tension flange
L_e
p
p
Filet weld around web
p
L_e
L_e
L_e

Answers Guide for Sample Questions MCQs

Question # 1

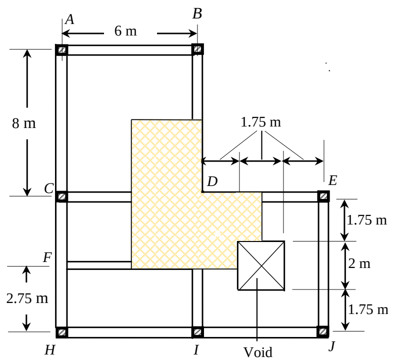
Topic Area: Structural Analysis.

HVAC-T1-02 STE-T1-1 identify various loads and load applications supported by structural elements.

Answer: D

Reference Sheet: # 1

Solution:

Reference SBC 301-07	Calculations
4.9.1	No reduction is permitted on the public assembly of special use (mosque) and for the roof live load.
	As shown in the figure, the tributary area for column *D* $A_T = 3(4 + 2.75) + 1(1.75) + 1.75(2.625) = 26.6\ \text{m}^2$ 
Table 4-3	$k_{LL} = 4$
4.8.1	$\Longrightarrow k_{LL}A_T = (4)(26.6) = 106.4\ \text{m}^2 > 37.0\ \text{m}^2 \Longrightarrow \text{reduction is permitted}$
	Live load on roof =1.0 kN/m^2 (Given)
Table 4-1	Unreduced live load on offices floor =2.5 kN/m^2 Live load on mosque floor=5.0 kN/m^2
Eq. 4-1	the reduced live load on offices floor, $L = L_o\left(0.25 + \frac{4.57}{\sqrt{k_{LL}A_T}}\right) = 2.5\left(0.25 + \frac{4.57}{\sqrt{4(26.6)}}\right) = 1.73\ \text{kN/m}^2$ Check that L =1.73 > 0.5 (2.5) =1.25 kN/m^2 O.K
	Therefore, the total reduced uniform live load on column *D* at ground floor = 26.6 (1.0+1.73+5) = 205.6 kN (*Ans.*)

Question # 2

Topic Area: Structural Analysis.

Indicator:

STE-T1-3 Compute the internal forces in determinate beams, frames and trusses subjected to various loading conditions

Answer: B

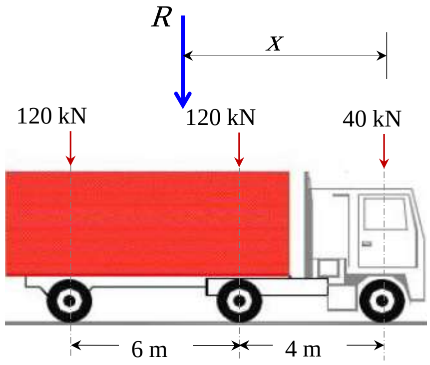
Reference Sheet: None

Solution:

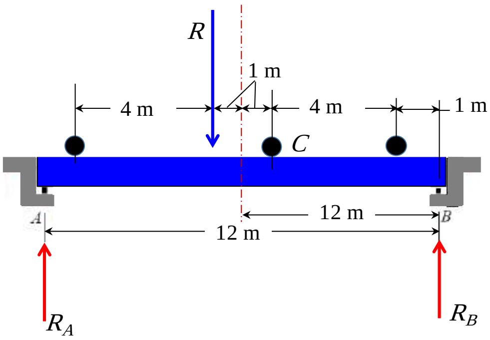
Location of the resultant load of the truck.

$$\boldsymbol{R = 120 + 120 + 40 = 280\ \mathrm{kN}}$$

$$\boldsymbol{X = \frac{120 \times 10 + 120 \times 4}{280} = 6\ \mathrm{m}}$$



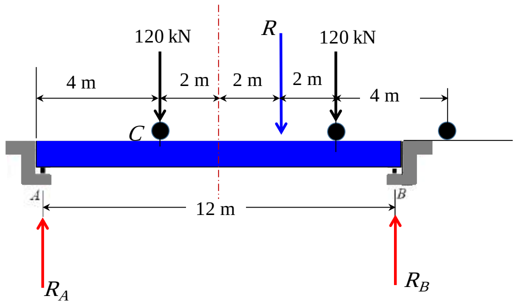
Case A.



$$\boldsymbol{CCW(+) \sum M_A = 0 \Rightarrow R_B = \frac{280 \times 5}{12} = 116.7\ \mathrm{kN}}$$

$$\boldsymbol{\Rightarrow M_C = 116.7 \times 5 - 40 \times 4 = 423.5\ \mathrm{kNm}}$$

Case B.



$$\boldsymbol{CCW(+) \sum M_B = 0 \Rightarrow R_A = \frac{120 \times (2 + 8)}{12} = 100\ \mathrm{kN}}$$

$$\boldsymbol{\Rightarrow M_C = 100 \times 4 = 400\ \mathrm{kNm}}$$

Therefore, the maximum moment is 423.5 kNm (*Ans.*)

Question # 3

Topic Area: Structural Materials

Indicator:

STE-T2-4 Design required concrete mixtures to satisfy design criteria related to strength, durability, specific performance, and economical constraints

Answer: D

Reference Sheet: # 2

Solution:

Exposure categories and classes (SBC 304-18 - Table 19.3.1.1)

1. Freezing and Thawing: Not relevant
2. Sulfate (S) is S2: 0.2% ≤ $SO4^{2-}$ ≤ 2.0%

Corrosion protection of reinforcement (C) is C4: Concrete in coastal areas exposed to moisture and an external source of chlorides from seawater.

