L-3/T-2/CE **Date : 28/03/2022**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2019-2020

Sub : **CE 317** (Design of Concrete Structures-II)

Full Marks : 210 Time : 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

The figures in the margin indicate full marks.

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE** questions.

Use USD method of Design.

1. (a) A 14″ × 24″ inch column is reinforced with Eight No. 10 bars as shown in Fig. 1. Construct the nominal strength interaction diagram for the column by calculating (not using chart) five points corresponding to pure axial load, pure bending, balanced condition $\varepsilon_s = \varepsilon_y$, $\varepsilon_s = 0$ and $\varepsilon_s = 0.005$ (tensile). Also find corresponding ϕ for the above points. Assume bending about Y-Y axis. Given: $f_c' = 4$ ksi, $f_y = 60$ ksi and $E_s = 29 \times 10^3$ ksi. **(20)**

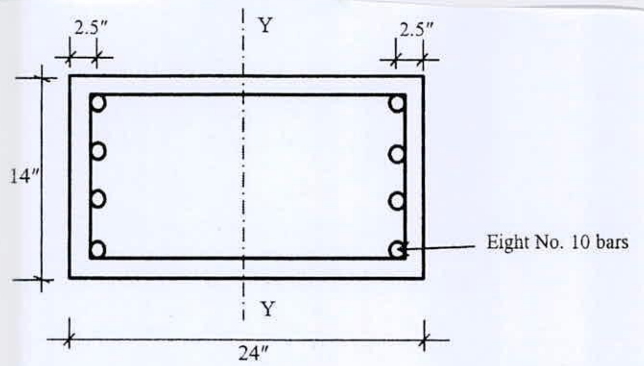

Fig. 1.

(b) For the problem 1(a), obtain nominal interaction diagram points corresponding to the

(i) balanced condition ($\varepsilon_s = \varepsilon_y$ or $f_s = f_y$),

(ii) $\varepsilon_s = 0$ or $f_s = 0$ and

(iii) $\varepsilon_s = 0.005$ (tensile)

using the Graph A. 11 (assuming $\gamma = 0.79 \approx 0.80$). How do they compare with (P_n, M_n) results of problem 1(a)? **(15)**

2. (a) A ground floor column of a multistoried building is to be designed for the following load combinations (axial force and uniaxial bending)-

Gravity load condition: $P_u = 700$ kip, $M_u = 80$ kip-ft

Lateral load combination: $P_u = 600$ kip, $M_u = 500$ kip-ft

Architectural considerations require that a rectangular column with b = 16 in. and h = 25 in. is to be used. Material strengths are $f_c' = 4$ ksi and $f_y = 60$ ksi.

Find the required column reinforcement (longitudinal and tie) and show in sketch. Use supplied design chart (A. 7) assuming reinforcement distributed along the perimeter. **(15)**

(b) Design tie for the above column considering seismic provisions of an IMRF system. Clear height of the column is 10 ft. Show arrangements in cross and long-sections. **(8)**

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Contd ... Q. No. 2

(c) A post tensioned bonded concrete beam as shown in Fig. 2 has a prestress of 355 kip in the steel immediately after prestressing and reduces to 308 kip due to losses. In addition to self weight 300 lb/ft, there is a live load of 700 lb/ft. Compute the extreme fibre stresses at midspan,

(i) Under the initial condition with full prestress and no live load.

(ii) At final condition with live load and considering losses. **(12)**

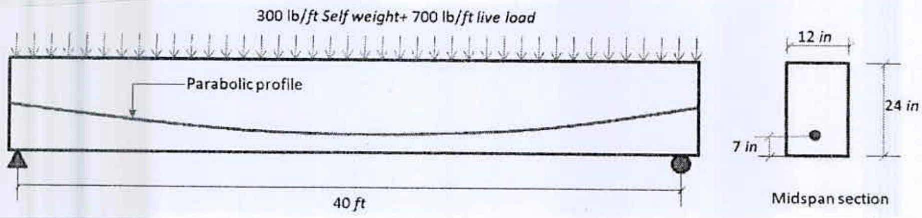


Fig. 2

3. (a) A 25″ × 25″ column is reinforced with sixteen No. 8 bars arranged around the column perimeter. Material strengths are f_c' = 4.0 ksi and f_y = 60 ksi. Check adequacy of the short column using Reciprocal Load method for: P_u = 400 kip, M_{ux} = 300 kip-ft and M_{uy} = 250 kip-ft. Use supplied design chart (A.7). **(15)**

(b) A shear wall of a 15-storey building is subjected to following factored loads:

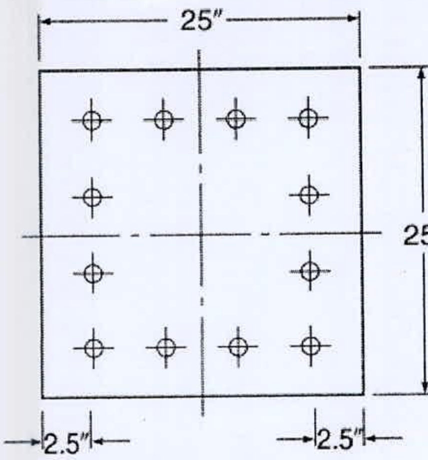
P_u = 500 kip
V_u = 600 kip
M_u = 5000 kip-ft

The wall is 18 ft long, 150 ft high and 14 inch thick. Design the shear wall with f_c' = 3 ksi and f_y = 60 ksi. Ignore axial force as it is less than balanced load of the section. **(15)**

(c) Write down the sources of loss of prestress. **(5)**

4. (a) A circular column carries a working unfactored DL = 700 kip and LL = 400 kip. Design the spirally reinforced column using about 2 percent main reinforcement. Also design the ACI spiral. Given: f_c' = 4.0 ksi and f_y = 60 ksi. **(15)**

(b) The column shown in Fig. 3 is subjected to axial load and bending moment, causing uniaxial bending about an axis parallel to that of the rows of bars. What moment M_n would cause the column to fail if the axial load Pn simultaneously was 1250 kip? Material strengths are f_c' = 4.0 ksi and f_y = 60 ksi. Use supplied chart (A. 7). **(15)**



A_{st} = 12 No. 10 (No. 32)

Fig. 3

Contd P/3

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(c) As per ACI/BNBC code, slenderness effects can be neglected if slenderness ratio of a column is below certain limits, write these limits for columns of sway and non-sway frames. **(5)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Two interior columns for a structure are spaced 15 ft apart, and each carries service DL = 300 kip and LL = 250 kip. Column sizes are 24″ × 24″. They are supported on a rectangular combined footing with a long-side dimension twice that of the short side. The allowable soil bearing pressure is 4200 psf. The bottom of the footing will be 5 ft below grade. Design the combined footing for these two columns and show the reinforcements in plan and section. Material strength for footing design: f_c' = 3.5 ksi and f_y = 60 ksi. **(20)**

(b) The plan of a pile cap with 12 nos. 20″ diameter cast-in-situ piles with the column (30″ × 30″) is shown in Fig. 4. The column carries a DL = 1000 kip and a LL = 600 kip (working). The individual pile capacity is adequate. Design the pile cap and show the reinforcements with neat sketches. Given:
f_c' = 4 ksi and f_y = 60 ksi. **(15)**

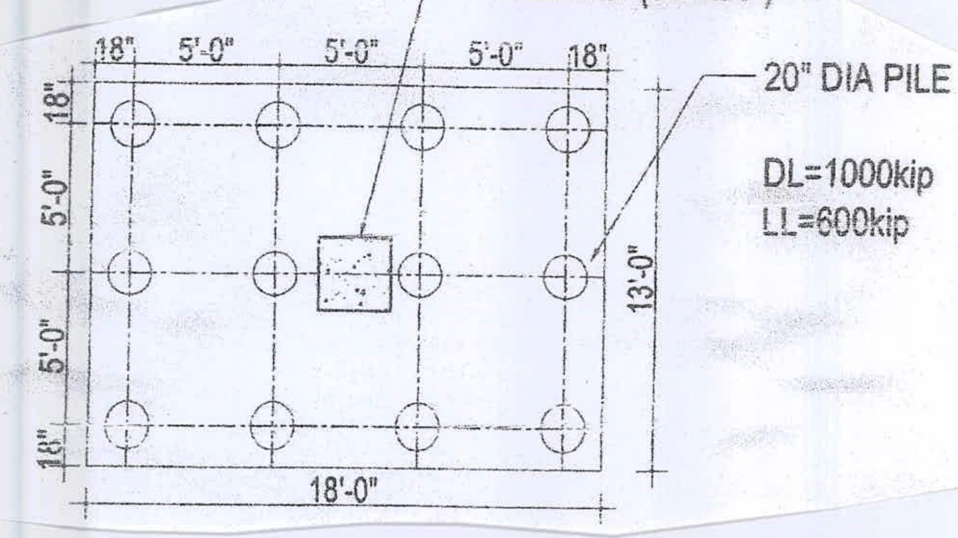

Fig. 4

6. (a) A residential building is to be designed using a flat plate floor system. The columns are 24″ × 24″ and they are spaced 22 ft c/c in one direction and 25 ft c/c in other direction. Design an interior panel (22′ × 25′) and show the reinforcements in short direction only with neat sketches. Specified Live load = 40 psf; floor finish and partition wall load = 80 psf in addition to the self weight of floor slab. Use f_c' = 3000 psi and f_y = 60,000 psi for your flat plate slab design. **(20)**

(b) A flat plate floor has an average effective depth d = 6 inch and is supported by 18″ × 18″ columns spaced 22 ft on centers each way. The floor will carry a total factored load of 310 psf. Check the adequacy of the slab in resisting punching shear at a typical interior column, and provide shear reinforcement, if needed, using bent bars. Given: f_c' = 4 ksi and f_y = 60 ksi. **(15)**

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7. (a) Write down the advantages and disadvantages of prestressed concrete as compared to reinforced concrete. **(9)**

(b) Differentiate between

(i) strand and wires

(ii) Pre tensioning and Post tensioning **(8)**

(c) Make a preliminary design for section of prestressed concrete beam to resist a total moment M_T = 330 kip-ft and girder moment M_G = 44 kip-ft. Total depth of the section is given as 38 inch. The effective prestress for steel, f_{se} =124000 psi and allowable compressive stress for concrete under working load, $f_c = -1750$ psi. **(18)**

8. (a) A post-tensioned simple beam as shown in Fig. 5 has an initial prestress of 145000 psi, reducing to 126000 psi after deducting all losses and assuming no bending of the beam. The parabolic cable has an area of 2.8 in^2 and n=6. The beam carries superimposed dead load of 800 *lb/ft.* in addition to its own weight of 375 *lb/ft.* Compute the stresses in the steel at midspan, assuming:

(i) the steel is bonded by grouting

(ii) the steel is unbonded and free to slip **(18)**

(b) For the beam shown in Fig. 5 compute the total dead and live uniform load that can be carried by the beam,

(i) For zero tensile stress at bottom fiber

(ii) For cracking at the bottom fiber at a modulus of rupture of 600 *psi* **(17)**

