L-3/T-2/CE **Date : 12/10/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2021-2022

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

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**.

Use USD Method of Design and ACI 318/BNBC 2020 Codes

1. (a) A circular bridge pier column carries a working unfactored dead load DL = 1700 kip and live load LL = 900 kip. Design the spirally reinforced column using about 2.5 percent main reinforcement. Also design the ACI/BNBC spiral.
Given: $f_c' = 4.5$ ksi and $f_y = f_{yt} = 72.5$ ksi. **(10)**

(b) A 14×26 inch column is reinforced with Eight No. 9 bars as shown in Fig. 1. Construct the nominal strength interaction diagram for the column by calculating five points corresponding to **(25)**

(i) pure axial load,

(ii) pure bending,

(iii) balanced condition $\varepsilon_s = \varepsilon_y$,

(iv) $\varepsilon_s = -0.0005$ (Compressive) and

(v) $\varepsilon_s = 0.005$ (Tensile)

Given: $f_c' = 5$ ksi and $f_y = 60$ ksi, $E_s = 29\times10^3$ ksi.

Also find corresponding ϕ for the above points. Assume bending about Y-Y axis.

2. (a) A ground floor column of a multistoried building is to be designed for the following three load combinations (axial force and uniaxial bending)- **(17)**

Gravity load combination (1.2D + 1.6L) : $P_u = 728$ kip, $M_u = 108$ kip-ft

Lateral load combination 1 (1.2D + 1.0L + 1.6W) : $P_u = 624$ kip, $M_u = 345$ kip-ft

Lateral load combination 2 (1.2D + 1.0L + 1.0E) : $P_u = 582$ kip, $M_u = 433$ kip-ft

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

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

(b) A shear wall of a 16-storey building is subjected to following factored loads at the base: **(18)**

$P_u = 600$ kip

$V_u = 500$ kip

$M_u = 3500$ kip-ft

Contd P/2

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Contd ... Q. No.2(b)

The wall is 14 ft long, 160 ft high and 14 inch thick. Design the shear wall at the base with f'_c=4 ksi and f_y = 60 ksi. Ignore axial force as it is less than balanced load of the section.

Find the reinforcements for the shear wall at the base for:

(i) Horizontal shear

(ii) Vertical shear

(iii) Moment considering contribution of distributed vertical shear reinforcement, A_{vv}

(iv) Moment ignoring contribution of distributed vertical shear reinforcement A_{vv} and providing flexural reinforcement at the boundary elements

Note: Design moment capacity of wall section with uniformly distributed reinforcement is

$$\phi M_n = \phi\left[0.5 A_{st} f_y l_w \left(1 - \frac{z}{l_w}\right)\right]$$

Where,

$$\frac{z}{l_w} = \frac{1}{2 + \frac{0.85\beta_1 l_w h f'_c}{A_{st} f_y}}$$

3. (a) A 25×25 inch column is to be designed with reinforcement arranged around the column perimeter. Material strengths are f_c'=4.0 ksi and f_y=60 ksi. Design the short column using Reciprocal Load method for the load combination: **(20)**

P_u = 500 kip, M_{ux} = 416.7 kip-ft, M_{uy} = 312.5 kip-ft

Use supplied design chart (A.7). Start the trial with 2% reinforcement and adjust if required. Show longitudinal and tie (not seismic) reinforcements in sketch.

(b) Design tie for the above column considering seismic provisions of an IMRF system. Clear height of the column is 10ft. Show arrangements in cross and long-sections. **(9)**

(c) What is a slender column? 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. **(6)**

4. (a) A flat plate floor has thickness h = 8" and is supported by 18″×20″ columns spaced 20 ft in one direction and 22 ft in other direction. The floor will carry a live load 100 psf in addition to its self-weight and superimposed dead load (FF+PW) 50 psf. Check the adequacy of the slab in resisting punching shear of a typical interior column and design integral beams (assume width 10") with stirrups to carry the excess shear. **(16)**

Consider material strengths, f'_c = 4.0 ksi and f_y = 60 ksi and d = 6.5".

Show stirrups with neat sketch.

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Contd ... Q. No.4

(b) A prestressed concrete rectangular beam 20 inch by 28 inch has a simple span of 30ft and is loaded by a superimposed uniform load of 3k/ft excluding its own weight as shown in Fig. 2. The prestress tendon produces an effective prestress of 350 k. Compute the extreme fiber stresses in the concrete at the midspan section. Use **first concept** for calculation. **(14)**

(c) What are the sources of loss of prestress? **(5)**

SECTION – B

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

Assume reasonable values for any missing data.

5. A commercial building is to be designed using flat plat floor system. The interior columns are 21"×21" and they are spaced 22 ft c/c in both direction. Specified live load 100 psf and superimposed dead load 150 psf including self weight of slab. Material strengths are f'_c = 3,500 psi and f_y = 60000 psi.

(a) Find the slab thickness for adequacy against punching shear failure, when no shear reinforcement is used. **(15)**

(b) Design a typical interior panel of the above building and show the reinforcement with neat sketches. **(20)**

6. (a) Two interior columns for a structure are spaced 16ft apart, and each carries service DL=300 kip and LL=250 kip. Column sizes are 20"×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 4000 psf. The bottom of the footing will be 5 ft below grade. Design the footing for these columns and show the reinforcements in plan and section. Material strength for footing f'_c = 3.5 ksi and f_y = 60 ksi. **(18)**

(b) The plan of a pile cap with 12 nos. 20 in. diameter cast-in-situ piles with the column (30in×30in) is shown in Fig. 3. The column carries a DL = 1200 kip and LL = 500 kip (working). The individual pile capacity is adequate. Design the pile cap. Given f'_c = 3.5 ksi and f_y = 60 ksi. **(17)**