Requirements for concrete by exposure class (SBC 304-18 - Table 19.3.2.1)

For S2, Minimum $f'c$ of 31 MPa, w/cm is 0.45, Cement Type V

For C4, Minimum $f'c$ of 35 MPa, w/cm of 0.40, Cement Type I + pozzolan or slag cement

The engineer must select the worst condition; (D) is the correct answer.

Question # 4

Topic Area: Reinforced Concrete Design
Indicator:
STE-T3-1 Analyze and design of continuous beams for shear and flexure to satisfy both strength and serviceability limit states according to code provisions
Answer: D
Reference Sheet: # 3
Solution:

Reference (SBC 304-18)	Calculations
	Checking the adequacy of the cross-sectional dimensions to be designed for shear
Eq. 22.5.6.1	Assuming $N_u = 0$ $V_c = 0.17\sqrt{f_c'} b_w d = 0.17\sqrt{30}(300)(500) \times 10^{-3} = 136.7 \text{ kN}$
Cl. 9.6.3.1	$\left(\frac{V_u}{\emptyset}\right) = 330 \text{ kN} > 0.5V_c = 68.4 \text{ kN} \Longrightarrow \text{stirrups are required}$
	Design of stirrups for the interval 1-2.
	Maximum spacing S^1_{max} , $3V_c = 410.1 \text{ kN} > \left(\frac{V_u}{\emptyset}\right) = 330 \text{ kN}$ $S^1_{max} = \text{Min}[0.5d, 500\,] = Min[0.5(500),500] = 250 \text{ mm}$ Maximum spacing S^2_{max}, $A_v = 2 \times \frac{\pi}{4} \times 10^2 = 157 \text{ mm}^2$
Table 9.7.6.2.2	$s^2_{max} = \text{Min}\left[\left(\frac{16}{\sqrt{f_c'}}, 3\right)\frac{A_v f_{yt}}{b_w}\right] = \text{Min}\left[\left(\frac{16}{\sqrt{30}}, 3\right)\frac{157\times280}{300}\right]$ $= \text{Min}\left[(2.92, 3)\frac{157 \times 280}{300}\right] = 428 \text{ mm}$
Cl. 22.5.10.1	$S^3_{max} = \frac{A_v f_{yt} d}{\left(\frac{V_u}{\emptyset} - V_c\right)} = \frac{(157)(280)(500)}{(330 - 136.7) \times 10^3} = 113.7 \text{ mm}$
	$\text{S} = \text{Min}[S^1_{max}, S^2_{max}, S^3_{max}\,] = \text{Min}[250,428,113.8\,] = 113.7 \text{ mm}$ Use Ø10 double leg stirrups at 100 mm c/c (Ans.)

Question # 5

Topic Area: Reinforced Concrete Design

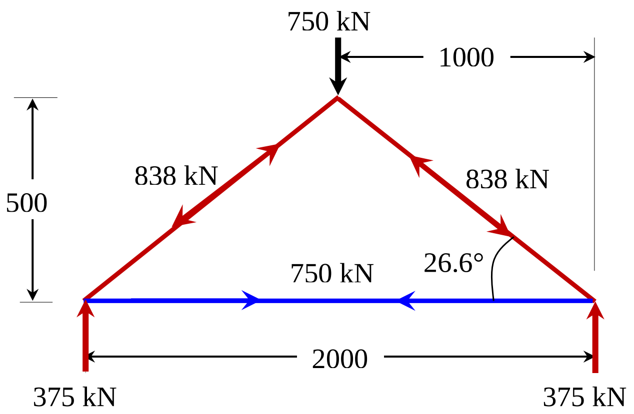
Indicator:

STE-T3-2 Design deep beams and corbels for shear and flexure

Answer: A

Reference Sheet: # 4

Solution:

Reference (SBC 304-18)	Calculations
9.9.1.1.	$\frac{\text{clear span}}{\text{depth}} = \frac{2200}{600} = 3.67 < 4 \implies \text{the beam is "deep"}$
	Using the strut-tie model (shown in the figure) The tension force of reinforcement = 750 kN 
Table 21.2.1	The strength reduction factor, $\emptyset = 0.75$
	$A_s = \frac{T}{\emptyset f_y} = \frac{750 \times 10^3}{0.75 \times 420} = 2381 \text{ mm}^2$ $(Ans.)$

Question # 6

Topic Area: Prestressed and Precast Concrete Design

Indicator:

STE-T4-4 Compute creep, shrinkage, frictional losses, and curvature in prestressed concrete elements.

Answer: C

Reference Sheet: None

Solution:

	Calculations
	$\frac{\varepsilon_{sh}}{\varepsilon_{sh,u}} = 0.6 \Rightarrow \varepsilon_{sh} = 0.6 \times 8 \times 10^{-4} = 4.8 \times 10^{-4}$ Loss of prestress due to shrinkage of concrete: $\Delta f_{sh} = \varepsilon_{sh} E_p = 4.8 \times 10^{-4} \times (2 \times 10^5) = 96$ MPa (*Ans.*)

Question # 7

Topic Area: Design of Steel Structures

Indicator:

STE-T5-1 Estimate the strength of different steel elements; beams, columns, and tension members

Answer: B

Reference Sheet: # 5

Solution:

Factored tensile strength based on fracture at effective area ; $\phi R_n = \phi\ A_e . Fu$

$\phi = 0.75$, $A_e = U. A_{net}$; U = 1.0 for case of all section elements are connected

Hole diameter =19 mm

$A_{net} = 2850 - 4 \times (19 \times 6.6) - 2(19 \times 5.80) = 2128\ mm^2$

$\phi Rn = \phi\ Ae . Fu = 0.75 \times 2128 \times 400 \times 10^{-3} = 638.4$ kN *(Ans.)*

Therefore the answer is B

Question # 8

Topic Area: Foundation Design

Indicator:

STE-T6-3: Design the various types of shallow foundation, including isolated, combined, and strap footings, and raft foundations.