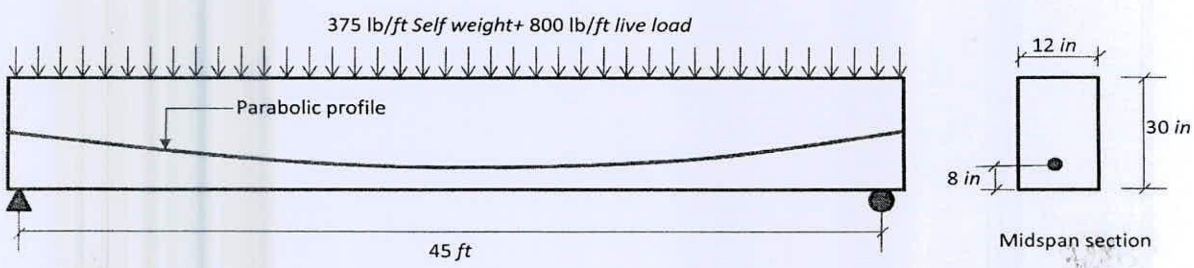
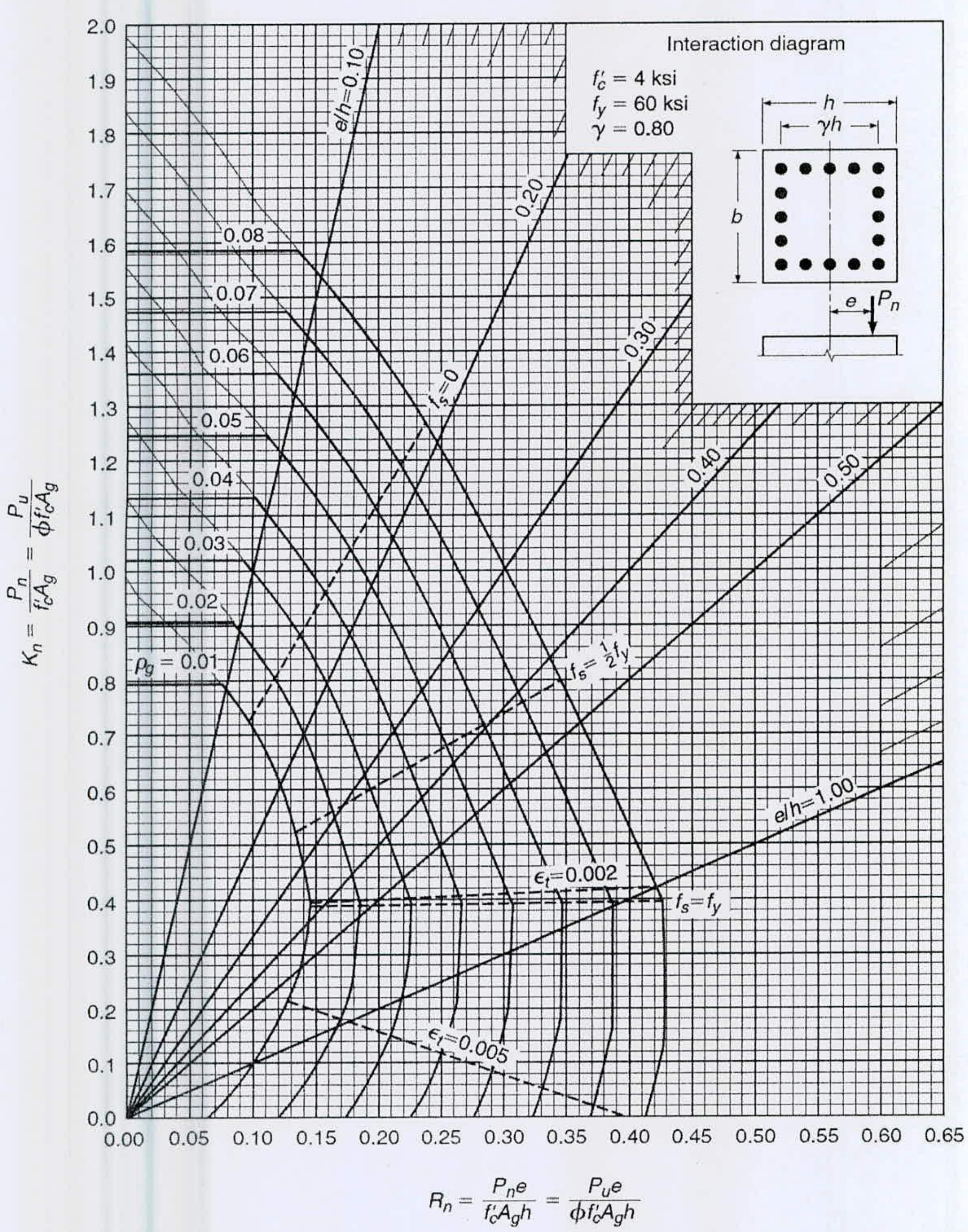
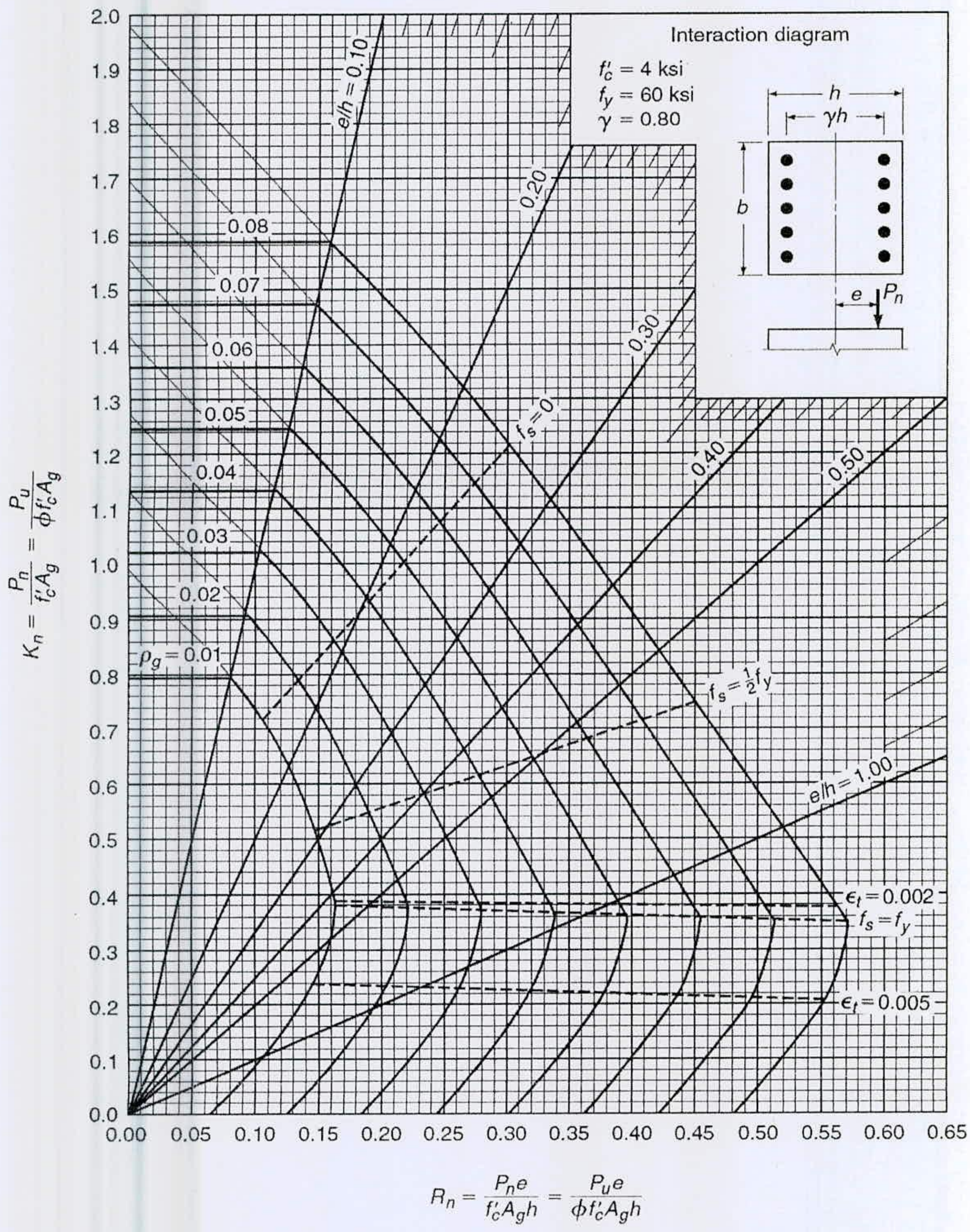


Fig. 5



GRAPH A.7
Column strength interaction diagram for rectangular section with bars on four faces and $\gamma = 0.80$.



GRAPH A.11

Column strength interaction diagram for rectangular section with bars on end faces and $\gamma = 0.80$.

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Full Marks: 210 Time: 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

The figures in the margin indicate full marks

Assume reasonable values for any missing data

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE** questions.

1. A compression member 30ft long with pin ended support condition is to carry a dead load of 140 kip and live load of 420 kip. Design the column with W-Shape section with a maximum nominal size of 14 inch. Use LRFD method with grade 50 steel. The chosen section should not have more than 7% capacity than the required factored capacity. **(35)**

2. (a) Design the welded connection for a double angle tension member 2L $5\times3\frac{1}{2}\times\frac{1}{2}$ made from 36 ksi steel. Use E70XX electrode for a factored load of 250 kip. The gusset plate is $\frac{1}{2}$ inch thick. Show the weld in a sketch. Assume that the member tensile strength is adequate. **(20)**

   (b) Check the adequacy of the tension member L$4\times4\times\frac{1}{2}$ - ASTM A36 with 4 - $\frac{3}{4}$ inch diameter bolts in standard holes to carry dead load of 20 kip and a live load of 60 kip tension (see Fig. 1). Use LRFD method. Assume that the connection limit state does not govern. Given : U=(1-x/L) and U=0.80 for 4 or more fastener per line in the direction of loading (use larger value of U). Angle properties are given: A = 3.75 sq. in. and $\bar{x} = \bar{y}$=1.18 inch. **(15)**

3. (a) Describe the concept of effective length to take account of the end conditions of compression member. What are the values of effective length factors for various conditions of supports of a member in compression? **(7)**

   (b) A two-story steel frame is shown in Fig. 2. Using the alignment chart for effective length, determine the capacity of the column DE and EF. The frame is braced at level 1 against sidesway. Given, E = 29,000 ksi and Fy = 36 ksi. Beam properties and chart are available in Fig. 2. Use LRFD method. Consider buckling in major axis of column. **(28)**

Contd P/2

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4. A W12×96 column carries a dead load of 115 kip and live load of 345 kip and is to rest on a concrete pedestal of 24″ × 24″ with f′c = 3 ksi. Design the base plate using LRFD method from A36 steel. Given column section properties: d = 12.7″, b_f = 12.2″, t_f = 0.9″, t_w = 0.55″. **(35)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE** questions.

5. Determine the capacity of the built-up 'T' section (addition of a plate to the flange of a typical T section) in tension for the bolt configuration shown in Figure 3. (6 no. $\frac{3}{4}''$ bolts in 2 rows along the direction of the tension load). The plate (the connected member) is of adequate capacity. All members of the built-up 'T' section have Fy and Fu of 50 ksi and 65 ksi, respectively. Bolts are A325 bolts in standard holes having Fy and Fu of 90 ksi and 120 ksi respectively. The connection is bearing type with threads excluded from the shear planes. The bolt bearing capacity needs not to be checked against the connected plate. Along the direction of the load, the spacing and edge distance of bolts are 2″ c/c and 4″ respectively. Use AISC ASD METHOD. **(35)**

6. Check the adequacy (both flexure and shear) of a simply supported beam having W18×71 as cross-section. The beam is carrying uniformly distributed dead load of 250 lb/ft (in addition to self-weight) and live load of 500 lb/ft. There is also a concentrated live load of 10 kips at the midpoint of the beam. The span length of the beam is 32′. Lateral support is provided at the ends and at midspan. Use A992 steel (Fy = 50 ksi) and follow AISC LRFD method. Draw shear force and bending moment diagram of the loaded beam. **(35)**

7. A 20′ W18 × 97 (50 ksi steel) is used as a beam-column in a braced frame. It is bent in single curvature with equal and opposite moments and is not subjected to intermediate transverse loads. Is the section satisfactory if $P_D = 150^k$, $P_L = 250^k$ and first order M_{pax} = 50 ft-k and M_{Lax} = 80 ft-k? Assume effective length factor of unity. Use AISC LRFD method. **(35)**

8. Design an all bolted double – angle connection for following conditions:
   - The connection is between a W18 × 65 floor beam and a W21 × 62 girder. Both have A572 Grade 50 steel. **(35)**
   - The end reactions: $R_D = 35^k$ & $R_L = 55^k$
   - The beam top flange is coped with a dimension of 2.5″ (deep) by 3.5″ (long)
   - L_{ev} = 1.25″ & L_{eh} = 1.5″
   - ASTM A 325–X bolts (Fy = 90 ksi and Fu = 120 ksi) with $\frac{3}{4}''$ diameter
   - Use AISC ASD method.

   Show the design connection in a neat sketch.