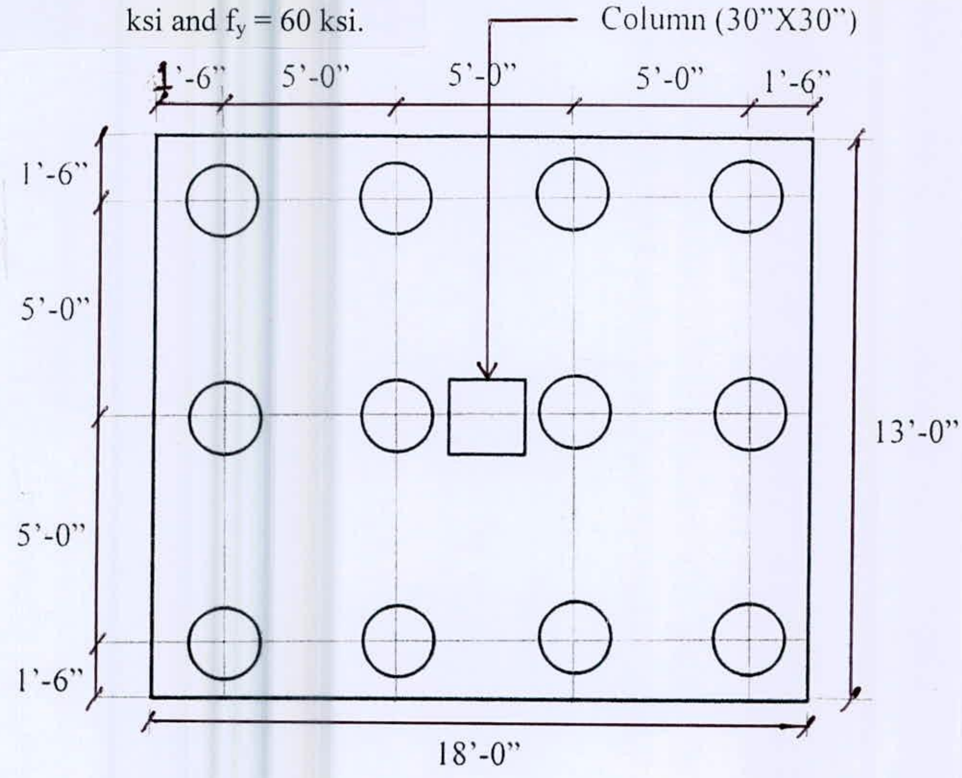

Fig. 3

Contd P/4

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

(b) Differentiate between strand and wires. **(4)**

(c) What methods are available for increasing strength of steel? What is most commonly used? **(4)**

(d) A pretensioned concrete member as shown in Fig. 4 is eccentrically prestressed with 1.2 sq. inch of steel wires which are anchored to the bulkheads with a stress of 152000 psi. Compute the loss of prestress due to elastic shortening of concrete at the transfer of prestress. Given, E_{ci} = 4,800,000 psi. E_s = 29,000,000 psi and n = 6. Solve using both gross area and transformed section for your calculation. **(20)**

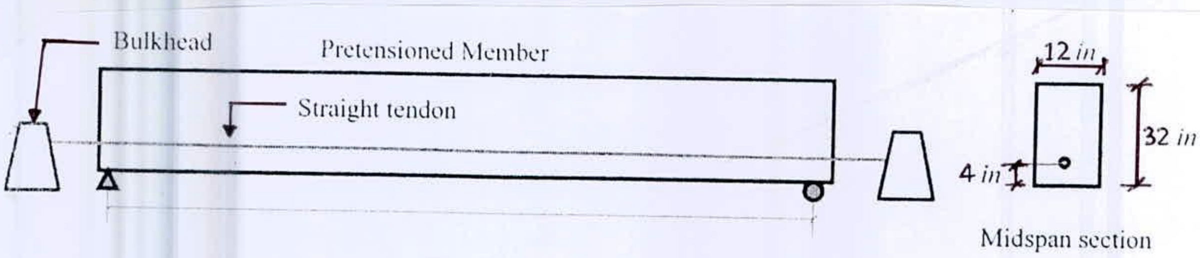


Fig. ~~7~~ 4

8. (a) A posttensioned simple beam as shown in Fig. 5 has an initial prestress of 135000 psi, reducing to 116000 psi after deducting all losses and assuming no bending of the beam. The parabolic cable has an area of 2.5 sq in., n=6. The heam carries superimposed dead load of 750 plf in addition to its own weight. Compute the stresses in the steel at midspan, assuming: **(18)**

(i) the steel is bonded by grouting

(ii) the steel is unbonded and free to slip

(b) For the beam shown in Fig. 5 compute the total dead and live uniform load that can be carried by the beam, **(17)**