Answer: C

Reference Sheet: # 6

Solution:

Reference SBC 304-18	Calculations
Section 13.3.3.3	$$\beta = \frac{Long\ side\ of\ the\ footing}{Short\ side\ of\ the\ footing} = \frac{4.6}{2.3} = 2$$ $$Width\ of\ the\ middle\ band = 2.3\ m$$ Number of bars in the middle band = $\frac{2}{\beta+1} \times 21 = \frac{2}{3} \times 21 = 14\ \ bars$ (*Ans.*)

Question # 9

Topic Area: Masonry Structures

Indicator: STE-T8-8 Design of lintels and arches

Answer: B

Reference Sheet: None

Solution:

The effective span of the lintel, L_e, is the distance center-t-center of bearing points

$$L_e = 1.5 + 0.25 = 1.75 \text{ m}$$

Height of the wall above the lintel =1.95 > L_e,

Therefore, the arch action governs loading (i.e. no effect of purlins) on the lintel.

Thus, the lintel carries a rectangular self-weight and triangle wall load.

- Self-weight, $w_1 = 0.2 \times 0.25 \times 23 = 1.15 \text{ kN/m}$
- Wall load, $w_2 = 0.2 \times \frac{1.75}{2} \times 20 = 3.5 \text{ kN/m}$
- The maximum moment on the simply supported lintel is,

$$M_{max} = \frac{w_1 L_e^2}{8} + \frac{w_2 L_e^2}{12} = \frac{1.15 \times 1.75^2}{8} + \frac{3.5 \times 1.75^2}{12} = 1.33 \text{ kNm} \qquad (Ans.)$$

Question # 10

Topic Area: SE-T12: Codes, Standards and Construction

Indicator:

SE-T12-2 Codes, standards and guidance documents

Answer: A

Reference Sheet: # 7

Solution:

Reference SBC 304-18	Calculations
Table 7.3.1.1	End bay: Min $h = \frac{l}{24} = \frac{4800}{24} = 200$ mm Interior bay: Min $h = \frac{l}{28} = \frac{4800}{28} = 171.4$ mm Take higher of the above values, $h = 200$ mm (*Ans.*)

Essay Question

Essay Question # 1

Topic Area: Reinforced Concrete Design

Reference Sheet: # 8

Solution:

Adequacy of Existing Roof:

1- Flexural Strength of Slab (Bottom Reinforcement)

Given Ø 10 @ 300 mm c/c (Bottom); As =262 mm2/m

h = 150 mm; f'c = 21 MPa, fy = 420 MPa for flexural reinforcement and = 280 MPa for Shear reinforcement

Effective depth d = 150-20-10/2 = 125 mm; b = 1000 mm

Assuming εs > εy

εy = 0.002 SBC 304 21.2.2.1

a = As x fy / (0.85 x f'c x b) = 262 x 420 / 0.85 x 21 x 1000 = 6.164 mm

Determine net tensile strain εs and ϕ

C = a / β1 = 6.164 / 0.85 = 7.251 mm SBC 304 Table 22.2.2.4.3

εs = 0.003 x (125-7.251)/ 7.251 = 0.0487 >> 0.004 SBC 304 9.3.3.1

Therefore section is tension controlled and ϕ = 0.9 SBC 304 21.2.1 and Table 21.2.1

ϕ Mn = ϕ x As x fy (d – a/2) = 0.9x262x420x(125-6.164/2) = 12,074,271 N-mm = 12.07 kN-m/m

Loads:

Dead Loads: For 1 m wide slab strip

Slab self wt. = 0.15 x 25 kN/m3 = 3.75 kN/m2

Superimposed dead load = 2.5 kN/m2 (Given)

Total D.L =3.75 + 2.5 = 6.25 kN/m2

Live Load: Need to find out L.L ?

wus = Ultimate load for a 1 m wide slab strip

wus = 1.4 D.L + 1.7 L.L = 1.4 x 6.25 + 1.7 x L.L = 8.75 + 1.7 L.L

ln = 3.5-0.35 = 3.15 m

Critical Ultimate Positive Moment = Mu = wus x ln2 /14 SBC 304 6.5.2 and Table 6.5.2

= 0.70875 wus

Mu ≤ ϕ Mn **SBC 304 9.5.1**

= 0.70875 wus = 12.07 kN-m/m

= 0.70875 (8.75 + 1.7 L.L) = 12.07

L.L = 4.87 kN/m2

2. Shear Strength of Main Beams:

Shear Capacity → Vn = Vc + Vs **SBC 304 22.5.1.1**

f'c = 21 MPa, fy = 280 MPa

Effective depth d = 700 - 40 -8-16/2= 644 mm,

bw = 350 mm, ln = 7.5 - 0.35 = 7.15 m

Vc = 0.17 x 350 x 644 x √ 21 = 175595 N = 175.6 kN (Given Equation in Reference)