Contd... P/3

L4×4×½
$A_g = 3.75$ in.^{2}
$r_z = 0.776$ in.
$\bar{y} = 1.18$ in. $= \bar{x}$

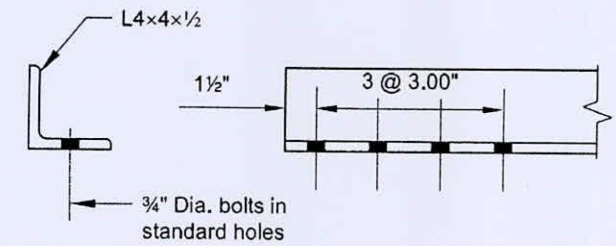


Fig. 1 (for Q. 2 (b))

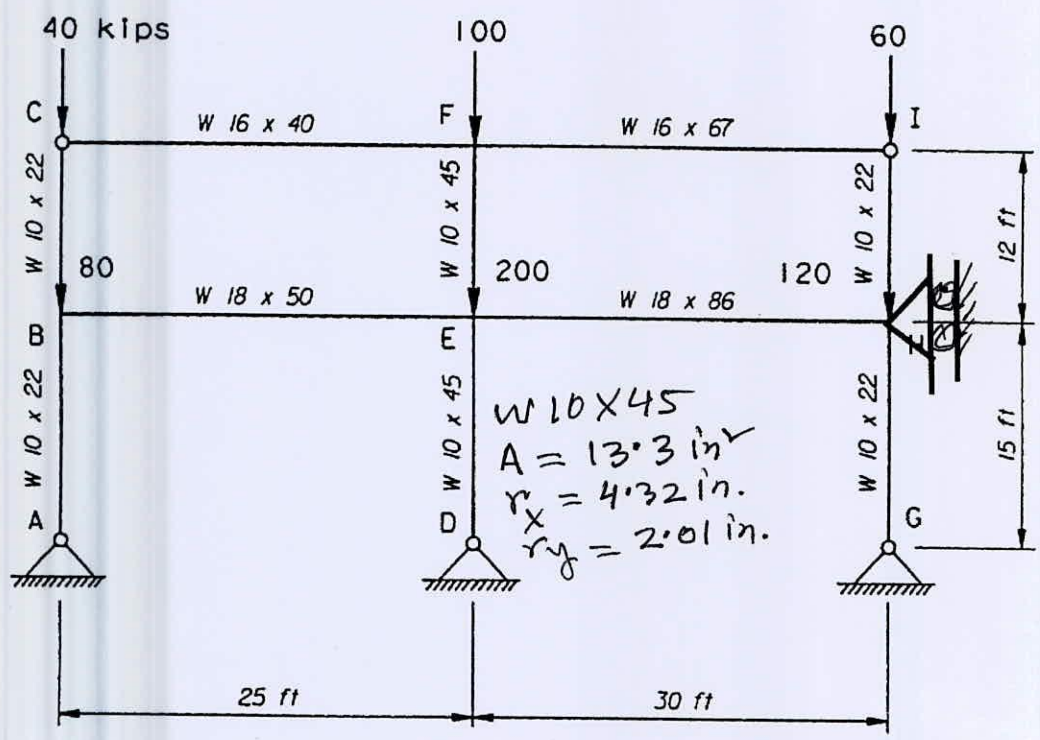
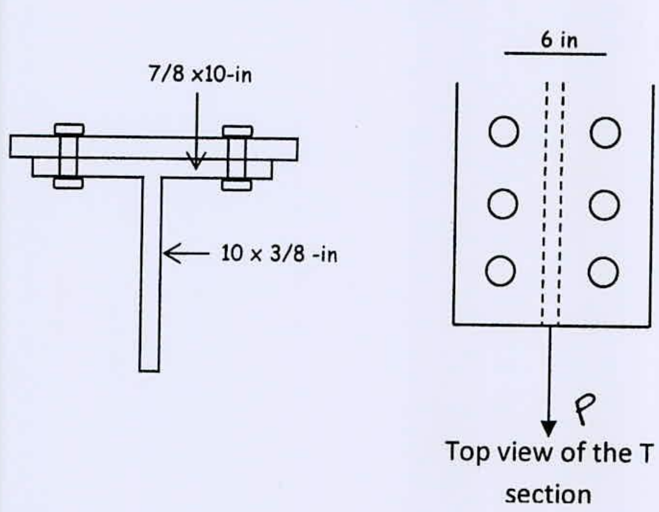


Fig. 2 (for Q. 3(b))



~~Figure~~ Figure 3 (for Q.NO. 5)

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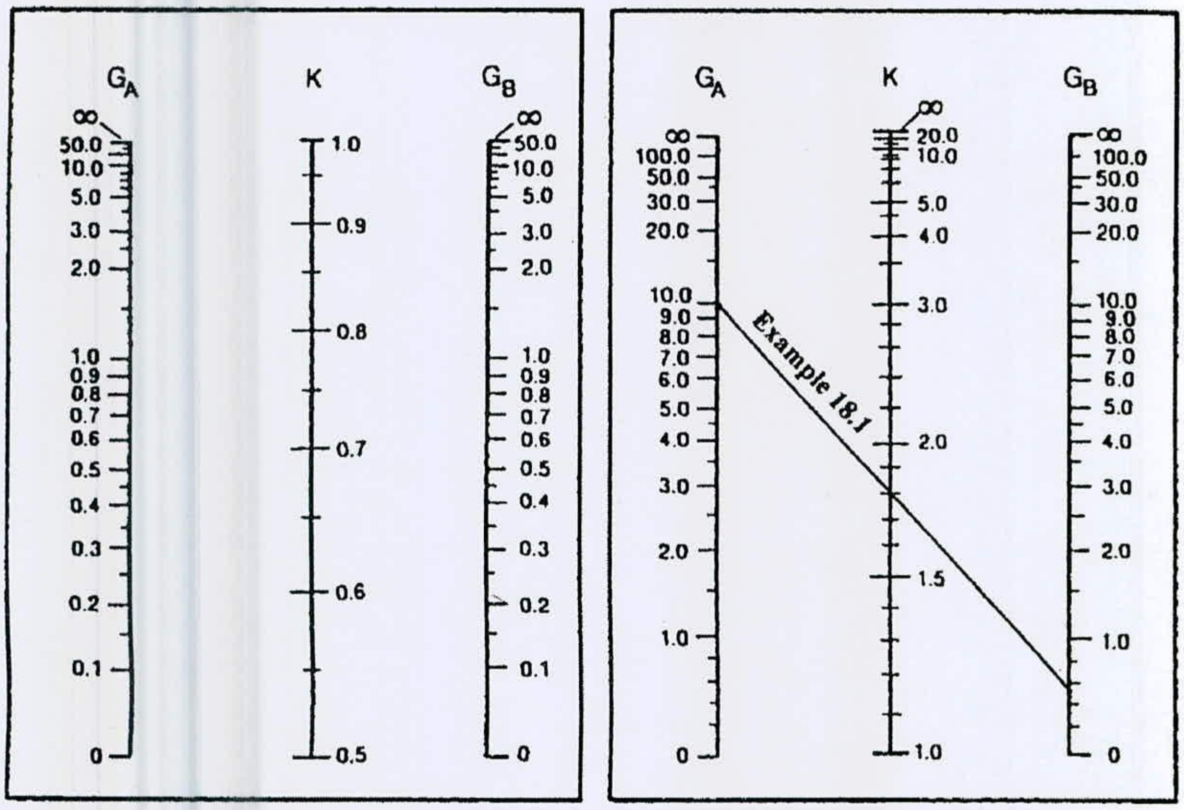

(a)

Braced Frames

(b)

Unbraced Frames

FIGURE 17.4: Alignment charts for effective length factors of framed columns.

Section	I_x in.^{4} (mm^4 × 10^8)
W 10x22	118 (0.49)
W10x22	118 (0.49)
W10x45	248 (1.03)
W10x45	248 (1.03)
W18x50	800 (3.33)
W18x86	1530 (6.37)
W16x40	518 (2.16)
W16x67	954 (3.97)

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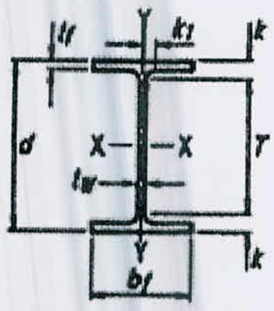

Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A (in.²)	r_x (in.)	r_y (in.)
W14×730[h]	215	8.17	4.69
×665[h]	196	7.98	4.62
×605[h]	178	7.80	4.55
×550[h]	162	7.63	4.49
×500[h]	147	7.48	4.43
×455[h]	134	7.33	4.38
×426[h]	125	7.26	4.34
×398[h]	117	7.16	4.31
×370[h]	109	7.07	4.27
×342[h]	101	6.98	4.24
×311[h]	91.4	6.88	4.20
×283[h]	83.3	6.79	4.17
×257	75.6	6.71	4.13
×233	68.5	6.63	4.10
×211	62.0	6.55	4.07
×193	56.8	6.50	4.05
×176	51.8	6.43	4.02
×159	46.7	6.38	4.00
×145	42.7	6.33	3.98
W14×132	38.8	6.28	3.76
×120	35.3	6.24	3.74
×109	32.0	6.22	3.73
×99[f]	29.1	6.17	3.71
×90[f]	26.5	6.14	3.70
W14×82	24.0	6.05	2.48
×74	21.8	6.04	2.48
×68	20.0	6.01	2.46
×61	17.9	5.98	2.45
W14×53	15.6	5.89	1.92
×48	14.1	5.85	1.91
×43[c]	12.6	5.82	1.89
W14×38[c]	11.2	5.87	1.55
×34[c]	10.0	5.83	1.53
×30[c]	8.85	5.73	1.49
W14×26[c]	7.69	5.65	1.08
×22[c]	6.49	5.54	1.04

Contd... P/6

Some of the required expressions:

$$P_n = A_g F_{cr}$$

$$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right] F_y \text{ for } \frac{KL}{r} \le 4.71\sqrt{\frac{E}{F_y}} \text{ or } F_e \ge 0.44F_y$$

$$F_{cr} = 0.877F_e \text{ for } \frac{KL}{r} > 4.71\sqrt{\frac{E}{F_y}} \text{ or } F_e < 0.44F_y$$

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

$$L_p = 1.76 r_y \sqrt{\frac{E}{F_y}}$$

$$L_r = 1.95 r_{ts} \frac{E}{0.7F_y} \sqrt{\frac{Jc}{S_x h_o}} \sqrt{1 + \sqrt{1 + 6.76\left(\frac{0.7F_y}{E}\frac{S_x h_o}{Jc}\right)^2}}$$

$$M_n = C_b\left[M_p - \left(M_p - 0.7F_y S_x\right)\left(\frac{L_b - L_p}{L_r - L_p}\right)\right] \le M_p$$

$$C_b = \frac{12.5M_{max}}{2.5M_{max} + 3M_A + 4M_B + 3M_c} R_m \le 3.0$$

$$c_m = 0.6 - 0.4\left(\frac{M_1}{M_2}\right)$$

$$B_1 = \frac{c_m}{1 - \frac{P_u}{P_{e1}}}$$

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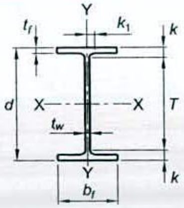

Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k k_{des}	Distance k k_{det}	k_1	T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W21×275[h]	81.8	24.1	24 1/8	1.22	1 1/4	5/8	12.9	12 7/8	2.19	2 3/16	3.37	3 7/16	1 13/16	17 1/4	5 1/2
×248	73.8	23.7	23 3/4	1.10	1 1/8	9/16	12.8	12 3/4	1.99	2	3.17	3 1/4	1 3/4		
×223	66.5	23.4	23 3/8	1.00	1	1/2	12.7	12 5/8	1.79	1 13/16	2.97	3 1/16	1 11/16		
×201	59.3	23.0	23	0.910	15/16	1/2	12.6	12 5/8	1.63	1 5/8	2.13	2 7/8	1 11/16		
×182	53.6	22.7	22 3/4	0.830	13/16	7/16	12.5	12 1/2	1.48	1 1/2	1.98	2 3/4	1 5/8		
×166	48.8	22.5	22 1/2	0.750	3/4	3/8	12.4	12 3/8	1.36	1 3/8	1.86	2 5/8	1 9/16		
×147	43.2	22.1	22	0.720	3/4	3/8	12.5	12 1/2	1.15	1 1/8	1.65	2 7/16	1 9/16		
×132	38.8	21.8	21 7/8	0.650	5/8	5/16	12.4	12 1/2	1.04	1 1/16	1.54	2 1/4	1 9/16		
×122	35.9	21.7	21 5/8	0.600	5/8	5/16	12.4	12 3/8	0.960	15/16	1.46	2 1/4	1 1/2		
×111	32.6	21.5	21 1/2	0.550	9/16	5/16	12.3	12 3/8	0.875	7/8	1.38	2 1/8	1 1/2		
×101[c]	29.8	21.4	21 3/8	0.500	1/2	1/4	12.3	12 1/4	0.800	13/16	1.30	2 1/16	1 7/16		
W21×93	27.3	21.6	21 5/8	0.580	9/16	5/16	8.42	8 3/8	0.930	15/16	1.43	1 5/8	15/16	18 3/8	5 1/2
×83[c]	24.4	21.4	21 3/8	0.515	1/2	1/4	8.36	8 3/8	0.835	13/16	1.34	1 1/2	7/8		
×73[c]	21.5	21.2	21 1/4	0.455	7/16	1/4	8.30	8 1/4	0.740	3/4	1.24	1 7/16	7/8		
×68[c]	20.0	21.1	21 1/8	0.430	7/16	1/4	8.27	8 1/4	0.685	11/16	1.19	1 3/8	7/8		
×62[c]	18.3	21.0	21	0.400	3/8	3/16	8.24	8 1/4	0.615	5/8	1.12	1 5/16	13/16		
×55[c]	16.2	20.8	20 3/4	0.375	3/8	3/16	8.22	8 1/4	0.522	1/2	1.02	1 3/16	13/16		
×48[c,f]	14.1	20.6	20 5/8	0.350	3/8	3/16	8.14	8 1/8	0.430	7/16	0.930	1 1/8	13/16		
W21×57[c]	16.7	21.1	21	0.405	3/8	3/16	6.56	6 1/2	0.650	5/8	1.15	1 5/16	13/16	18 3/8	3 1/2
×50[c]	14.7	20.8	20 7/8	0.380	3/8	3/16	6.53	6 1/2	0.535	9/16	1.04	1 1/4	13/16		
×44[c]	13.0	20.7	20 5/8	0.350	3/8	3/16	6.50	6 1/2	0.450	7/16	0.950	1 1/8	13/16		

[c] Shape is slender for compression with $F_y = 50$ ksi.
[f] Shape exceeds compact limit for flexure with $F_y = 50$ ksi.
[h] Flange thickness greater than 2 in. Special requirements may apply per AISC *Specification* Section A3.1c.