(i) For zero tensile stress at bottom fiber

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

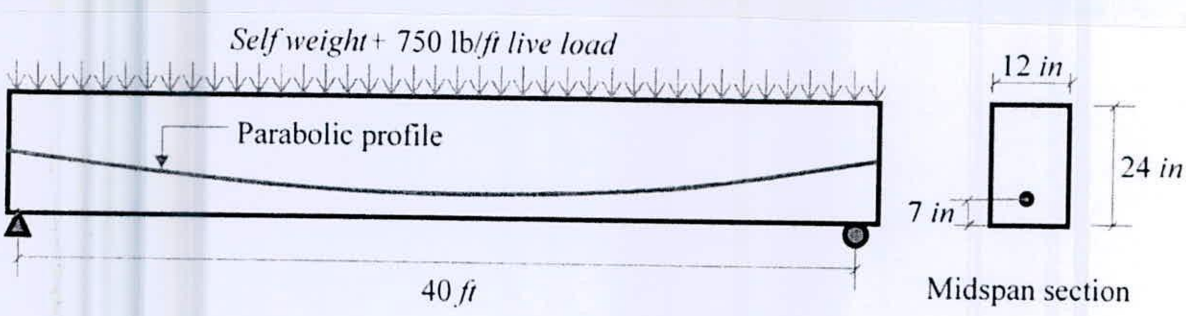


Fig. ~~8~~ 5

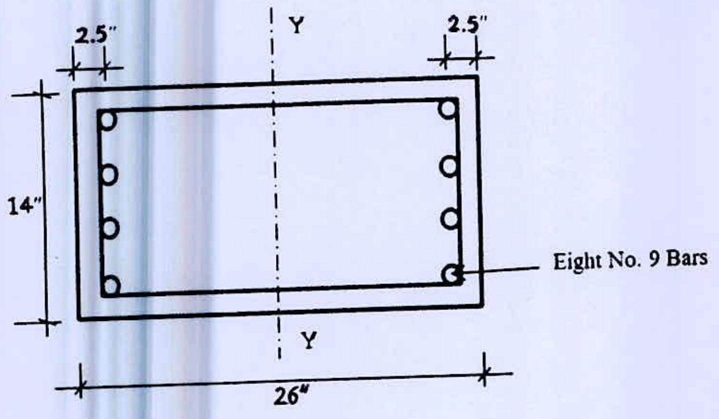


Fig. 1

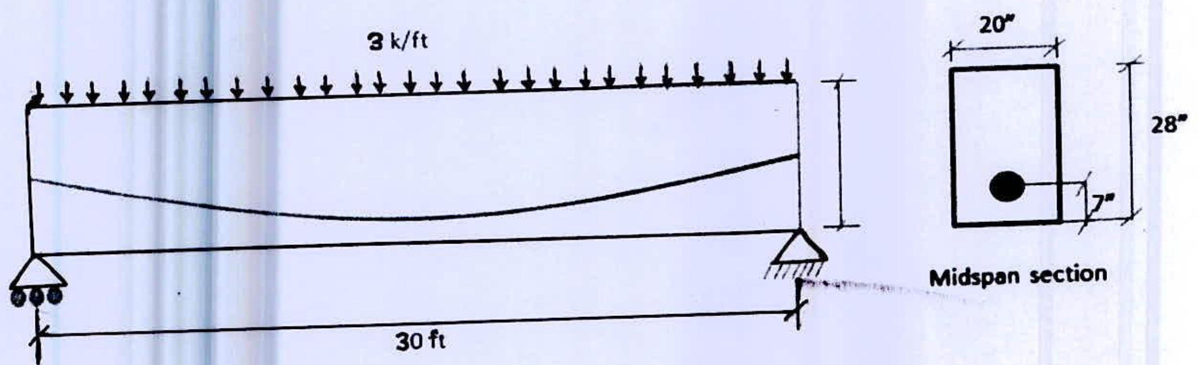
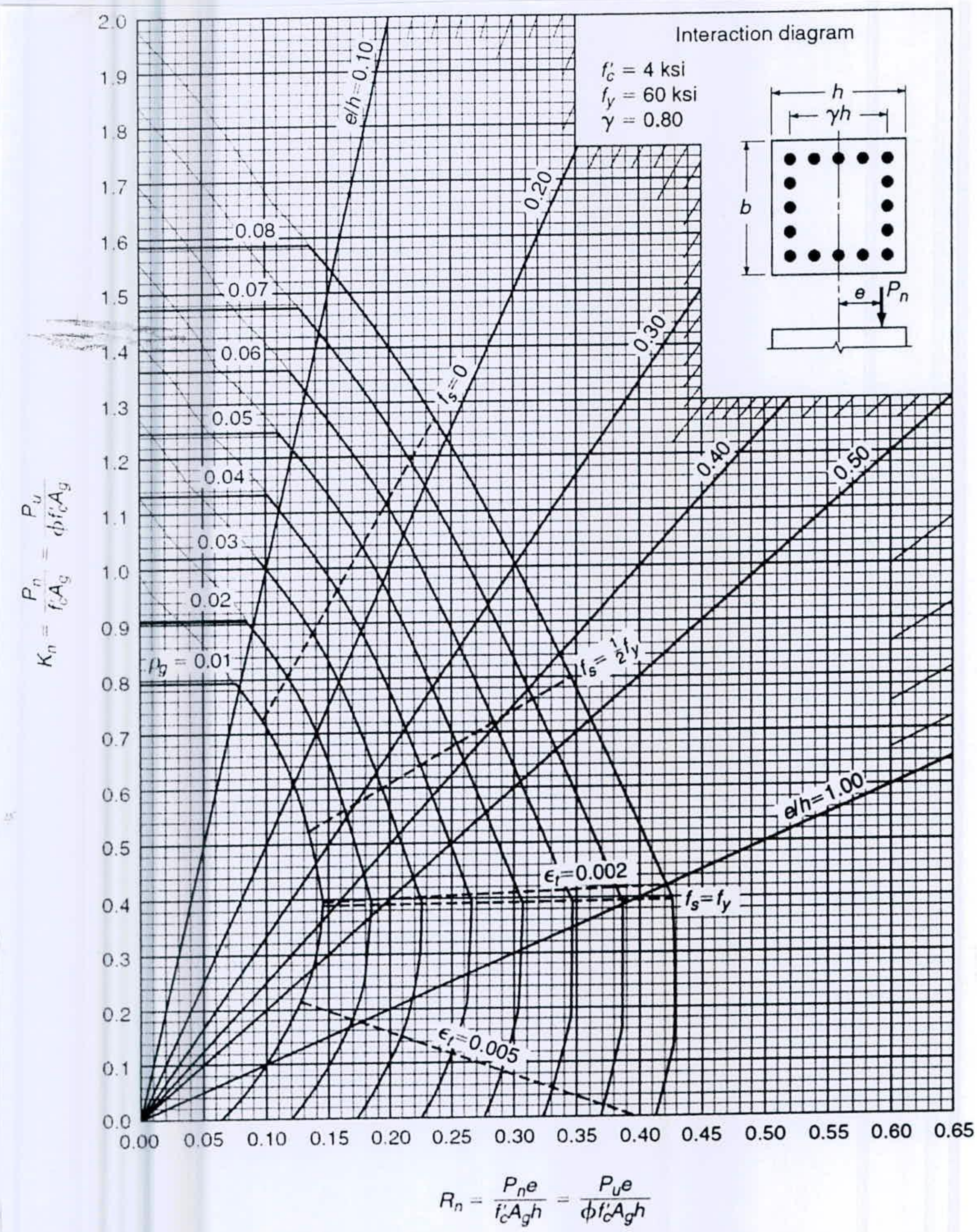