Vs = Av x fy x d / s = ((π (〚8)〛 ^2)/4 x 2)280 x 644/100 = 181.2 kN SBC 304 22.5.10.5.3

Vn = 175.6 + 181.2 = 356.8 kN

φ Vn = 0.75 x 356.8 = 267.6 kN **SBC 304 21.2.1 and Table 21.2.1**

Vu = 1.15 x wub x ln/2 = 4.11125 x wub **SBC 304 6.5.4 and Table 6.5.4**

Vu @ d = 4.11125 x wub – 0.644 x wub= 3.4685 wub

wub = Ultimate load on beam;

Vu ≤ ϕ Vn **SBC 304 9.5.1.1**

3.4685 wub = 267.6 kN

wub = 77.15 kN/m

Load on Beam:

From Slab = wus x 3.5

Self wt. of beam, Factored = 0.35 x (0.7-0.15) x 25 x 1.4 = 6.74 kN/m

Wall load, Factored = 3 x 2.8 x 1.4 = 11.76 kN/m

Total Ultimate load on Beam = wus x 3.5 + 6.74 + 11.76 = wus x 3.5 + 18.5

wus = 8.75 + 1.7 L.L (From Slab)

Total Ultimate load on Beam = 3.5 x (8.75 + 1.7 L.L) + 18.5 = 49.125 + 5.95 L.L

Now equating 49.125 + 5.95 L.L = 77.15

Solving equation gives L.L = 4.71 kN/m2

Therefore, from the given criteria, maximum live load the existing roof can support is the least of 4.87 kN/m2 as obtained from beam flexural strength, and 4.71kN/m2 as obtained from beam shear strength.

Therefore the maximum allowed live load L.L = 4.71 kN/m2

Essay Question # 2

Topic Area: Design of Steel Structures

Reference Sheet: # 9

Solution:

a) Determine the A325 bolt diameter used to resist the tension force

For W 460x60, d= 455 mm, t_f = 13.3 mm, t_w = 8.0 mm, b_f = 153 mm

$P_f = (200 \times 1000) / (455 - 13.3) = 452.8$ kN

$\phi R_n = 0.75 \times A_b \times F_{ub} \times N_b > P_f$

$= 0.75 \times (\pi d_b^2) /4 * 620 * 4 > 452.8 \times 10^3$

$d_b > 17.6$ mm , choose $d_b = 18$ mm

b) Check the slip critical strength of the connection.

$\phi R_n = \phi \times 1.13 \times \mu (0.7 A_b \times F_{ub}) \times N_b \times N_s$

$= 1.0 \times 1.13 \times 0.5 \times \{0.7 \times (\pi *18^2) /4 \times 620 \} \times 6 \times 1 \times 10^{-3} = 374$ kN > 300 kN

∴ Safe

c) Check the shear strength on the bolts

$\phi R_n = \phi \times A_b \times F_{vb} \times N_b \times N_s$

$= 0.75 \times (\pi *18^2) /4 \times 400 \times 6 \times 1 \times 10^{-3} = 457.8$ kN > 300 kN ∴ Safe

d) Determine the required weld size around the tension flange.

$\phi R_n = \phi \times 0.6 F_{EX} \times L_w \times 0.707 \times S_w > P_f$

$L_w = 2 \times(153 +13.3) - 8 = 324.6$ mm

$\phi R_n = 0.75 \times 0.6 \times 500 \times 324.6 \times 0.707 \times S_w > 452.8 \times 10^3$

$S_w > 8.77$ mm , therefore choose weld size = 10 mm

f) Determine the weld size around the web to resist the shear

$L_w = 455 /2 – 13.3 = 214.2$ mm

$\phi R_n = \phi \times 0.6 F_{EX} \times 0.707 S_w \times 2 L_w > 300 \times 10^3$

$0.75 \times 0.6 \times 500 \times 0.707 \times S_w \times 2 \times 214.2 > 300 \times 10^3$

$\therefore$ $S_w > 4.4$ mm ; Therefore use $S_w = 6$ mm

g) Determine the required end plate thickness.

$\alpha_m = C_a \,.\, C_b \,.\, (A_f/A_w)^{1/3} \,.\, (p_e/d_b)^{1/4}$. Plate width $b_{p\,eff} = b_f + 25 = 153 + 25 = 178$ mm

$Ca = 1.38$, $C_b = (b_f/b_p)^{1/2}$, $C_b = (153 / 178)^{1/2} = 0.927$,

$(A_f/A_w)^{1/3} = \{153 \times 13.3 / (455 - 2 \times 13.3) \times 8\}^{1/3} = 0.8388$

$p_e = 50 - 18/4 - 0.707 \times 10 = 38.4$ mm

$\alpha_m = 1.38 \times 0.927 \times 0.8388 \times (38.4/ 18)^{1/4} = 1.297$

$M_{eu} = \alpha_m \; P_f \,.\, p_e / 4 = 1.297 \times 452.8 \times 1000 \times 38.4 / 4 = 5637{,}608$ N.mm

$t_{ep} = \{ 4\, M_{eu}/ \phi\, F_y \,.\, b_p\}^{1/2} = \{ 4 \times 5637{,}608 / 0.9 \times 250 \times 178 \}^{1/2} = 23.73$ mm