Table 1-1 (continued)
W-Shapes
Properties

W21

Nominal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	Compact Section Criteria $\frac{h}{t_w}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	r_{ts}	h_o	Torsional Properties J	Torsional Properties C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
275	2.95	14.2	7690	638	9.70	749	787	122	3.10	191	3.68	21.9	107	94400
248	3.22	15.8	6830	576	9.62	671	699	109	3.08	170	3.63	21.7	80.7	82400
223	3.55	17.5	6080	520	9.56	601	614	96.7	3.04	150	3.57	21.6	59.5	71700
201	3.86	20.6	5310	461	9.47	530	542	86.1	3.02	133	3.55	21.4	40.9	62000
182	4.22	22.6	4730	417	9.40	476	483	77.2	3.00	119	3.51	21.2	30.7	54400
166	4.57	25.0	4280	380	9.36	432	435	70.0	2.99	108	3.48	21.1	23.6	48500
147	5.44	26.1	3630	329	9.17	373	376	60.1	2.95	92.6	3.46	21.0	15.4	41100
132	6.01	28.9	3220	295	9.12	333	333	53.5	2.93	82.3	3.43	20.8	11.3	36000
122	6.45	31.3	2960	273	9.09	307	305	49.2	2.92	75.6	3.40	20.7	8.98	32700
111	7.05	34.1	2670	249	9.05	279	274	44.5	2.90	68.2	3.37	20.6	6.83	29200
101	7.68	37.5	2420	227	9.02	253	248	40.3	2.89	61.7	3.35	20.6	5.21	26200
93	4.53	32.3	2070	192	8.70	221	92.9	22.1	1.84	34.7	2.24	20.7	6.03	9940
83	5.00	36.4	1830	171	8.67	196	81.4	19.5	1.83	30.5	2.21	20.6	4.34	8630
73	5.60	41.2	1600	151	8.64	172	70.6	17.0	1.81	26.6	2.19	20.5	3.02	7410
68	6.04	43.6	1480	140	8.60	160	64.7	15.7	1.80	24.4	2.17	20.4	2.45	6760
62	6.70	46.9	1330	127	8.54	144	57.5	14.0	1.77	21.7	2.15	20.4	1.83	5960
55	7.87	50.0	1140	110	8.40	126	48.4	11.8	1.73	18.4	2.11	20.3	1.24	4980
48	9.47	53.6	959	93.0	8.24	107	38.7	9.52	1.66	14.9	2.05	20.2	0.803	3950
57	5.04	46.3	1170	111	8.36	129	30.6	9.35	1.35	14.8	1.68	20.5	1.77	3190
50	6.10	49.4	984	94.5	8.18	110	24.9	7.64	1.30	12.2	1.64	20.3	1.14	2570
44	7.22	53.6	843	81.6	8.06	95.4	20.7	6.37	1.26	10.2	1.60	20.3	0.770	2110

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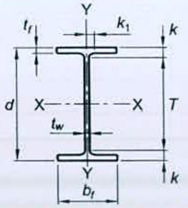

Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		Web $\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k k_{des}	Distance k k_{det}	Distance k_1	Distance T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W18×311[h]	91.6	22.3	22 3/8	1.52	1 1/2	3/4	12.0	12	2.74	2 3/4	3.24	3 9/16	1 9/16	15 1/8	5 1/2
×283[h]	83.3	21.9	21 7/8	1.40	1 3/8	11/16	11.9	11 7/8	2.50	2 1/2	3.00	3 3/8	1 1/2		
×258[h]	76.0	21.5	21 1/2	1.28	1 1/4	5/8	11.8	11 3/4	2.30	2 5/16	2.70	3 3/16	1 7/16		
×234[h]	68.6	21.1	21	1.16	1 3/16	5/8	11.7	11 5/8	2.11	2 1/8	2.51	3	1 3/8		
×211	62.3	20.7	20 5/8	1.06	1 1/16	9/16	11.6	11 1/2	1.91	1 15/16	2.31	2 13/16	1 3/8		
×192	56.2	20.4	20 3/8	0.960	15/16	1/2	11.5	11 1/2	1.75	1 3/4	2.15	2 5/8	1 5/16		
×175	51.4	20.0	20	0.890	7/8	7/16	11.4	11 3/8	1.59	1 9/16	1.99	2 7/16	1 1/4		
×158	46.3	19.7	19 3/4	0.810	13/16	7/16	11.3	11 1/4	1.44	1 7/16	1.84	2 3/8	1 1/4		
×143	42.0	19.5	19 1/2	0.730	3/4	3/8	11.2	11 1/4	1.32	1 5/16	1.72	2 3/16	1 3/16		
×130	38.3	19.3	19 1/4	0.670	11/16	3/8	11.2	11 1/8	1.20	1 3/16	1.60	2 1/16	1 3/16		
×119	35.1	19.0	19	0.655	5/8	5/16	11.3	11 1/4	1.06	1 1/16	1.46	1 15/16	1 3/16		
×106	31.1	18.7	18 3/4	0.590	9/16	5/16	11.2	11 1/4	0.940	15/16	1.34	1 13/16	1 1/8		
×97	28.5	18.6	18 5/8	0.535	9/16	5/16	11.1	11 1/8	0.870	7/8	1.27	1 3/4	1 1/8		
×86	25.3	18.4	18 3/8	0.480	1/2	1/4	11.1	11 1/8	0.770	3/4	1.17	1 5/8	1 1/16		
×76[c]	22.3	18.2	18 1/4	0.425	7/16	1/4	11.0	11	0.680	11/16	1.08	1 9/16	1 1/16		
W18×71	20.9	18.5	18 1/2	0.495	1/2	1/4	7.64	7 5/8	0.810	13/16	1.21	1 1/2	7/8	15 1/2	3 1/2[g]
×65	19.1	18.4	18 3/8	0.450	7/16	1/4	7.59	7 5/8	0.750	3/4	1.15	1 7/16	7/8		
×60[c]	17.6	18.2	18 1/4	0.415	7/16	1/4	7.56	7 1/2	0.695	11/16	1.10	1 3/8	13/16		
×55[c]	16.2	18.1	18 1/8	0.390	3/8	3/16	7.53	7 1/2	0.630	5/8	1.03	1 5/16	13/16		
×50[c]	14.7	18.0	18	0.355	3/8	3/16	7.50	7 1/2	0.570	9/16	0.972	1 1/4	13/16		
W18×46[c]	13.5	18.1	18	0.360	3/8	3/16	6.06	6	0.605	5/8	1.01	1 1/4	13/16	15 1/2	3 1/2[g]
×40[c]	11.8	17.9	17 7/8	0.315	5/16	3/16	6.02	6	0.525	1/2	0.927	1 3/16	13/16		
×35[c]	10.3	17.7	17 3/4	0.300	5/16	3/16	6.00	6	0.425	7/16	0.827	1 1/8	3/4		
W16×100	29.4	17.0	17	0.585	9/16	5/16	10.4	10 3/8	0.985	1	1.39	1 7/8	1 1/8	13 1/4	5 1/2
×89	26.2	16.8	16 3/4	0.525	1/2	1/4	10.4	10 3/8	0.875	7/8	1.28	1 3/4	1 1/16		
×77	22.6	16.5	16 1/2	0.455	7/16	1/4	10.3	10 1/4	0.760	3/4	1.16	1 5/8	1 1/16		
×67[c]	19.6	16.3	16 3/8	0.395	3/8	3/16	10.2	10 1/4	0.665	11/16	1.07	1 9/16	1		
W16×57	16.8	16.4	16 3/8	0.430	7/16	1/4	7.12	7 1/8	0.715	11/16	1.12	1 3/8	7/8	13 5/8	3 1/2[g]
×50[c]	14.7	16.3	16 1/4	0.380	3/8	3/16	7.07	7 1/8	0.630	5/8	1.03	1 5/16	13/16		
×45[c]	13.3	16.1	16 1/8	0.345	3/8	3/16	7.04	7	0.565	9/16	0.967	1 1/4	13/16		
×40[c]	11.8	16.0	16	0.305	5/16	3/16	7.00	7	0.505	1/2	0.907	1 3/16	13/16		
×36[c]	10.6	15.9	15 7/8	0.295	5/16	3/16	6.99	7	0.430	7/16	0.832	1 1/8	3/4		
W16×31[c]	9.13	15.9	15 7/8	0.275	1/4	1/8	5.53	5 1/2	0.440	7/16	0.842	1 1/8	3/4	13 5/8	3 1/2
×26[c,v]	7.68	15.7	15 3/4	0.250	1/4	1/8	5.50	5 1/2	0.345	3/8	0.747	1 1/16	3/4	13 5/8	3 1/2

[c] Shape is slender for compression with F_y = 50 ksi.
[g] The actual size, combination and orientation of fastener components should be compared with the geometry of the cross section to ensure compatibility.
[h] Flange thickness greater than 2 in. Special requirements may apply per AISC *Specification* Section A3.1c.
[v] Shape does not meet the h/t_w limit for shear in AISC *Specification* Section G2.1(a) with F_y = 50 ksi.

Table 1-1 (continued)
W-Shapes
Properties

W18–W16

Nom-inal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	Compact Section Criteria $\frac{h}{t_w}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X Z	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	Axis Y-Y Z	r_{ts}	h_o	Torsional Properties J	Torsional Properties C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
311	2.19	10.4	6970	624	8.72	754	795	132	2.95	207	3.53	19.6	176	76200
283	2.38	11.3	6170	565	8.61	676	704	118	2.91	185	3.47	19.4	134	65900
258	2.56	12.5	5510	514	8.53	611	628	107	2.88	166	3.42	19.2	103	57600
234	2.76	13.8	4900	466	8.44	549	558	95.8	2.85	149	3.37	19.0	78.7	50100
211	3.02	15.1	4330	419	8.35	490	493	85.3	2.82	132	3.32	18.8	58.6	43400
192	3.27	16.7	3870	380	8.28	442	440	76.8	2.79	119	3.28	18.7	44.7	38000
175	3.58	18.0	3450	344	8.20	398	391	68.8	2.76	106	3.24	18.4	33.8	33300
158	3.92	19.8	3060	310	8.12	356	347	61.4	2.74	94.8	3.20	18.3	25.2	29000
143	4.25	22.0	2750	282	8.09	322	311	55.5	2.72	85.4	3.17	18.2	19.2	25700
130	4.65	23.9	2460	256	8.03	290	278	49.9	2.70	76.7	3.13	18.1	14.5	22700
119	5.31	24.5	2190	231	7.90	262	253	44.9	2.69	69.1	3.13	17.9	10.6	20300
106	5.96	27.2	1910	204	7.84	230	220	39.4	2.66	60.5	3.10	17.8	7.48	17400
97	6.41	30.0	1750	188	7.82	211	201	36.1	2.65	55.3	3.08	17.7	5.86	15800
86	7.20	33.4	1530	166	7.77	186	175	31.6	2.63	48.4	3.05	17.6	4.10	13600
76	8.11	37.8	1330	146	7.73	163	152	27.6	2.61	42.2	3.02	17.5	2.83	11700
71	4.71	32.4	1170	127	7.50	146	60.3	15.8	1.70	24.7	2.05	17.7	3.49	4700
65	5.06	35.7	1070	117	7.49	133	54.8	14.4	1.69	22.5	2.03	17.7	2.73	4240
60	5.44	38.7	984	108	7.47	123	50.1	13.3	1.68	20.6	2.02	17.5	2.17	3850
55	5.98	41.1	890	98.3	7.41	112	44.9	11.9	1.67	18.5	2.00	17.5	1.66	3430
50	6.57	45.2	800	88.9	7.38	101	40.1	10.7	1.65	16.6	1.98	17.4	1.24	3040
46	5.01	44.6	712	78.8	7.25	90.7	22.5	7.43	1.29	11.7	1.58	17.5	1.22	1720
40	5.73	50.9	612	68.4	7.21	78.4	19.1	6.35	1.27	10.0	1.56	17.4	0.810	1440
35	7.06	53.5	510	57.6	7.04	66.5	15.3	5.12	1.22	8.06	1.51	17.3	0.506	1140
100	5.29	24.3	1490	175	7.10	198	186	35.7	2.51	54.9	2.92	16.0	7.73	11900
89	5.92	27.0	1300	155	7.05	175	163	31.4	2.49	48.1	2.88	15.9	5.45	10200
77	6.77	31.2	1110	134	7.00	150	138	26.9	2.47	41.1	2.85	15.7	3.57	8590
67	7.70	35.9	954	117	6.96	130	119	23.2	2.46	35.5	2.82	15.6	2.39	7300
57	4.98	33.0	758	92.2	6.72	105	43.1	12.1	1.60	18.9	1.92	15.7	2.22	2660
50	5.61	37.4	659	81.0	6.68	92.0	37.2	10.5	1.59	16.3	1.89	15.7	1.52	2270
45	6.23	41.1	586	72.7	6.65	82.3	32.8	9.34	1.57	14.5	1.87	15.5	1.11	1990
40	6.93	46.5	518	64.7	6.63	73.0	28.9	8.25	1.57	12.7	1.86	15.5	0.794	1730
36	8.12	48.1	448	56.5	6.51	64.0	24.5	7.00	1.52	10.8	1.83	15.5	0.545	1460
31	6.28	51.6	375	47.2	6.41	54.0	12.4	4.49	1.17	7.03	1.42	15.5	0.461	739
26	7.97	56.8	301	38.4	6.26	44.2	9.59	3.49	1.12	5.48	1.38	15.4	0.262	565