Fig. 2



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

L-3/T-2/CE **Date : 07/10/2023**

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L-3/T-2 B. Sc. Engineering Examinations 2021-2022

Sub : **CE 319** (Design of Steel Structure)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

Assume reasonable value for any missing data.

USE SEPARATE SCRIPTS FOR EACH SECTION

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 150 kip and live load of 400 kip. Choose the lightest column with W-Shape with a maximum nominal size of 14 inch. Use LRFD method with grade 50 steel. **(35)**

2. (a) Stating the assumptions, derive the formula for elastic buckling of a compression member. Explain how the concept of effective length factor can be used to evaluate the capacity of a compression member with various end conditions. **(10)**

   (b) A two-story steel frame is shown in Fig. 1. Using the alignment chart for effective length, determine the LRFD Design capacity of the column DE and EF. Consider column buckles about major axis in the plane of the frame. The frame is braced at Joint I (level 2) against the sidesway. Given, E=29,000 ksi and Fy=36 ksi. Member properties and chart are available. For W14 × 82: A=24 sq. in. r_x=6.05 in and r_y=2.48 in. **(25)**

3. (a) A ½ inch A36 steel plate is welded to a ¾ inch gusset plate as shown in Fig. 2. Determine the LRFD design strength of the connection, taking into consideration (i) plate yielding (ii) plate fracture, (iii) block shear failure (iv) weld strength (v) base metal shear strength. **(15)**

   (b) A W 14×145 column carries a dead load of 400 kip and a live load of 275 kip and is to rest on a concrete pedestal with a dimension of 6 in larger than the base plate in each direction and f'c=3ksi. Design the base plate using LRFD method from A36 steel. **(20)**

4. (a) Design a 10 ft long single angle to carry a service dead load of 25 kip and a live load of 60 kip in tension using grade 36 steel. The angle is connected to a gusset plate using 8 nos. ¾ inch dia bolts in two rows (i.e 4 bolts per line in the loading direction). Use LRFD method and neglect block shear mode. **(17)**

   (b) Identify the possible block shear modes for the 6x4x3/8 angle with its 6-inch side bolted a ½-inch gusset plate. The plates are made of A36 steel. For the bolting arrangement shown in Fig. 3 how much design load can be carried by the angle considering only block shear failure under LRFD. (A_g = 3.61 in^2). **(18)**

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SECTION – B

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

5. A W 16×77 (50 ksi steel) section is used as a 25 ft column in a braced frame system to carry a dead load of 100 kip and live load of 200 kip. The column is also subjected to a dead and live load moment of 50 kip.ft and 60 kip.ft, respectively at the top end and the same for bottom end are 30 kip.ft and 45 kip.ft, respectively. The top and bottom end moments are acting in opposite directions around the strong axis of the column section. There is no transverse load acting on the column. Consider the factor G (relative stiffness of column and beams) at the top and bottom ends of the column as 0.50 and 0.35, respectively to evaluate the effective length factor for weak direction. On the other hand, the effective length factor for strong direction is 0.85. For flexure, consider lateral support only at the ends. Is the section satisfactory to carry the load? Use AISC LRFD method. Assume E = 29000 ksi. **(35)**

6. (a) A simply supported floor beam is carrying uniformly distributed dead (in addition to its own weight) and live load of 1.5 kip/ft and 2.0 kip/ft, respectively. In addition, the beam supports a concentrated live load of 75 kips at 7 ft distance from the left support. The beam has a span length of 20 ft. Is it possible to design an all bolted double-angle connection for the critical joint among the two considering the following information? If possible, show the design connection in a neat sketch. Follow AISC ASD method. **(25)**

   - The cross section of the floor beam is W18×71 floor beam
   - The floor beam is connected to a W21×93 girder
   - Both floor beam and girder are made of A572 Grade 50 steel
   - The floor beam top flange is coped with a dimension of 3.0 inch (deep) by 4.5 inch (long)
   - L_{ev} = 1.5 inch & L_{eh} = 1.5 inch
   - ASTM A325-X bolts (F_y = 90 ksi and F_u = 120 ksi) with ¾ inch diameter
   - Consider bolt spacing of 3 inch

   (b) Determine the value of the uniformly distributed live load, a simply supported W14×82 steel beam can support to satisfy the live load deflection limit of L/360. The span length of the beam is 40 ft. Also, check the flexural adequacy of the beam to support the moment resulting from the measured distributed live load and uniformly distributed dead load of 1 kip/ft (in addition to the self weight). The beam has adequate lateral support. Follow AISC LRFD method. Assume E = 29000 ksi. **(10)**

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7. Check the adequacy (both flexure and shear) of a simply supported beam having W18×65 as cross section. The beam is carrying uniformly distributed dead load of 500 lb/ft (in addition to the self weight) and live load of 700 lb/ft. There are also two concentrated live loads of 10 kip acting at one-third points of the beam. The span length of the beam is 36 ft. Lateral support is provided at the ends and at the locations of the concentrated live loads. Use A992 steel (F_y = 50 ksi) and follow AISC LRFD method. Draw shear force and bending moment diagram of the loaded beam. Need to use calculated C_b value for moment capacity evaluation. Assume E = 29000 ksi. **(35)**