Therefore choose plate thickness = 24 mm

Reference Sheets

Reference Sheet # 1: for Question # 1

TABLE 4-1:
MINIMUM UNIFORMLY DISTRIBUTED LIVE LOADS, L_o,
AND MINIMUM CONCENTRATED LIVE LOADS

Occupancy or Use	Uniform kN/m^2	Conc. kN
Apartments (see residential)		
Access floor systems		
Office use	2.5	9
Computer use	5	9
Armories and drill rooms	7.5	
Assembly areas and theaters		
• Fixed seats (fastened to floor)	3	
• Lobbies	5	
• Movable seats	5	
• Platforms (assembly)	5	
• Stage floors	7.5	
Balconies (exterior)	5	
On one- and two-family residences only, and not exceeding 10 m^2	3	
Bowling alleys, poolrooms, and similar recreational areas	4	
Catwalks for maintenance access	2	1.5
Corridors		
First floor	5	
Other floors, same as occupancy served except as indicated		
Mosques	5	
Decks (patio and roof)		
Same as area served, or for the type of occupancy accommodated		
Dining rooms and restaurants	5	
Dwellings (see residential)		
Elevator machine room grating (on area of 2500 mm^2)		1.5
Finish light floor plate construction (on area of 650 mm^2)		1
Fire escapes	5	

Reference Sheet # 1: for Question # 1 (contd.)

SECTION 4.8
REDUCTION IN LIVE LOADS

The minimum uniformly distributed live loads, L_o in Table 4-1, may be reduced according to the following provisions.

4.8.1 **General.** Subject to the limitations of Sections 4.8.2 through 4.8.5, members for which a value of $K_{LL}A_T$ is 37.0 m^2 or more are permitted to be designed for a reduced live load in accordance with the following formula:

Reference Sheet # 1: for Question # 1 (contd.)

$$L = L_o\left(0.25 + \frac{4.57}{\sqrt{K_{LL} A_T}}\right) \quad \textbf{(Eq. 4-1)}$$

where

L = reduced design live load per square m of area supported by the member.

L_o = unreduced design live load per square m of area supported by the member (see Table 4-1)

K_{LL} = live load element factor (see Table 4-3).

A_T = tributary area m^2

L = shall not be less than $0.50L_0$ for members supporting one floor and L shall not be less than $0.40L_0$ for members supporting two or more floors.

4.8.2 **Heavy Live Loads.** Live loads that exceed 5 kN/m^2 shall not be reduced except the live loads for members supporting two or more floors may be reduced by 20%.

4.8.3 **Passenger Car Garages.** The live loads shall not be reduced in passenger car garages except the live loads for members supporting two or more floors may be reduced by 20%.

4.8.4 **Special Occupancies.** Live loads of 5 kN/m^2 or less shall not be reduced in public assembly occupancies.

4.8.5 **Limitations on One-Way Slabs.** The tributary area, A_T, for one-way slabs shall not exceed an area defined by the slab span times a width normal to the span of 1.5 times the slab span.

Reference sheet # 2: for Question # 3

SBC 304 – 18

Table 19.3.1.1—Exposure categories and classes

Category	Class	Condition	
Freezing and thawing (F)	Not applicable in the Kingdom of Saudi Arabia		
Sulfate (S)		Water-soluble sulfate (SO_4^{2-}) in soil, percent by mass[1]	Dissolved sulfate (SO_4^{2-}) in water, ppm[2]
	S0	$SO_4^{2-} < 0.10$	$SO_4^{2-} < 150$
	S1	$0.10 \le SO_4^{2-} < 0.20$	$150 \le SO_4^{2-} < 1500$ or seawater
	S2	$0.20 \le SO_4^{2-} \le 2.00$	$1500 \le SO_4^{2-} \le 10{,}000$
	S3	$SO_4^{2-} > 2.00$	$SO_4^{2-} > 10{,}000$
Corrosion protection of reinforcement (C)	C0	Concrete dry or protected from moisture	
	C1	Concrete exposed to moisture or in contact with water but not to an external source of chlorides	
	C2	Concrete exposed to moisture and an external source of chlorides from soil, groundwater or other sources in moderate concentrations (water-soluble chloride ion, Cl^- less than 0.1% by mass in soil or less than 2000 ppm in water).	
	C3	a) Concrete exposed to moisture and an external source of chlorides from soil, groundwater or other sources in high concentrations (water-soluble chloride ion, Cl^- more than 0.1% by mass in soil or more than 2000 ppm in water). b) Concrete in coastal areas exposed to moisture and airborne chlorides but not in direct contact with sea water	
	C4	Concrete in coastal areas exposed to moisture and an external source of chlorides from seawater, brackish water or spray from these sources	
	C5	Concrete exposed to sabkha soils characterized by very high concentration of chlorides	

[1]Percent sulfate by mass in soil shall be determined by ASTM C1580

[2]Concentration of dissolved sulfate in water, in ppm, shall be determined by ASTM D516 or ASTM D4130.

Reference sheet # 2: for Question # 3 (contd.)

SBC 304 – 18

Table 19.3.2.1—Requirements for concrete by exposure class

Exposure class	Maximum w/cm[1][2]	Minimum f'_c, MPa	Cement type[3]	Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement[6]		Additional provisions
				Non pre-stressed concrete	Pre-stressed concrete	
S0	N/A	20	No type restriction			
S1	0.50	28	II[4]			
S2	0.45	31	V			
S3	0.45	31	V + pozzolan or slag cement[5]			
C0	N/A	20	No type restriction	1.00	0.06	None
C1	0.50	28	No type restriction	0.30	0.06	None
C2	0.50	28	No type restriction	0.15	0.06	Concrete cover[7]
C3	0.45	31	I or II	0.15	0.06	Concrete cover[7]
C4	0.40	35	I + pozzolan or slag cement	0.15	0.06	Concrete cover[7]
C5	0.35	40	I + pozzolan or slag cement	0.15	0.06	Concrete cover[7]

[1] The maximum w/cm limits in Table 19.3.2.1 do not apply to lightweight concrete.