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TABLE 5.2 Limiting Width–Thickness Ratios for Compression Elements

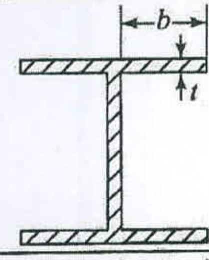
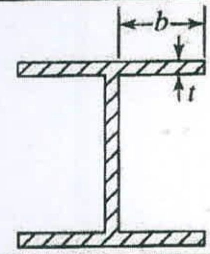
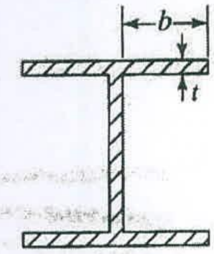
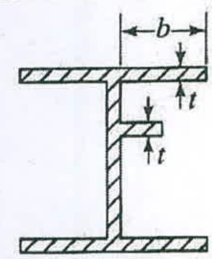
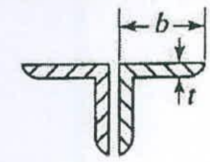
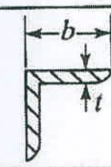
	Case	Description of Element	Width–Thickness Ratio	Limiting Width–Thickness Ratios: λ_p (compact)	Limiting Width–Thickness Ratios: λ_r (noncompact)	Example
Unstiffened Elements	1	Flexure in flanges of rolled I-shaped sections and channels	b/t	$0.38\sqrt{E/F_y}$	$1.0\sqrt{E/F_y}$	
	2	Flexure in flanges of doubly and singly symmetric I-shaped built-up sections	b/t	$0.38\sqrt{E/F_y}$	$0.95\sqrt{k_cE/F_L}$ [a],[b]	
	3	Uniform compression in flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections; outstanding legs of pairs of angles in continuous contact and flanges of channels	b/t	NA	$0.56\sqrt{E/F_y}$	
	4	Uniform compression in flanges of built-up I-shaped sections and plates or angle legs projecting from built-up I-shaped sections	b/t	NA	$0.64\sqrt{k_cE/F_y}$ [a]	
	5	Uniform compression in legs of single angles, legs of double angles with separators, and all other unstiffened elements	b/t	NA	$0.45\sqrt{E/F_y}$	
	6	Flexure in legs of single angles	b/t	$0.54\sqrt{E/F_y}$	$0.91\sqrt{E/F_y}$	

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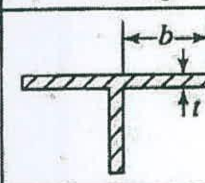
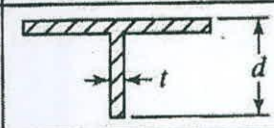
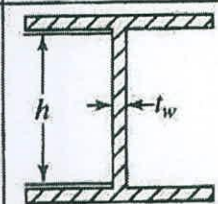
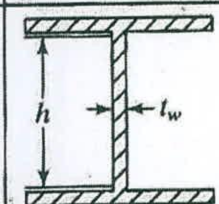
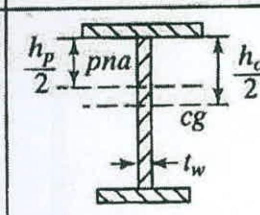
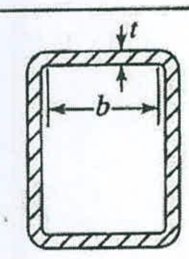
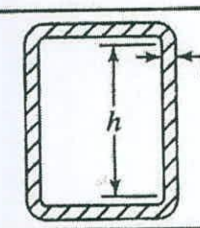
TABLE 5.2 (cont.) Limiting Width–Thickness Ratios for Compression Elements

	Case	Description of Element	Width–Thickness Ratio	Limiting Width–Thickness Ratios λ_p (compact)	λ_r (noncompact)	Example
Stiffened Elements	7	Flexure in flanges of tees	b/t	$0.38\sqrt{E/F_y}$	$1.0\sqrt{E/F_y}$	
	8	Uniform compression in stems of tees	d/t	NA	$0.75\sqrt{E/F_y}$	
	9	Flexure in webs of doubly symmetric I-shaped sections and channels	h/t_w	$3.76\sqrt{E/F_y}$	$5.70\sqrt{E/F_y}$	
	10	Uniform compression in webs of doubly symmetric I-shaped sections	h/t_w	NA	$1.49\sqrt{E/F_y}$	
	11	Flexure in webs of single-symmetric I-shaped sections	h_c/t_w	$\dfrac{\frac{h_c}{h_p}\sqrt{\frac{E}{F_y}}}{\left(0.54\frac{M_p}{M_y}-0.09\right)^2} \le \lambda_r$	$5.70\sqrt{E/F_y}$	
	12	Uniform compression in flanges of rectangular box and hollow structural sections of uniform thickness subject to bending or compression; flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.12\sqrt{E/F_y}$	$1.40\sqrt{E/F_y}$	
	13	Flexure in webs of rectangular HSS	h/t	$2.42\sqrt{E/F_y}$	$5.70\sqrt{E/F_y}$	

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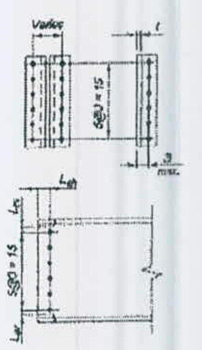
Beam	F_y = 50 ksi F_u = 65 ksi
Angle	F_y = 36 ksi F_u = 58 ksi

Table 10-1 (continued)
All-Bolted Double-Angle Connections

3/4-in. Bolts

Bolt and Angle Available Strength, kips

6 Rows W40, 36, 33, 30, 27, 24, 21	Bolt Group	Thread Cond.	Hole Type	Angle Thickness, in. 1/4 ASD	1/4 LRFD	5/16 ASD	5/16 LRFD	3/8 ASD	3/8 LRFD	1/2 ASD	1/2 LRFD
	Group A	N	STD	99.5	149	124	187	143	215	143	215
		X	STD	99.5	149	124	187	149	224	180	271
		SC Class A	STD	75.9	114	75.9	114	75.9	114	75.9	114
			OVS	64.7	96.8	64.7	96.8	64.7	96.8	64.7	96.8
			SSLT	75.9	114	75.9	114	75.9	114	75.9	114
		SC Class B	STD	99.5	149	124	187	127	190	127	190
			OVS	98.6	148	108	161	108	161	108	161
			SSLT	98.2	147	123	184	127	190	127	190
	Group B	N	STD	99.5	149	124	187	149	224	180	271
		X	STD	99.5	149	124	187	149	224	199	299
		SC Class A	STD	94.9	142	94.9	142	94.9	142	94.9	142
			OVS	80.9	121	80.9	121	80.9	121	80.9	121
			SSLT	94.9	142	94.9	142	94.9	142	94.9	142
		SC Class B	STD	99.5	149	124	187	149	224	158	237
			OVS	98.6	148	123	185	135	202	135	202
			SSLT	98.2	147	123	184	147	221	158	237

Beam Web Available Strength per Inch Thickness, kips/in.

Hole Type		STD				OVS				SSLT			
		L_{eh}*, in.											
L_{ev}, in.		1 1/2 ASD	1 1/2 LRFD	1 3/4 ASD	1 3/4 LRFD	1 1/2 ASD	1 1/2 LRFD	1 3/4 ASD	1 3/4 LRFD	1 1/2 ASD	1 1/2 LRFD	1 3/4 ASD	1 3/4 LRFD
Coped at Top Flange Only	1 1/4	249	374	258	386	234	351	242	363	246	370	255	382
	1 3/8	252	378	260	390	236	355	245	367	249	373	257	385
	1 1/2	254	381	262	394	239	358	247	371	251	377	259	389
	1 5/8	257	385	265	397	241	362	249	374	254	381	262	393
	2	264	396	272	408	249	373	257	385	261	392	269	404
	3	284	425	292	438	268	402	276	414	281	421	289	433
Coped at Both Flanges	1 1/4	239	358	239	358	224	336	224	336	239	358	239	358
	1 3/8	244	366	244	366	229	344	229	344	244	366	244	366
	1 1/2	249	373	249	373	234	351	234	351	249	373	249	373
	1 5/8	254	380	254	380	239	358	239	358	254	380	254	380
	2	264	396	268	402	249	373	254	380	261	392	268	402
	3	284	425	292	438	268	402	276	414	281	421	289	433
Uncoped		351	527	351	527	351	527	351	527	351	527	351	527

Support Available Strength per Inch Thickness, kips/in.

Hole Type	ASD	LRFD
STD/ OVS/ SSLT	702	1050

Notes:
STD = Standard holes
OVS = Oversized holes
SSLT = Short-slotted holes transverse to direction of load
N = Threads included
X = Threads excluded
SC = Slip critical

* Tabulated values include 1/4-in. reduction in end distance, L_{eh}, to account for possible underrun in beam length.

Note: Slip-critical bolt values assume no more than one filler has been provided or bolts have been added to distribute loads in the fillers.

Contd-- P/12

=12= CE 319 (13)

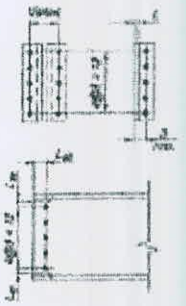
Beam	F_y = 50 ksi F_u = 65 ksi
Angle	F_y = 36 ksi F_u = 58 ksi

Table 10-1 (continued)
All-Bolted Double-Angle Connections

3/4-in. Bolts

Bolt and Angle Available Strength, kips

5 Rows W30, 27, 24, 21, 18	Bolt Group	Thread Cond.	Hole Type	1/4 ASD	1/4 LRFD	5/16 ASD	5/16 LRFD	3/8 ASD	3/8 LRFD	1/2 ASD	1/2 LRFD
	Group A	N	STD	83.3	125	104	156	119	179	119	179
		X	STD	83.3	125	104	156	125	187	150	225
		SC Class A	STD	63.3	94.9	63.3	94.9	63.3	94.9	63.3	94.9
			OVS	53.9	80.7	53.9	80.7	53.9	80.7	53.9	80.7
			SSLT	63.3	94.9	63.3	94.9	63.3	94.9	63.3	94.9
		SC Class B	STD	83.3	125	104	156	105	158	105	158
			OVS	82.4	124	89.9	134	89.9	134	89.9	134
			SSLT	82.0	123	102	154	105	158	105	158
	Group B	N	STD	83.3	125	104	156	125	187	150	225
		X	STD	83.3	125	104	156	125	187	167	250
		SC Class A	STD	79.1	119	79.1	119	79.1	119	79.1	119
			OVS	67.4	101	67.4	101	67.4	101	67.4	101
			SSLT	79.1	119	79.1	119	79.1	119	79.1	119
		SC Class B	STD	83.3	125	104	156	125	187	132	198
			OVS	82.4	124	103	155	112	168	112	168
			SSLT	82.0	123	102	154	123	184	132	198



Beam Web Available Strength per Inch Thickness, kips/in.

Hole Type		STD L_{eh}* = 1 1/2 ASD	STD 1 1/2 LRFD	STD 1 3/4 ASD	STD 1 3/4 LRFD	OVS 1 1/2 ASD	OVS 1 1/2 LRFD	OVS 1 3/4 ASD	OVS 1 3/4 LRFD	SSLT 1 1/2 ASD	SSLT 1 1/2 LRFD	SSLT 1 3/4 ASD	SSLT 1 3/4 LRFD
Coped at Top Flange Only	L_{ev} = 1 1/4	208	312	216	324	195	293	203	305	205	307	213	320
	1 3/8	210	316	219	328	197	296	206	308	207	311	216	323
	1 1/2	213	319	221	332	200	300	208	312	210	315	218	327
	1 5/8	215	323	223	335	202	303	210	316	212	318	220	331
	2	223	334	231	346	210	314	218	327	220	329	228	342
	3	242	363	250	375	229	344	237	356	239	359	247	371
Coped at Both Flanges	1 1/4	197	296	197	296	185	278	185	278	197	296	197	296
	1 3/8	202	303	202	303	190	285	190	285	202	303	202	303
	1 1/2	207	311	207	311	195	293	195	293	207	311	207	311
	1 5/8	212	318	212	318	200	300	200	300	212	318	212	318
	2	223	334	227	340	210	314	215	322	220	329	227	340
	3	242	363	250	375	229	344	237	356	239	359	247	371
Uncoped		293	439	293	439	293	439	293	439	293	439	293	439

Support Available Strength per Inch Thickness, kips/in.