8. (a) Check the adequacy of the bolt configuration to support the tension capacity of the "C" shaped sections of the built-up member as shown in Figure 4. The "C" shaped section was built with three plates. The plate acting as web has the dimension of 3/8 in (thickness) by 10 in and the plates acting as flanges have dimension of 3/8 in (thickness) by 2 in (also shown in Figure 4). The bolt configuration consists of 6 no. 7/8-in bolts in 2 rows along the direction of the tension load. The plate (the connected member) and other design considerations are adequate. The "C" section has F_y and F_u of 50 ksi and 65 ksi, respectively. Bolts are A325 bolts in standard holes having F_y and F_u of 90 ksi and 120 ksi, respectively. The connection is bearing type with threads excluded from the shear planes. Checking for block shear is not required to evaluate the tension capacity of the "C" section. Assume deformation at bolt hole at service load is a design consideration. Along the direction of the load, the spacing and edge distance of bolts are 3-in c/c and 4-in, respectively. Follow AISC LRFD method. **(25)**

   (b) Determine the force in the most stressed bolt of the group shown in Figure 5, using the elastic analysis method. **(10)**

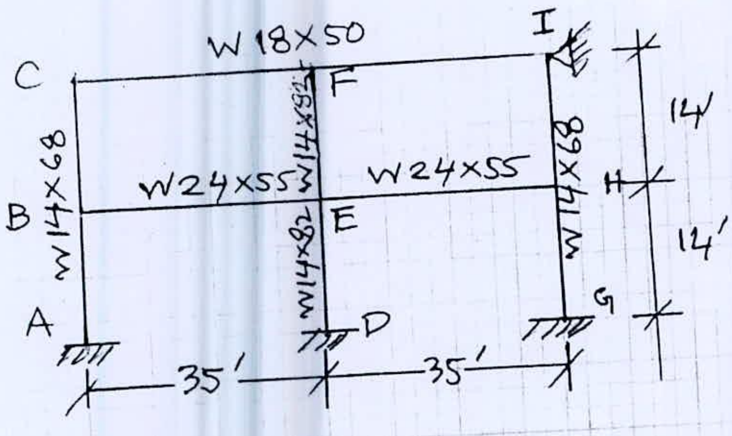

Fig. 1

section	I_x, in^4
W18X50	800
W24X55	1350
W14X82	881
W14X68	722

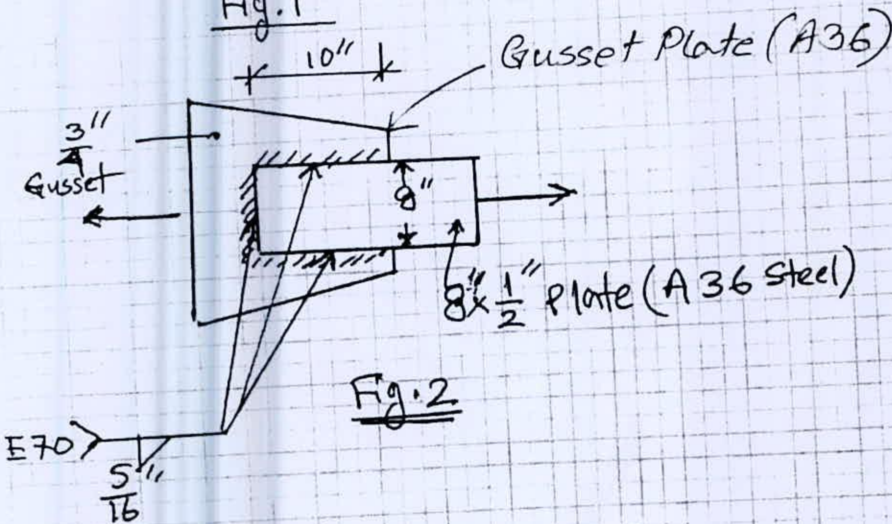

Fig. 2

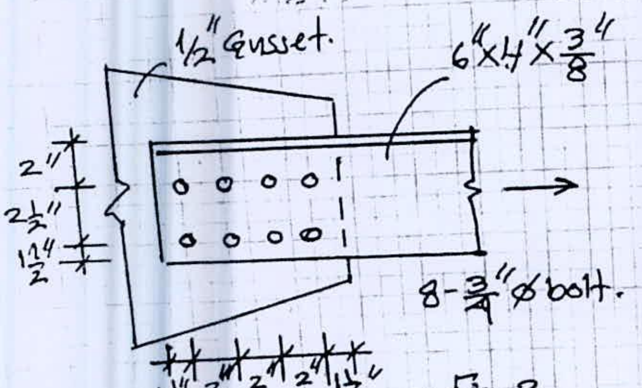

Fig. 3

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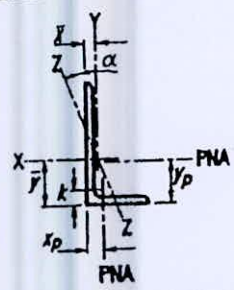