[2] For concrete exposed in service to both chlorides and sulfates, the lowest applicable maximum water-cementitious materials ratio shall be used.

[3] For concrete exposed in service to both chlorides and sulfates, the cement type specified for chloride exposures shall be used.

[4] The use of Type V cement instead of Type II cement is permitted.

[5] The amount of the specific source of the pozzolan or slag cement to be used shall be at least the amount that has been determined by service record to improve sulfate resistance when used in concrete containing Type V cement.

[6] Water-soluble chloride ion content that is contributed from the ingredients including water, aggregates, cementitious materials, and admixtures shall be determined on the concrete mixture by ASTM C1218 at age between 28 and 42 days.

[7] Concrete cover shall be in accordance with 20.6.

Reference sheet # 3: for Question # 4

22.5.6.1 For nonprestressed members with axial compression, V_c shall be calculated by:

$$V_c = 0.17\left(1 + \frac{N_u}{14A_g}\right)\lambda\sqrt{f_c'}b_w d \qquad (22.5.6.1)$$

unless a more detailed calculation is made in accordance with Table 22.5.6.1, where N_u is positive for compression.

9.6.3 Minimum shear reinforcement

9.6.3.1 A minimum area of shear reinforcement, $A_{v,min}$, shall be provided in all regions where $V_u > 0.5\phi V_c$ except for the cases in Table 9.6.3.1. For these cases, at least $A_{v,min}$ shall be provided where $V_u > \phi V_c$.

Table 9.7.6.2.2—Maximum spacing of shear reinforcement

V_s		Maximum s, mm	
		Nonprestressed beam	Prestressed beam
$\leq 0.33\sqrt{f_c'}b_w d$	Lesser of:	$d/2$	$3h/4$
		600	
$>0.33\sqrt{f_c'}b_w d$	Lesser of:	$d/4$	$3h/8$
		300	

Reference sheet # 3: for Question # 4 (contd.)

22.5.10.1 At each section where $V_u > \phi V_c$, transverse reinforcement shall be provided such that Eq. (22.5.10.1) is satisfied.

$$V_s \geq \frac{V_u}{\phi} - V_c \qquad (22.5.10.1)$$

22.5.10.2 For one-way members reinforced with transverse reinforcement, V_s shall be calculated in accordance with 22.5.10.5.

22.5.10.3 For one-way members reinforced with bent-up longitudinal bars, V_s shall be calculated in accordance with 22.5.10.6.

22.5.10.4 If more than one type of shear reinforcement is provided to reinforce the same portion of a member, V_s shall be the sum of the V_s values for the various types of shear reinforcement.

22.5.10.5 One-way shear strength provided by transverse reinforcement

22.5.10.5.1 In nonprestressed and prestressed members, shear reinforcement satisfying (a), (b), or (c) shall be permitted:

(a) Stirrups, ties, or hoops perpendicular to longitudinal axis of member
(b) Welded wire reinforcement with wires located perpendicular to longitudinal axis of member
(c) Spiral reinforcement

22.5.10.5.2 Inclined stirrups making an angle of at least 45 degrees with the longitudinal axis of the member and crossing the plane of the potential shear crack shall be permitted to be used as shear reinforcement in nonprestressed members.

22.5.10.5.3 V_s for shear reinforcement in 22.5.10.5.1 shall be calculated by:

$$V_s = \frac{A_s f_{yt} d}{s} \qquad (22.5.10.5.3)$$

Reference sheet # 4: for Question # 5

9.9—Deep beams

9.9.1 General

9.9.1.1 Deep beams are members that are loaded on one face and supported on the opposite face such that strut-like compression elements can develop between the loads and supports and that satisfy (a) or (b):

(a) Clear span does not exceed four times the overall member depth h

(b) Concentrated loads exist within a distance $2h$ from the face of the support

TABLES OF CHAPTER 21

Table 21.2.1—Strength reduction factors ϕ

	Action or structural element	ϕ	Exceptions
(a)	Moment, axial force, or combined moment and axial force	0.65 to 0.90 in accordance with 21.2.2	Near ends of pretensioned members where strands are not fully developed, ϕ shall be in accordance with 21.2.3.
(b)	Shear	0.75	Additional requirements are given in 21.2.4 for structures designed to resist earthquake effects.
(c)	Torsion	0.75	-
(d)	Bearing	0.65	-
(e)	Post-tensioned anchorage zones	0.85	-
(f)	Brackets and corbels	0.75	-
(g)	Struts, ties, nodal zones, and bearing areas designed in accordance with strut-and-tie method in Chapter 23	0.75	-
(h)	Components of connections of precast members controlled by yielding of steel elements in tension	0.90	-
(i)	Plain concrete elements	0.60	-
(j)	Anchors in concrete elements	0.45 to 0.75 in accordance with Chapter 17	-

Reference Sheet # 5: for Question # 7

4.2 Design Tensile Strength

The design strength of tension members, $\phi_t P_n$, shall be the lower value obtained according to the limit states of yielding in the gross section and fracture in the net section.