Hole Type	ASD	LRFD
STD/ [illegible]	585	878

Notes:
STD = Standard holes
OVS = Oversized holes
SSLT = Short-slotted holes transverse to direction of load
N = Threads included
X = Threads excluded
SC = Slip critical

* Tabulated values include 1/4-in. reduction in end distance, L_{eh}, to account for possible underrun in beam length.

Note: Slip-critical bolt values assume no more than one filler has been provided or bolts have been added to distribute loads in the fillers.

=13= CE319 (B)

Beam	F_y = 50 ksi, F_u = 65 ksi
Angle	F_y = 36 ksi, F_u = 58 ksi

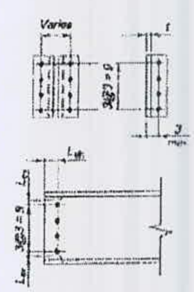
Table 10-1 (continued)
All-Bolted Double-Angle Connections

3/4-in. Bolts

Bolt and Angle Available Strength, kips

4 Rows

W24, 21, 18, 16



Bolt Group	Thread Cond.	Hole Type	1/4 ASD	1/4 LRFD	5/16 ASD	5/16 LRFD	3/8 ASD	3/8 LRFD	1/2 ASD	1/2 LRFD
Group A	N	STD	67.1	101	83.9	126	95.5	143	95.5	143
	X	STD	67.1	101	83.9	126	101	151	120	180
	SC Class A	STD	50.6	75.9	50.6	75.9	50.6	75.9	50.6	75.9
		OVS	43.1	64.5	43.1	64.5	43.1	64.5	43.1	64.5
		SSLT	50.6	75.9	50.6	75.9	50.6	75.9	50.6	75.9
	SC Class B	STD	67.1	101	83.9	126	84.4	127	84.4	127
		OVS	65.3	97.9	71.9	108	71.9	108	71.9	108
		SSLT	65.8	98.7	82.2	123	84.4	127	84.4	127
Group B	N	STD	67.1	101	83.9	126	101	151	120	180
	X	STD	67.1	101	83.9	126	101	151	134	201
	SC Class A	STD	63.3	94.9	63.3	94.9	63.3	94.9	63.3	94.9
		OVS	53.9	80.7	53.9	80.7	53.9	80.7	53.9	80.7
		SSLT	63.3	94.9	63.3	94.9	63.3	94.9	63.3	94.9
	SC Class B	STD	67.1	101	83.9	126	101	151	105	158
		OVS	65.3	97.9	81.6	122	89.9	134	89.9	134
		SSLT	65.8	98.7	82.2	123	98.7	148	105	158

Angle Thickness, in.

Beam Web Available Strength per Inch Thickness, kips/in.

Hole Type		STD				OVS				SSLT			
		L_{eh}*, in.											
L_{ev}, in.		1 1/2		1 3/4		1 1/2		1 3/4		1 1/2		1 3/4	
		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD
Coped at Top Flange Only	1 1/4	167	250	175	262	156	234	164	246	164	245	172	257
	1 3/8	169	254	177	266	158	238	167	250	166	249	174	261
	1 1/2	171	257	180	269	161	241	169	254	168	253	177	265
	1 5/8	174	261	182	273	163	245	171	257	171	256	179	268
	2	181	272	189	284	171	256	179	268	178	267	186	279
	3	201	301	209	313	190	285	198	297	198	296	206	309
Coped at Both Flanges	1 1/4	156	234	156	234	146	219	146	219	156	234	156	234
	1 3/8	161	241	161	241	151	227	151	227	161	241	161	241
	1 1/2	166	249	166	249	156	234	156	234	166	249	166	249
	1 5/8	171	256	171	256	161	241	161	241	171	256	171	256
	2	181	272	185	278	171	256	176	263	178	267	185	278
	3	201	301	209	313	190	285	198	297	198	296	206	309
Uncoped		234	351	234	351	234	351	234	351	234	351	234	351

Support Available Strength per Inch Thickness, kips/in.

Hole Type	ASD	LRFD
STD/ OVS/ SSLT	468	702

Notes:
STD = Standard holes
OVS = Oversized holes
SSLT = Short-slotted holes transverse to direction of load
N = Threads included
X = Threads excluded
SC = Slip critical

* Tabulated values include 1/4-in. reduction in end distance, L_{eh}, to account for possible underrun in beam length.

Note: Slip-critical bolt values assume no more than one filler has been provided or bolts have been added to distribute loads in the fillers.

L-3/T-2/CE **Date: 22/03/2022**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2019-2020

Sub: **CE 333** (Environmental Engineering II)

Full Marks: 280 Time: 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

The figures in the margin indicate full marks

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.
Assume any reasonable value, if needed.

1. (a) What are the methods commonly applied in TOC analyzer to convert organics into carbon dioxide?
Consider a 3.58×10^{-3} M glycine solution [$CH_2(NH_2)COOH$] that is completely oxidized to CO_2, NO_3 and H_2O. Find the amount of oxygen required (theoretically) to complete the reaction. **($4+11\frac{2}{3}$)**

(b) How the waste is treated in the facultative pond? Discuss the mechanism. How to check the surface BOD loading in the facultative pond used for biological wastewater treatment? **(8+7)**

(c) How the growth phases are related to efficient biological treatment of wastewater? Discuss the effect of food to microorganism ratio on bacterial growth.
Draw a diagram and show the relation of specific microbial growth rate with substrate concentration. **(5+5+6)**

2. (a) Write down the significance of sludge stabilizations. Describe the methods of sludge dewatering. **($4+8\frac{2}{3}$)**

(b) What are the advantages of sludge recirculation in wastewater treatment using trickling filter? **(5)**

(c) A completely mixed activated sludge treatment system is designed to treat domestic wastewater of a community. From lab analysis the following information are obtained: **(16)**

Influent flow rate = 22.5 m^3/min

Sludge density index = 0.92

SSV_{30} = 175 mL

Hydraulic retention time = 8.2 hr

Sludge age = 9 days

F/M = 0.4

Organic waste removal efficiency = 98.5%

Determine the substrate concentration in the final treated effluent and Sludge recirculation rate.

Contd …… P/2

CE 333

Contd... Q. No. 2

(d) Write short note on phosphorous removal by chemical oxidation.
Describe the thioglycolate tubes test for determination of bacterial oxygen requirements. **(4+9)**

3. (a) What are the effects of environmental pollution on the health of humans? **(15)**
(b) List the consequences of ozone layer depletion. **(10)**
(c) What are the basic principles of waste treatment? Write down the application of – (i) Pressure-chlorination and (ii) Flotation in wastewater treatment. **(6+6)**
(d) List the disadvantages of high water pressure in water distribution system of a building? How will you ensure no risk of contamination of water supply to a building? **($3+6\frac{2}{3}$)**

4. (a) Write the pressure balance equation of designing an upfeed zone of water supply to a building with the meaning of each term. How can you evaluate fitting friction? **(4+2)**
(b) Differentiate between self-siphonage and induced-siphonage of a plumbing drainage system. Write down the steps to design the rain water down pipe for a flat roof of a building. **(4+4)**
(c) What is a sustainable water supply or sanitation system? List the merits of community participation in a water supply or sanitation program. **($4\frac{2}{3}+10$)**
(d) The roof tank of a 30 storied tall building is placed 26 ft above the top-most fixture whose pressure requirement is 9 psi. The maximum fixture pressure requirement of the two top-most floors is 9 psi. The top-most zone covers 8 floors and the floor to floor height is 10 ft. The maximum fixture pressure requirement of each floor is 16 psi except the two top-most floors. Calculate the permissible pressure drops in the concerned riser pipe. Assume reasonable value of any missing data if required. **(18)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) A WWTP employing biological treatment has been designed for a long-term average inflow of 300 g/m^3 BOD_5 and 20 g/m^3 P. Given the average flow rate of 2 m^3/s, draw the sustained peak mass loading curves for BOD_5 and low-flow loading curves for NH_3-N using the typical curves provided in **Figure 1**. Briefly explain the need for such sustained low-flow curves in the operation of a WWTP. Briefly explain the need for such sustained peak mass loading and low-flow loading curves in the operation of this WWTP. **($26\frac{2}{3}$)**

Contd P/3

CE 333

Contd... Q. No. 5

(b) Briefly explain the working principle of an anaerobic baffled reactor (ABR) (with an appropriate sketch) and discuss its advantages over a conventional septic tank. What do you understand by DEWATS? Draw the flow diagram of a typical DEWATS, identifying the treatment processes employed. **(10)**

(c) You have been appointed by a GRP/FRP pipe manufacturing company with the responsibility to promote the use of GRP/FRP in place of Concrete Sewer pipes. What points would you present in favor of your product to client such as DWASA? How would you counter the argument of the client that GRP/FRP is very expensive compared to concrete sewer pipes? **(10)**

6. (a) Design a suitable latrine for a family having 9 members living in a village, where tubewell based water supply is available. The estimated water use for the latrine is at 12 lpcd. The long-term infiltration capacity of soil in the area is estimated at 30 L/m^2.day. The village is located in a high water table area, and the depth to groundwater level is 3.2 m below the ground surface. The latrine pit needs to be constructed with concrete ring that are 1.1 m in diameter and 0.3 m in depth. **($26\frac{2}{3}$)**

   (i) What type of latrine would you suggest for the family? Explain.
   (ii) Design the latrine (including venting system) and estimate its design life.
   (iii) Draw a neat sketch (both plan and section) showing all elements of the designed latrine. Also, list the facilities that should be provided within the latrine.

   [Assume reasonable values for parameters not given]

   (b) The Khan Shaheb Osman Ali Crikcket Stadium gets inundated due to overflow of wastewater and run-off water every season. A 300m long, 1200mm (48 inch) new relief sewer has been installed to carry the wastewater from the manhole on the south-west corner to the local canal running along the eastern boundary wall. The upstream manhole invert is at 98.750m and the invert at the canal discharge point is at 98.450m. The design flow rate for this relief sewer is 0.69 m^3/s. What is the water level at the upstream manhole when the downstream water surface is at (a) 98m? (b) At 100.5m? Head loss at the entrance and exit is about 0.024m. Head loss due to friction along the surface of the pipe is given by the following equation. **(10)**

$$h_f = \left[\frac{\frac{n}{Q}}{\left\{ A \times \left(\frac{D}{4} \right)^{\frac{2}{3}} \right\}} \right]^2$$; symbols have usual meaning in SI unit as appropriate

[**Note**: Hydraulic element diagram provided in **Figure 2**]

Contd P/4

CE 333

Contd... Q. No. 6

(c) Sand envelopes are sometimes placed around the pits of pour-flush latrines. What are the purposes of such sand envelops? Explain with appropriate figures/sketches. **(10)**

7. (a) A trunk sewer is to be sized for a 25 km^2 (2,500 ha) city with a naturally sloped towards the major river with a gradient of 1 in 1000. It will be 60% residential, 30% commercial, and 10% industrial. The residential area will have 40% large lots, 55% small single family lots, and 5% multi-story apartments. The average domestic wastewater flow rate is 800 L/d/capita (9.26×10^{-6} m^3/sec/person), the average commercial flow rate is 25,000 L/D/ha (2.89×10^{-4} m^3/sec/ha), and the average industrial flow rate is 40,000 L/d/ha (4.63×10^{-4} m^3/sec/ha). I&I is 1,000 L/d/ha for the entire area. Estimate the peak and minimum flows to be handled by the trunk sewer. Given: $Q_{peak}/Q_{avg} = 5.5/\ (p^{0.18})$ and $Q_{min}/Q_{avg} = 0.2/\ (p^{0.16})$, where *'p'* is the total city population in thousands. Also design the sewer based on the estimated flow and the saturation densities for the residential areas given in the table below: **($26\frac{2}{3}$)**

Type of area	**Density (Persons/ha)**
Large lots	5-7
Small lots, single-family	75
Small lots, two-family	125
Multistory apartments	2,500

(b) What do you understand by onsite and offsite sanitation systems? **(10)**

Draw flow diagrams showing all elements of the complete sanitation systems (including FSM, as appropriate) based on: (a) septic tank system; (b) single off-set pit pour-flush latrine; (c) alternating twin off-set pit pour-flush latrine.