Table 1-7
Angles
Properties

Shape	k	Wt.	Area, A	Axis X-X			Axis Y-Y			Axis Z-Z	
				I	S	r	I	S	r	S	r
	in.	lb/ft	in.²	in.⁴	in.³	in.	in.⁴	in.³	in.	in.³	in.
L8×8×1 1/8	1 3/4	56.9	16.8	98.1	17.5	2.41	98.1	17.5	2.41	12.0	1.56
×1	1 5/8	51.0	15.1	89.1	15.8	2.43	89.1	15.8	2.43	11.0	1.56
×7/8	1 1/2	45.0	13.3	79.7	14.0	2.45	79.7	14.0	2.45	10.0	1.57
×3/4	1 3/8	38.9	11.5	69.9	12.2	2.46	69.9	12.2	2.46	8.90	1.57
×5/8	1 1/4	32.7	9.69	59.6	10.3	2.48	59.6	10.3	2.48	7.72	1.58
×9/16	1 3/16	29.6	8.77	54.2	9.33	2.49	54.2	9.33	2.49	7.09	1.58
×1/2	1 1/8	26.4	7.84	48.8	8.36	2.49	48.8	8.36	2.49	6.44	1.59
L8×6×1	1 1/2	44.2	13.1	80.9	15.1	2.49	38.8	8.92	1.72	7.60	1.28
×7/8	1 3/8	39.1	11.5	72.4	13.4	2.50	34.9	7.94	1.74	6.71	1.28
×3/4	1 1/4	33.8	9.99	63.5	11.7	2.52	30.8	6.92	1.75	5.82	1.29
×5/8	1 1/8	28.5	8.41	54.2	9.86	2.54	26.4	5.88	1.77	4.91	1.29
×9/16	1 1/16	25.7	7.61	49.4	8.94	2.55	24.1	5.34	1.78	4.45	1.30
×1/2	1	23.0	6.80	44.4	8.01	2.55	21.7	4.79	1.79	3.98	1.30
×7/16	15/16	20.2	5.99	39.3	7.06	2.56	19.3	4.23	1.80	3.51	1.31
L8×4×1	1 1/2	37.4	11.1	69.7	14.0	2.51	11.6	3.94	1.03	3.48	0.844
×7/8	1 3/8	33.1	9.79	62.6	12.5	2.53	10.5	3.51	1.04	3.06	0.846
×3/4	1 1/4	28.7	8.49	55.0	10.9	2.55	9.37	3.07	1.05	2.65	0.850
×5/8	1 1/8	24.2	7.16	47.0	9.20	2.56	8.11	2.62	1.06	2.24	0.856
×9/16	1 1/16	21.9	6.49	42.9	8.34	2.57	7.44	2.38	1.07	2.03	0.859
×1/2	1	19.6	5.80	38.6	7.48	2.58	6.75	2.15	1.08	1.82	0.863
×7/16	15/16	17.2	5.11	34.2	6.59	2.59	6.03	1.90	1.09	1.61	0.867
L7×4×3/4	1 1/4	26.2	7.74	37.8	8.39	2.21	9.00	3.01	1.08	2.57	0.855
×5/8	1 1/8	22.1	6.50	32.4	7.12	2.23	7.79	2.56	1.10	2.16	0.860
×1/2	1	17.9	5.26	26.6	5.79	2.25	6.48	2.10	1.11	1.76	0.866
×7/16	15/16	15.7	4.63	23.6	5.11	2.26	5.79	1.86	1.12	1.55	0.869
×3/8	7/8	13.6	4.00	20.5	4.42	2.27	5.06	1.61	1.12	1.34	0.873
L6×6×1	1 1/2	37.4	11.0	35.4	8.55	1.79	35.4	8.55	1.79	5.70	1.17
×7/8	1 3/8	33.1	9.75	31.9	7.61	1.81	31.9	7.61	1.81	5.18	1.17
×3/4	1 1/4	28.7	8.46	28.1	6.64	1.82	28.1	6.64	1.82	4.63	1.17
×5/8	1 1/8	24.2	7.13	24.1	5.64	1.84	24.1	5.64	1.84	4.04	1.17
×9/16	1 1/16	21.9	6.45	22.0	5.12	1.85	22.0	5.12	1.85	3.73	1.18
×1/2	1	19.6	5.77	19.9	4.59	1.86	19.9	4.59	1.86	3.40	1.18
×7/16	15/16	17.2	5.08	17.6	4.06	1.86	17.6	4.06	1.86	3.05	1.18
×3/8	7/8	14.9	4.38	15.4	3.51	1.87	15.4	3.51	1.87	2.69	1.19
×5/16	13/16	12.4	3.67	13.0	2.95	1.88	13.0	2.95	1.88	2.30	1.19