(a) For tesile yielding in the gross section:

$$\phi_t = 0.90$$

$$P_n = F_y A_g \qquad (4.2\text{-}1)$$

(b) For tensile rupture in the net section:

$$\phi_t = 0.75$$

$$P_n = F_u A_e \qquad (4.2\text{-}2)$$

where

A_e = effective net area, mm^2

A_g = gross area of member, mm^2

F_y = specified minimum yield stress, MPa

F_u = specified minimum tensile strength, MPa

4.3 Effective Net Area

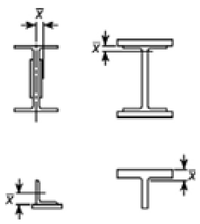
The gross area, A_g, and *net area*, A_n, of tension members shall be determined in accordance with the provisions of Section 2.4.3.

The effective net area of tension members shall be determined as follows:

$$A_e = A_n U \qquad (4.3\text{-}1)$$

where U, the *shear lag* factor, is determined as shown in Table 4.4-1.

Table 4.4-1 : Shear Lag Factors for Connections to Tension Members

Case	Description of Element	Shear Lag Factor, U	Example
1	All tension members where the tension load is transmitted directly to each of the cross-sectional elements by fasteners or welds (except as in Cases 4, 5 and 6).	$U = 1.0$	---
2	All tension members, except plates and HSS, where the tension load is trans- mitted to some but not all of the cross- sectional elements by fasteners or longitudinal welds or by longitudinal welds in combination with transverse welds. (Alternatively, for W, M, S and HP, Case 7 may be used. For angles Case 8 may be used.)	$U = 1 - \bar{x}/l$	
3	All tension members where the tension load is transmitted only by transverse welds to some but not all of the cross-sectional elements.	$U = 1.0$ and A_n = area of the directly connected elements	---

Reference Sheet # 6: for Question # 8

SBC 304-18

13.3.3.3 In rectangular footings, reinforcement shall be distributed in accordance with (a) and (b):

(a) Reinforcement in the long direction shall be distributed uniformly across entire width of footing.

(b) For reinforcement in the short direction, a portion of the total reinforcement, $\gamma_s A_s$, shall be distributed uniformly over a band width equal to the length of short side of footing, centered on centerline of column or pedestal. Remainder of reinforcement required in the short direction, $(1 - \gamma_s)A_s$, shall be distributed uniformly outside the center band width of footing, where γ_s is calculated by:

$$\gamma_s = \frac{2}{(\beta + 1)} \qquad (13.3.3.3)$$

where β is the ratio of long to short side of footing.

Reference Sheet # 7: for Question # 10

7.3.1.1 For solid nonprestressed slabs not supporting or attached to partitions or other construction likely to be damaged by large deflections, overall slab thickness h shall not be less than the limits in Table 7.3.1.1, unless the calculated deflection limits of 7.3.2 are satisfied.

Table 7.3.1.1—Minimum thickness of solid nonprestressed one-way slabs

Support condition	Minimum h[1]
Simply supported	$l/20$
One end continuous	$l/24$
Both ends continuous	$l/28$
Cantilever	$l/10$

Reference Sheet # 7: for Question # 10

SBC 304-18

21.2—Strength reduction factors for structural concrete members and connections

21.2.1 Strength reduction factors ϕ shall be in accordance with Table 21.2.1, except as modified by 21.2.2, 21.2.3, and 21.2.4.

21.2.2 Strength reduction factor for moment, axial force, or combined moment and axial force shall be in accordance with Table 21.2.2.

21.2.2.1 For deformed reinforcement, ε_{ty} shall be f_y/E_s. For Grade 420 deformed reinforcement, it shall be permitted to take ε_{ty} equal to 0.002.

$$a = A_s \times f_y / (0.85 \times f'c \times b)$$

$$C = a / \beta_1$$

TABLES OF CHAPTER 22

Table 22.2.2.4.3—Values of β_1 for equivalent rectangular concrete stress distribution

f'_c, MPa	β_1	
$17 \le f'_c \le 28$	0.85	(a)

9.3.3 Reinforcement strain limit in nonprestressed beams

9.3.3.1 For nonprestressed beams with $P_u < 0.10 f'_c A_g$, ε_t shall be at least 0.004.

Reference Sheet # 8: for Essay Question # 1 (contd.)

CHAPTER 21–STRENGTH REDUCTION FACTORS

TABLES OF CHAPTER 21

Table 21.2.1—Strength reduction factors ϕ

	Action or structural element	ϕ	Exceptions
(a)	Moment, axial force, or combined moment and axial force	0.65 to 0.90 in accordance with 21.2.2	Near ends of pretensioned members where strands are not fully developed, ϕ shall be in accordance with 21.2.3.
(b)	Shear	0.75	Additional requirements are given in 21.2.4 for structures designed to resist earthquake effects.

6.5—Simplified method of analysis for nonprestressed continuous beams and one-way slabs

6.5.1 It shall be permitted to calculate M_u and V_u due to gravity loads in accordance with this section for continuous beams and one-way slabs satisfying (a) through (e):

(a) Members are prismatic
(b) Loads are uniformly distributed
(c) $L \leq 3D$
(d) There are at least two spans
(e) The longer of two adjacent spans does not exceed the shorter by more than 20 percent

6.5.2 M_u due to gravity loads shall be calculated in accordance with Table 6.5.2.

6.5.3 Moments calculated in accordance with 6.5.2 shall not be redistributed.

6.5.4 V_u due to gravity loads shall be calculated in accordance with Table 6.5.4.

Reference Sheet # 8: for Essay Question # 1 (contd.)