(c) The conventional method of ranking a set of values for plotting Cumulative Density Function uses the expression **m/(n + 1)**. However, the Blom's Transformation suggests the use of the expression **(m-3/8)/(n + $\frac{1}{4}$)**. What is the justification of using Bolm's Transformation compare to the conventional method? **(10)**

Contd P/5

CE 333

8. (a) List the major processes that occur in a septic tank. **($26\frac{2}{3}$)**

Design a septic tank for 2 families, each with 8 family members, Consider the wastewater flow rate to be 110 lpcd and a desludging frequency of 2 (two) years. The hydraulic detention time of the tank should be at least 1 day in order to maintain acceptable effluent quality. Also draw:

(i) A plan view of the designed septic tank (consider two chambers)

(ii) A section showing depths of different zones of the septic tank, and

(iii) A section showing the positions and sizes of inlet and outlet devices, and dimensions of the vertical legs of the inlet and outlet devices.

[Consider a design temperature of 24°C; assume reasonable values for parameters not given]

(b) Write down the important issues that need to be considered in the planning of fecal sludge collection (emptying) and transportation in a city/community. **(10)**

Draw a flow diagram showing the common treatment processes employed for the treatment of fecal sludge. Which technologies are commonly used for solid-liquid separation in the fecal sludge treatment plants (FSTPs) in Bangladesh?

(c) The following schematic diagram (**Figure 3**) represents the treatment processes adopted at an ETP in a Textile Industry. Being the Environmental Engineer in charge of ETP operations, it is your responsibility to identify the possible reasons(s) for the problems and briefly suggest remedial measure(s) for each of these. Also, identify the sampling locations on the diagram for each problems, if required. **(10)**

i) On the day of commissioning, the Equalization Tank is found to be forming foams/froths covering the entire top layer.

ii) On a certain workday, it was observed that in the Aeration Chamber the Fine Bubble Blower is blowing coarse bubbles. What may be the reason for this? What would be its effect on the operation of the ETP? How would you fix it?

iii) On another day, the BOD_5 of the effluent exceeded the discharge standard set by the DoE.

iv) On a separate day, the Aeration Tank formed a sludge blanket at the top.

Contd ... P/6

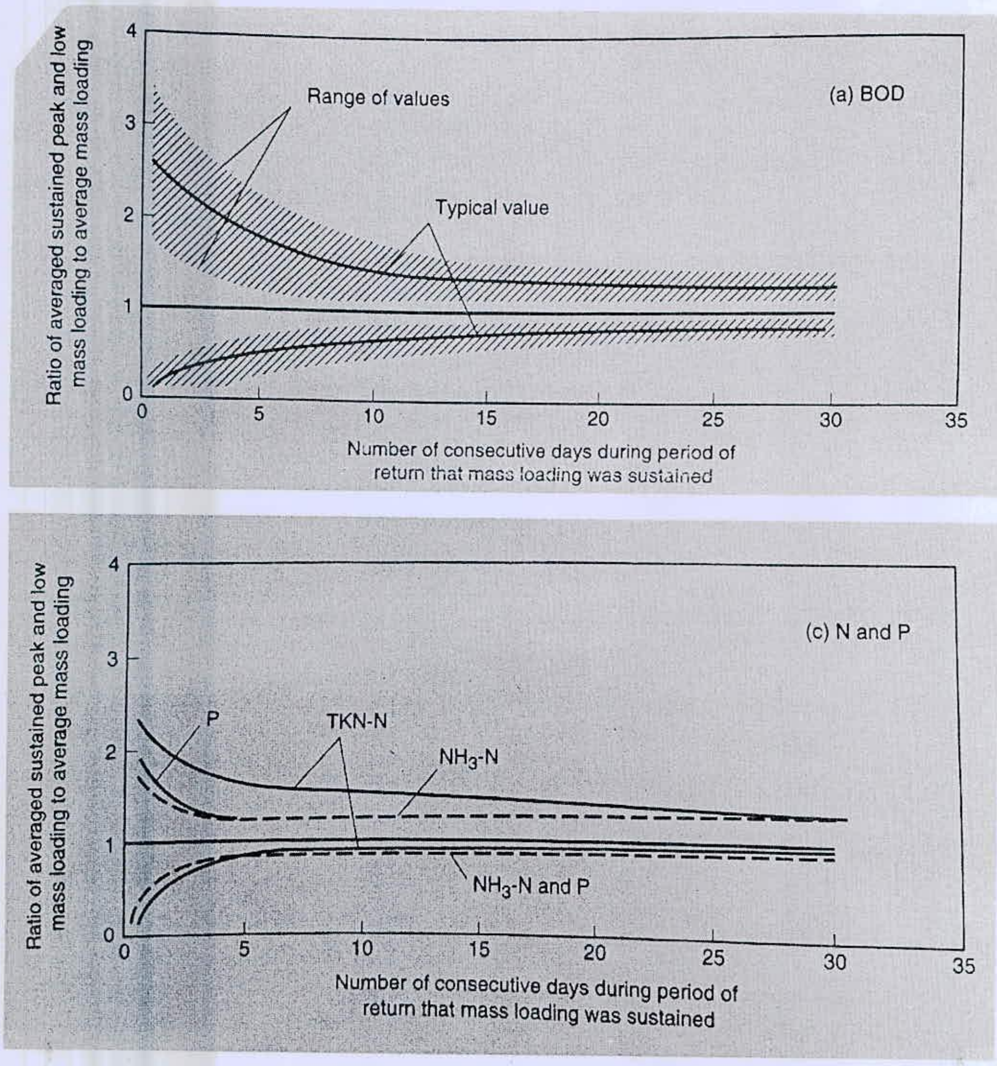


Figure 1: For Question 5 (a)

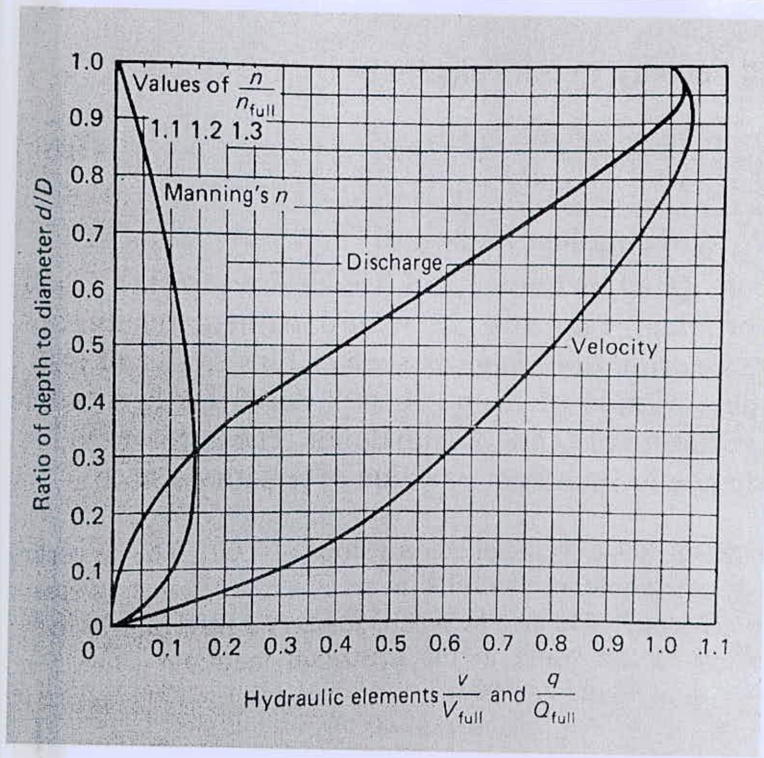


Figure 2: For Question 6 (b)

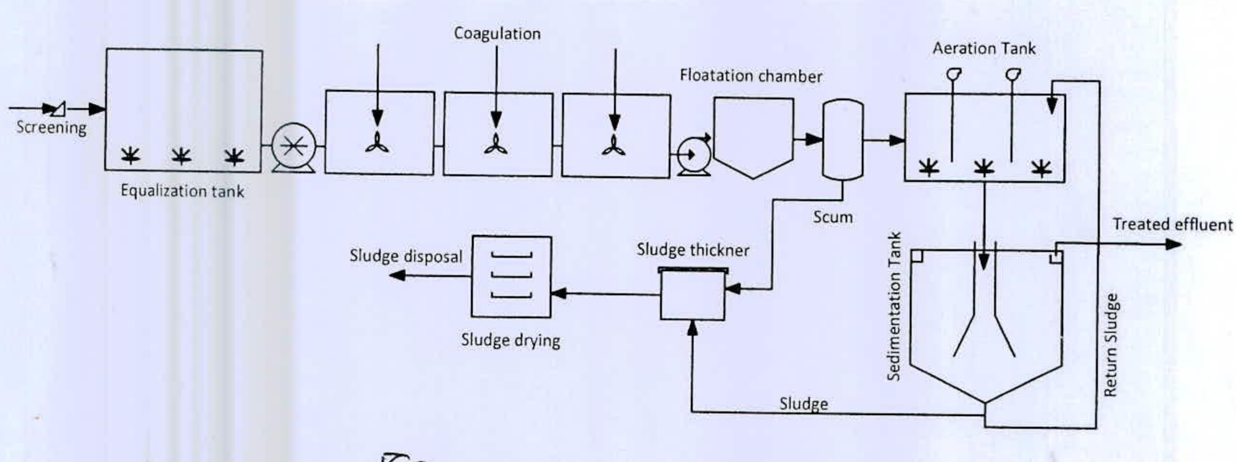


Figure 3 [for Question No. 8(c)]

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L-3/T-2/CE **Date: 10/04/2022**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2019-2020

Sub: **CE 351** (Transportation Engineering I: Transportation Planning and Traffic Engineering)

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE** questions.

1. (a) Explain diagrammatically the basic movements to categorize travel pattern in a planning area. **(11)**

(b) Explain the following: **(12)**

(i) Design Speed, (ii) Design Vehicle, (iii) Transition Runoff and (iv) Widening of Curves.

(c) Calculate the inter zonal trips using a simple gravity model from the following data. Assume exponent of travel time as 0.6. **(12)**

Production Zone i	Employment Zone	Employments	Travel Time from Zone i
Ti = 450 work trips	1	750	9 minutes
	2	400	5 minutes
	3	300	7 minutes

2. (a) What are the functions of shoulder and median in a highway? Why roads are widened at highway curves? **(11)**

(b) A driver moving at a speed of 65 mph on a 3 percent upgrade section of a highway sights an object 500 ft away on the highway and applied the brake. If the coefficient of friction for the pavement is 0.29 and acceleration due to gravity is 32.2 ft/sec^2, would the driver be able to stop the car before hitting the object? **(12)**

(c) Show diagrammatically the method of attaining super-elevation considering pavement revolved about centre line. **(12)**

3. (a) State the advantages and disadvantages of a rotary intersection. **(11)**

(b) Show with neat sketches the minimum passing sight distance for a two-lane two-way highway for right-band drive vehicle and keep-to-left convention. **(12)**

(c) What is the difference between the terms "Accident" and "Crash" in road safety study? Show the following action with collision diagram: **(12)**

(i) rear-end, (ii) right angle, (iii) side swipes and (iv) Head-on.

Contd P/2

4. (a) Briefly describe the importance of Traffic Engineering. Write down the ways of classifying roadway system. Name the common tools that are available to traffic engineer to tackle congestion and road safety problems. **(3+4+4=11)**

(b) State the objectives and methods of collecting data for the following surveys: **(4×5=20)**

(i) Volume, (ii) Speed, (iii) Delay, (iv) Origin - destination (O-D)

(c) Define: (i) PIEV, (ii) DHV, (iii) Pace, (iv) PCU/PCE. **(4×1=4)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE** questions.

5. (a) Explain different components, dimensions and interdisciplinary breadth of Transportation system with figures. Draw a graph showing vehicle-miles of travel by street class and based on this develop a road hierarchy strategy for a city like Dhaka. **(10+9=19)**

(b) Write down 4 (four) key points of Transportation system with relevant discussion. Also, draw a Transportation System model showing its link with real transportation elements and services. **(8+8=16)**

6. (a) Explain Intelligent Transport System (ITS) Architecture and major sub system components. Discuss ITS applications for Traffic management and public transport operations. **(11+8=19)**

(b) Discuss five properties of transport physical environment that directly impact human behavior. Explain the importance of Accessibility vs. Mobility interaction diagram for urban road types and road network design. **(10+6=16)**

7. (a) Develop a comparative table showing capacity, cost, flexibility, safety and implementation difficulties features of public transport modes: Bus Rapid Transit (BRT), Light Rail Transit (LRD), Heavy Metro Rail (MRT) and Commuter Train (CT). Draw simple network diagram of various public transport network shape mentioning one advantage and one disadvantage for each. Explain why Bus sub-system is still considered as the backbone of urban public transport system? **(8+8+3=19)**

(b) Write short notes on: (i) Water Transport in Bangladesh, (ii) Road network development in Bangladesh, (iii) Urban Transport System of Bangladesh, and (iv) Prospects of Bangladesh Railway Service expansion. **(4×4=16)**

Contd P/3

8. (a) Differentiate between: **(3+3+3=9)**

   (i) Time mean speed and Space mean speed

   (ii) On-street parking and off-street parking

   (iii) Pre-timed signal and vehicle-actuated signal

   (b) Briefly explain the importance of street lighting. State the problems associated with the larger sized vehicles and mention important requirements of a truck terminal. State the regulation measures that are needed to ensure proper functioning and effective use of a Bus terminal. **(3+3+3=9)**

   (c) Differentiate between roadway signs and markings. At what circumstances all-red period is considered in traffic signal design? Mention the problems associated with traffic signals in Bangladesh. **(4+4+4=12)**

   (d) Spot speed data were collected at a section of highway during an improvement work. The speed characteristics are given below. Determine whether there was any significant difference between the average speeds at the 95% confidence level. Assume reasonable value for any missing data. **(5)**

   $U_1 = 34.0$ kmph $\quad\quad U_2 = 37.0$ kmph

   $S_1 = 6.0$ kmph $\quad\quad S_2 = 7.0$ kmph

   $n_1 = 250$ nos. $\quad\quad n_2 = 260$ nos.