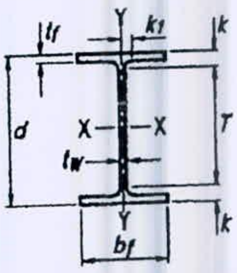

Table 1-1 (continued)
W-Shapes
Dimensions

Shape	Area, A	Depth, d		Web Thickness, t_w		$\frac{t_w}{2}$	Flange Width, b_f		Flange Thickness, t_f		Distance k_{des}	k_{det}	k_1	T	Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W14×730^h	215	22.4	22 3/8	3.07	3 1/16	1 9/16	17.9	17 7/8	4.91	4 15/16	5.51	6 3/16	2 3/4	10	3-7½-3^g
×665^h	196	21.6	21 5/8	2.83	2 13/16	1 7/16	17.7	17 5/8	4.52	4 1/2	5.12	5 13/16	2 5/8		3-7½-3^g
×605^h	178	20.9	20 7/8	2.60	2 5/8	1 5/16	17.4	17 3/8	4.16	4 3/16	4.76	5 7/16	2 1/2		3-7½-3
×550^h	162	20.2	20 1/4	2.38	2 3/8	1 3/16	17.2	17 1/4	3.82	3 13/16	4.42	5 1/8	2 3/8		
×500^h	147	19.6	19 5/8	2.19	2 3/16	1 1/8	17.0	17	3.50	3 1/2	4.10	4 13/16	2 5/16		
×455^h	134	19.0	19	2.02	2	1	16.8	16 7/8	3.21	3 3/16	3.81	4 1/2	2 1/4		
×426^h	125	18.7	18 5/8	1.88	1 7/8	15/16	16.7	16 3/4	3.04	3 1/16	3.63	4 5/16	2 1/8		
×398^h	117	18.3	18 1/4	1.77	1 3/4	7/8	16.6	16 5/8	2.85	2 7/8	3.44	4 1/8	2 1/8		
×370^h	109	17.9	17 7/8	1.66	1 11/16	13/16	16.5	16 1/2	2.66	2 11/16	3.26	3 15/16	2 1/16		
×342^h	101	17.5	17 1/2	1.54	1 9/16	13/16	16.4	16 3/8	2.47	2 1/2	3.07	3 3/4	2		
×311^h	91.4	17.1	17 1/8	1.41	1 7/16	3/4	16.2	16 1/4	2.26	2 1/4	2.86	3 9/16	1 15/16		
×283^h	83.3	16.7	16 3/4	1.29	1 5/16	11/16	16.1	16 1/8	2.07	2 1/16	2.67	3 3/8	1 7/8		
×257	75.6	16.4	16 3/8	1.18	1 3/16	5/8	16.0	16	1.89	1 7/8	2.49	3 3/16	1 13/16		
×233	68.5	16.0	16	1.07	1 1/16	9/16	15.9	15 7/8	1.72	1 3/4	2.32	3	1 3/4		
×211	62.0	15.7	15 3/4	0.980	1	1/2	15.8	15 3/4	1.56	1 9/16	2.16	2 7/8	1 11/16		
×193	56.8	15.5	15 1/2	0.890	7/8	7/16	15.7	15 3/4	1.44	1 7/16	2.04	2 3/4	1 11/16		
×176	51.8	15.2	15 1/4	0.830	13/16	7/16	15.7	15 5/8	1.31	1 5/16	1.91	2 5/8	1 5/8		
×159	46.7	15.0	15	0.745	3/4	3/8	15.6	15 5/8	1.19	1 3/16	1.79	2 1/2	1 9/16		
×145	42.7	14.8	14 3/4	0.680	11/16	3/8	15.5	15 1/2	1.09	1 1/16	1.69	2 3/8	1 9/16		

[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.

Nominal Wt.	Compact Section Criteria $\frac{b_f}{2t_f}$	$\frac{h}{t_w}$	Axis X-X I	S	r	Z	Axis Y-Y I	S	r	Z	r_{ts}	h_o	Torsional Properties J	C_w
lb/ft			in.^{4}	in.^{3}	in.	in.^{3}	in.^{4}	in.^{3}	in.	in.^{3}	in.	in.	in.^{4}	in.^{6}
730	1.82	3.71	14300	1280	8.17	1660	4720	527	4.69	816	5.68	17.5	1450	362000
665	1.95	4.03	12400	1150	7.98	1480	4170	472	4.62	730	5.57	17.1	1120	305000
605	2.09	4.39	10800	1040	7.80	1320	3680	423	4.55	652	5.44	16.7	869	258000
550	2.25	4.79	9430	931	7.63	1180	3250	378	4.49	583	5.35	16.4	669	219000
500	2.43	5.21	8210	838	7.48	1050	2880	339	4.43	522	5.26	16.1	514	187000
455	2.62	5.66	7190	756	7.33	936	2560	304	4.38	468	5.17	15.8	395	160000
426	2.75	6.08	6600	706	7.26	869	2360	283	4.34	434	5.11	15.7	331	144000
398	2.92	6.44	6000	656	7.16	801	2170	262	4.31	402	5.05	15.5	273	129000
370	3.10	6.89	5440	607	7.07	736	1990	241	4.27	370	5.00	15.2	222	116000
342	3.31	7.41	4900	558	6.98	672	1810	221	4.24	338	4.95	15.0	178	103000
311	3.59	8.09	4330	506	6.88	603	1610	199	4.20	304	4.87	14.8	136	89100
283	3.89	8.84	3840	459	6.79	542	1440	179	4.17	274	4.80	14.6	104	77700
257	4.23	9.71	3400	415	6.71	487	1290	161	4.13	246	4.75	14.5	79.1	67800
233	4.62	10.7	3010	375	6.63	436	1150	145	4.10	221	4.69	14.3	59.5	59000
211	5.06	11.6	2660	338	6.55	390	1030	130	4.07	198	4.64	14.1	44.6	51500
193	5.45	12.8	2400	310	6.50	355	931	119	4.05	180	4.59	14.1	34.8	45900
176	5.97	13.7	2140	281	6.43	320	838	107	4.02	163	4.55	13.9	26.5	40500
159	6.54	15.3	1900	254	6.38	287	748	96.2	4.00	146	4.51	13.8	19.7	35600
145	7.11	16.8	1710	232	6.33	260	677	87.3	3.98	133	4.47	13.7	15.2	31700

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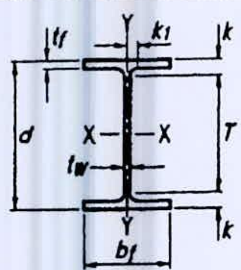
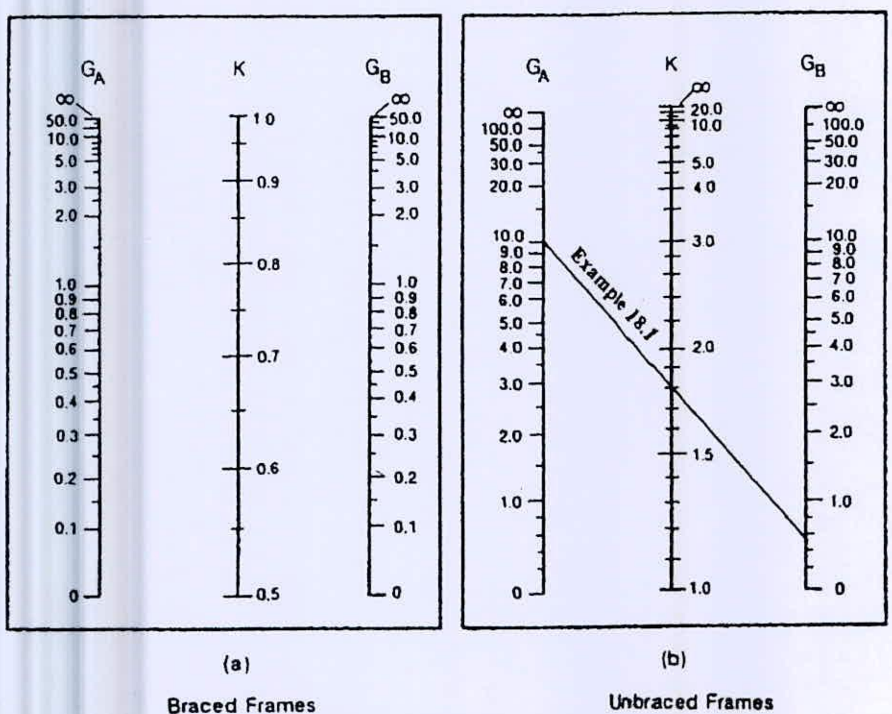