Table 6.5.2—Approximate moments for nonprestressed continuous beams and one-way slabs

Moment	Location	Condition	M_u
Positive	End span	Discontinuous end integral with support	$w_u l_n^2/14$
		Discontinuous end unrestrained	$w_u l_n^2/11$
	Interior spans	All	$w_u l_n^2/16$
Negative[1]	Interior face of exterior support	Member built integrally with supporting spandrel beam	$w_u l_n^2/24$
		Member built integrally with supporting column	$w_u l_n^2/16$
	Exterior face of first interior support	Two spans	$w_u l_n^2/9$
		More than two spans	$w_u l_n^2/10$
	Face of other supports	All	$w_u l_n^2/11$
	Face of all supports satisfying (a) or (b)	(a) slabs with spans not exceeding 3 m (b) beams where ratio of sum of column stiffnesses to beam stiffness exceeds 8 at each end of span	$w_u l_n^2/12$

[1]To calculate negative moments, l_n shall be the average of the adjacent clear span lengths.

Reference Sheet # 8: for Essay Question # 1 (contd.)

9.5—Design strength

9.5.1 General

9.5.1.1 For each applicable factored load combination, design strength at all sections shall satisfy $\phi S_n \geq U$ including (a) through (d). Interaction between load effects shall be considered.

(a) $\phi M_n \geq M_u$
(b) $\phi V_n \geq V_u$
(c) $\phi T_n \geq T_u$

9.5.1.2 ϕ shall be determined in accordance with 21.2.

9.5.2 Moment

9.5.2.1 If $P_u < 0.10 f_c' A_g$, M_n shall be calculated in accordance with 22.3.

9.5.2.2 If $P_u \geq 0.10 f_c' A_g$, M_n shall be calculated in accordance with 22.4.

9.5.2.3 For prestressed beams, external tendons shall be considered as unbonded tendons in calculating flexural strength, unless the external tendons are effectively bonded to the concrete along the entire length.

9.5.3 Shear

9.5.3.1 V_n shall be calculated in accordance with 22.5.

22.5—One-way shear strength

22.5.1 General

22.5.1.1 Nominal one-way shear strength at a section, V_n, shall be calculated by:

$$V_n = V_c + V_s \qquad (22.5.1.1)$$

22.5.1.2 Cross-sectional dimensions shall be selected to satisfy Eq. (22.5.1.2).

$$V_u \leq \phi\left(V_c + 0.66\sqrt{f_c'} b_w d\right) \qquad (22.5.1.2)$$

$$V_c = 0.17\, b_w\, d \sqrt{f_c'}$$

Reference Sheet # 8: for Essay Question # 1 (contd.)

22.5.10.1 At each section where $V_u > \phi V_c$, transverse reinforcement shall be provided such that Eq. (22.5.10.1) is satisfied.

$$V_s \geq \frac{V_u}{\phi} - V_c \qquad (22.5.10.1)$$

22.5.10.2 For one-way members reinforced with transverse reinforcement, V_s shall be calculated in accordance with 22.5.10.5.

22.5.10.5 One-way shear strength provided by transverse reinforcement

22.5.10.5.1 In nonprestressed and prestressed members, shear reinforcement satisfying (a), (b), or (c) shall be permitted:

(a) Stirrups, ties, or hoops perpendicular to longitudinal axis of member

(b) Welded wire reinforcement with wires located perpendicular to longitudinal axis of member

(c) Spiral reinforcement

22.5.10.5.3 V_s for shear reinforcement in 22.5.10.5.1 shall be calculated by:

$$V_s = \frac{A_s f_{yt} d}{s} \qquad (22.5.10.5.3)$$

where s is the spiral pitch or the longitudinal spacing of the shear reinforcement, and A_v is given in 22.5.10.5.5 or 22.5.10.5.6.

Table 6.5.4—Approximate shears for nonprestressed continuous beams and one-way slabs

Location	V_u
Exterior face of first interior support	$1.15 w_u l_n / 2$
Face of all other supports	$w_u l_n / 2$

Reference Sheet # 9: for Essay Question # 2

Factored tensile strength of bolts ; $\phi R_n = 0.75 \times A_b \times F_{ub} \times N_b$

Factored slip resistance of bolts; $\phi R_n = 1.0 \times 1.13 \times \mu\ (0.7\ A_b \times F_{ub}) \times N_b \times N_s$

Factored shear strength of bolts ; $\phi R_n = 0.75 \times A_b \times F_{vb} \times N_b \times N_s$

Where; A_b : Bolt area , N_b : number of bolts , N_s : number of shear plans

F_{ub}: Tensile ultimate strength of bolt

F_{vb} : Shear ultimate strength of bolt

μ : Coefficient of friction

Factored fillet weld strength ; $\phi R_n = 0.75 \times 0.6\ F_{EX} \times L_w \times 0.707 \times S_w$

F_{Ex}: Electrode Strength

L_w : length of weld

S_w : Weld size

End plate thickness, $t_{ep} = \{ 4\ M_{eu} / \phi\ F_y\ .\ b_{p\ eff}\}^{½}$,

Ultimate moment on end plate, $M_{eu} = \alpha_m\ .\ P_{uf}\ .\ p_e / 4$

$b_{p\ eff} = b_f + 25mm < b_p$

where : b_f : Beam flange width ; b_p : end plate width

P_{uf} = ultimate flange force, $p_e = p - d_b/4 - 0.707\ S_w$

$\alpha_m = 1.38\ .\ C_b\ .\ (A_f/A_w)^{1/3}\ .\ (p_e/d_b)^{1/4}$

where: $C_b = (b_f / b_{p\ eff})^{½}$

d_b : bolt diameter ,

A_f : Flange area ,

A_w : Web area excluding the flanges

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