L-3/T-2/CE Date: 18/04/2022

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2019-2020

Sub: **WRE 311** (Open Channel Hydraulics)

Full Marks: 210 Time: 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

The figures in the margin indicate full marks

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) Determine the state of flow for a circular section whose diameter is 2.5m. The depth of flow in the channel is 1m and mean velocity is 3m/s. Assume the coefficient of velocity to be unity. **(10)**

(b) Show that for a channel with large slope the pressure distribution is less than the hydrostatic pressure. **(10)**

(c) For the following open channel identify the channel types: (i) chute, (ii) culvert (ii) tunnel **($6\frac{2}{3}$)**

(d) For the following velocity distribution in an open channel flow compute, the velocity distribution correction coefficients. **(20)**

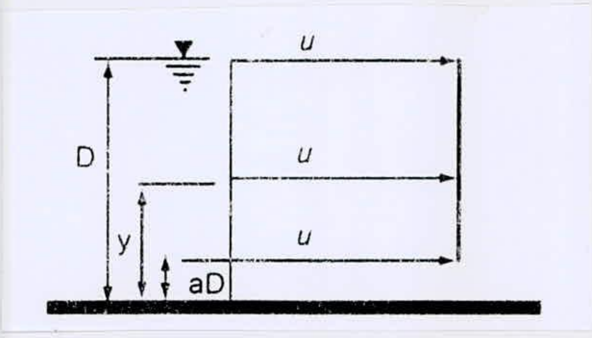

Figure 1 for Question 1(d)

2. (a) Show that the hydraulic exponent for critical flow computation for parabolic section is equal to 4. **(10)**

(b) A 2.5 m wide rectangular channel carries a discharge of 6.0 m^3/s of flow at a depth of 0.50 m. Calculate the minimum height of a flat topped hump required to be placed at a section to cause critical flow over the hump. The energy loss over the hump can be taken as 10% of the upstream velocity head. **(15)**

(c) A 3m wide rectangular channel carriers a discharge of 3 m^3/s at a depth of 1.0 m. If the width is to be reduced to 2.0 m and bed raised by 10 cm, what would be the depth in the contracted section? What maximum rise in the bed level is possible without affecting the depth of flow upstream of the transition. Neglect all energy losses. **(15)**

(d) Show that at critical state of flow the discharge is maximum. **($6\frac{2}{3}$)**

Contd P/2

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3. (a) Show that forecasting a rectangular channel if F_1 and F_2 are the Froude numbers corresponding to the alternate depths of a certain discharge then, **(10)**

$$\left(\frac{F_2}{F_1}\right)^{2/3} = \frac{2+F_2^2}{2+F_1^2}$$

(b) An overflow spillway shown in Figure 2 is 40.0m high. If the design energy head is 2.5m over the spillway, find the sequent depths and energy loss in a hydraulic jump formed on a horizontal apron at the toe of the spillway. Neglect energy loss due to flow over the spillway face and assume $C_d = 0.738$. **(16)**

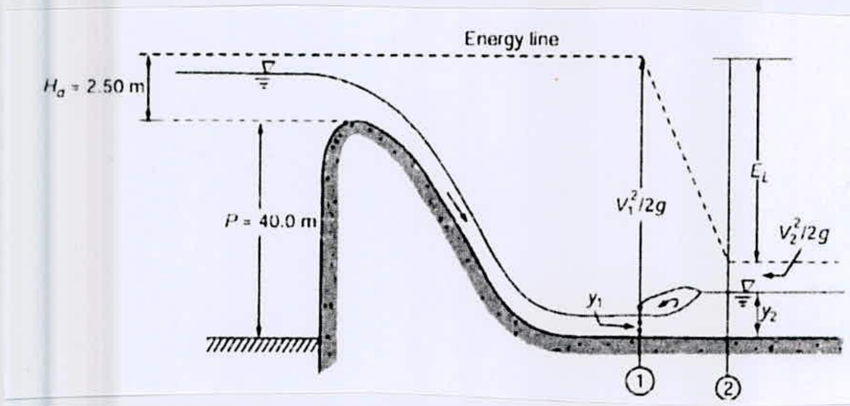

Figure 2 for Question 3(b)

(c) Design a USBR stilling basin **type III** for an overflow spillway with the following data: **(20 $\frac{2}{3}$)**

Elevation of ground: 0.0 m

Velocity at the foot of the spillway: 14.70 m/s

Assume other design parameters based on the type III basin criteria.

Show sketches of the final design with all the appurtenances.

4. (a) Show that most economical trapezoidal section is half of a regular hexagon. **(10)**

(b) Design a trapezoidal channel to carry a discharge of 20 m^3/s through a slightly sinous channel on a slope of 0.0015. The channel is to be excavated in coarse alluvium with moderately rounded particles (D_{75} = 2.0 cm) on the perimeter of the channel. Assume Manning's roughness coefficient value to be 0.025 for coarse gravel. Show all sketches. **(20 $\frac{2}{3}$)**

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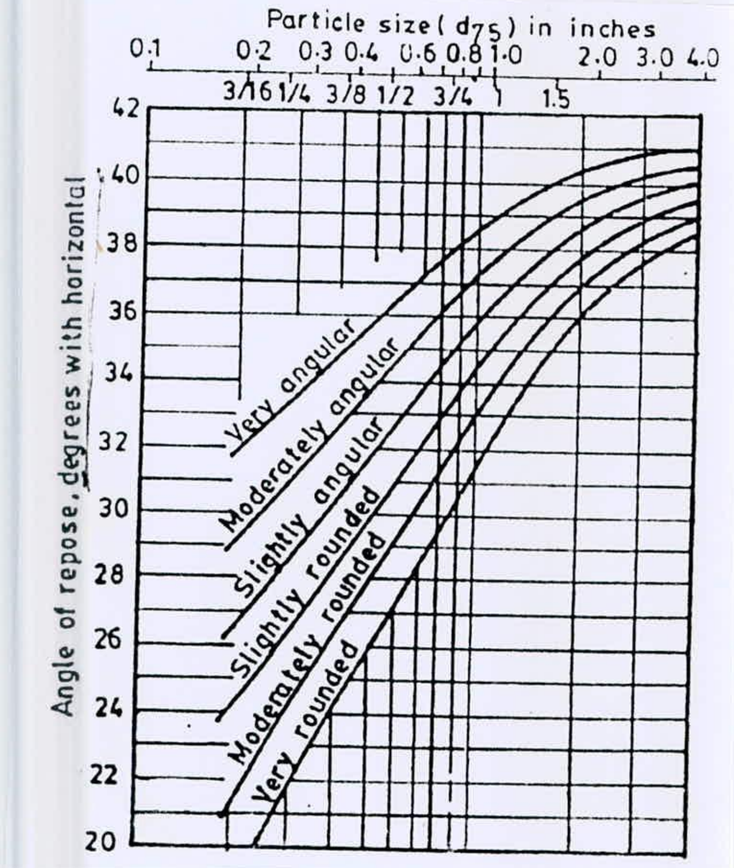

Figure 3 for Question 4(b)

(c) Design a stable alluvial channel using Lacey's theory. The channel carries a discharge of 10 cumec through 0.1 cm sand. **(10)**

(d) Define angle of repose. Why is it important in designing mobile boundary channels? **(6)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) Define uniform flow. Can uniform flow be possible in an adverse sloped channel? Justify your answer with necessary sketch. **(10)**

(b) Compute the normal depth and normal velocity in a trapezoidal channel whose bottom width is 5 m and discharge is 20 m^3/s. Given, n=0.025, s=2, s_0=0.0008. Apply 'Bisection' method. **(15)**

(c) A rectangular channel with a sharp crested weir is shown in Figure 4. If discharge per unit width of the weir is 6 $m^3/s/m$, estimate the energy loss due to the presence of the weir and also determine the force on the weir plate for the submerged flow condition as shown. Consider, energy coefficient and momentum coefficient are 1.15 and 1.12, respectively. **($21\frac{2}{3}$)**

6. (a) Explain the statement, "Uniform flow seems to be self-adjusting and any deviation from the condition '$W\sin\theta = F_f$' tends to re-establish this condition". **(10)**

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Contd... Q. No. 6

(b) Differentiate between normal slope and critical slope. A rectangular channel has a bottom width of 6 m, $\alpha = 1.12$ and n = 0.02. Determine the critical slope if the normal depth of this channel is 1.8 m. **(5+10=15)**

(c) A wide channel with bed slope of 0.0025 carries a discharge of 3.5 m^2/s. Compute the normal depth and normal velocity when the Chezy's C is 45 $m^{1/2}/s$. What will be the magnitude of normal discharge if width of the channel is 500 m? Comment on your result. **($21\frac{2}{3}$)**

7. (a) Determine the value of hydraulic exponent uniform flow computation 'N', for a triangular channel section when conveyance is expressed by Manning formula. **(10)**

(b) Derive the dynamic equation of steady gradually varied flow with necessary assumptions. What is the implication of this equation? **(10+5=15)**

(c) A rectangular channel with b=5 m, a=1.15 and n = 0.025 has two reaches arranged serially. The bottom slopes of these reaches are 0.0090 and 0.0020, respectively. For discharge of 15 m^3/s in the channel, name and sketch qualitatively the resulting flow profiles. **($21\frac{2}{3}$)**

8. (a) Explain why 'A1' profile is not physically possible in gradually varied flow. Draw a qualitative flow profile as a result of increase in bed surface roughness in a steep slope channel. **(5+5=10)**

(b) Draw qualitatively the possible flow profiles as a result of changes in channel width in a mild slope channel followed by critical slope channel as shown in Figure 5. **(15)**

(c) A trapezoidal channel with bottom width of 6 m, s = 2, n = 0.025 is laid on a slope of 0.0030 and carries a discharge of 30 m^3/s. The depth produced by a dam immediately upstream of it is 3 m. Compute the resulting flow profile. Consider the normal depth and critical depth as 2 m and 1.5 m, respectively. Given, the energy coefficient is 1.15. **($21\frac{2}{3}$)**

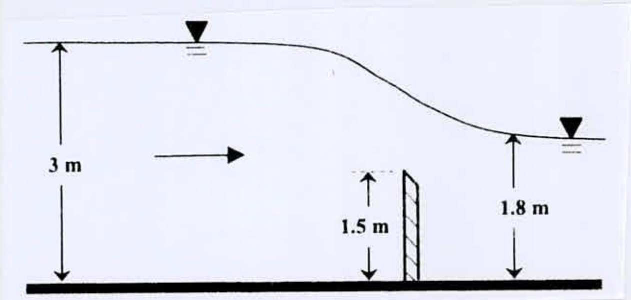

Figure 4 for Question 5(c)

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Contd... Q. No. 8(c)

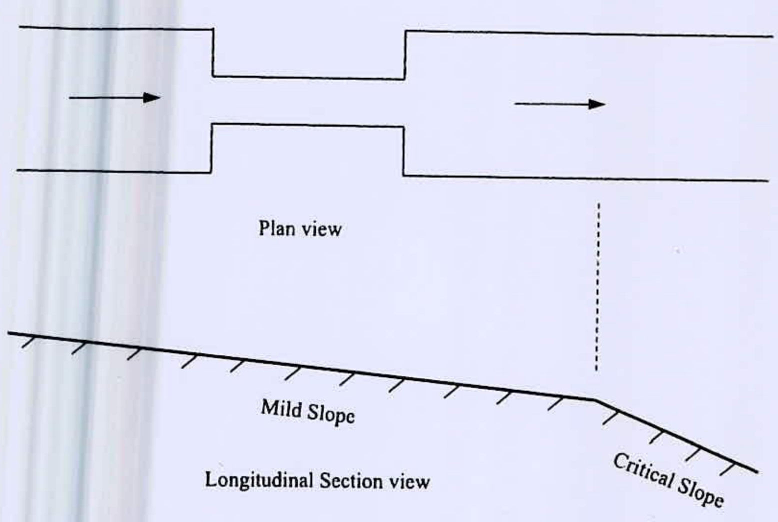

Figure 5 for Question 8(b)