Table 1-1 (continued)
W-Shapes
Dimensions

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.
W14×132	38.8	14.7	14 5/8	0.645	5/8	5/16	14.7	14 3/4	1.03	1	1.63	2 5/16	1 9/16	10	5 1/2
×120	35.3	14.5	14 1/2	0.590	9/16	5/16	14.7	14 5/8	0.940	15/16	1.54	2 1/4	1 1/2	↓	↓
×109	32.0	14.3	14 3/8	0.525	1/2	1/4	14.6	14 5/8	0.860	7/8	1.46	2 3/16	1 1/2		
×99^f	29.1	14.2	14 1/8	0.485	1/2	1/4	14.6	14 5/8	0.780	3/4	1.38	2 1/16	1 7/16		
×90^f	26.5	14.0	14	0.440	7/16	1/4	14.5	14 1/2	0.710	11/16	1.31	2	1 7/16		
W14×82	24.0	14.3	14 1/4	0.510	1/2	1/4	10.1	10 1/8	0.855	7/8	1.45	1 11/16	1 1/16	10 7/8	5 1/2
×74	21.8	14.2	14 1/8	0.450	7/16	1/4	10.1	10 1/8	0.785	13/16	1.38	1 5/8	1 1/16	↓	↓
×68	20.0	14.0	14	0.415	7/16	1/4	10.0	10	0.720	3/4	1.31	1 9/16	1 1/16		
×61	17.9	13.9	13 7/8	0.375	3/8	3/16	10.0	10	0.645	5/8	1.24	1 1/2	1		
W14×53	15.6	13.9	13 7/8	0.370	3/8	3/16	8.06	8	0.660	11/16	1.25	1 1/2	1	10 7/8	5 1/2
×48	14.1	13.8	13 3/4	0.340	5/16	3/16	8.03	8	0.595	5/8	1.19	1 7/16	1	↓	↓
×43^c	12.6	13.7	13 5/8	0.305	5/16	3/16	8.00	8	0.530	1/2	1.12	1 3/8	1		
W14×38^c	11.2	14.1	14 1/8	0.310	5/16	3/16	6.77	6 3/4	0.515	1/2	0.915	1 1/4	13/16	11 5/8	3 1/2^g
×34^c	10.0	14.0	14	0.285	5/16	3/16	6.75	6 3/4	0.455	7/16	0.855	1 3/16	3/4	↓	3 1/2
×30^c	8.85	13.8	13 7/8	0.270	1/4	1/8	6.73	6 3/4	0.385	3/8	0.785	1 1/8	3/4		3 1/2
W14×26^c	7.69	13.9	13 7/8	0.255	1/4	1/8	5.03	5	0.420	7/16	0.820	1 1/8	3/4	11 5/8	2 3/4^g
×22^c	6.49	13.7	13 3/4	0.230	1/4	1/8	5.00	5	0.335	5/16	0.735	1 1/16	3/4	11 5/8	2 3/4^g

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}
132	7.15	17.7	1530	209	6.28	234	548	74.5	3.76	113	4.23	13.7	12.3	25500
120	7.80	19.3	1380	190	6.24	212	495	67.5	3.74	102	4.20	13.6	9.37	22700
109	8.49	21.7	1240	173	6.22	192	447	61.2	3.73	92.7	4.17	13.4	7.12	20200
99	9.34	23.5	1110	157	6.17	173	402	55.2	3.71	83.6	4.14	13.4	5.37	18000
90	10.2	25.9	999	143	6.14	157	362	49.9	3.70	75.6	4.10	13.3	4.06	16000
82	5.92	22.4	881	123	6.05	139	148	29.3	2.48	44.8	2.85	13.4	5.07	6710
74	6.41	25.4	795	112	6.04	126	134	26.6	2.48	40.5	2.83	13.4	3.87	5990
68	6.97	27.5	722	103	6.01	115	121	24.2	2.46	36.9	2.80	13.3	3.01	5380
61	7.75	30.4	640	92.1	5.98	102	107	21.5	2.45	32.8	2.78	13.3	2.19	4710
53	6.11	30.9	541	77.8	5.89	87.1	57.7	14.3	1.92	22.0	2.22	13.2	1.94	2540
48	6.75	33.6	484	70.2	5.85	78.4	51.4	12.8	1.91	19.6	2.20	13.2	1.45	2240
43	7.54	37.4	428	62.6	5.82	69.6	45.2	11.3	1.89	17.3	2.18	13.2	1.05	1950
38	6.57	39.6	385	54.6	5.87	61.5	26.7	7.88	1.55	12.1	1.82	13.6	0.798	1230
34	7.41	43.1	340	48.6	5.83	54.6	23.3	6.91	1.53	10.6	1.80	13.5	0.569	1070
30	8.74	45.4	291	42.0	5.73	47.3	19.6	5.82	1.49	8.99	1.77	13.4	0.380	887
26	5.98	48.1	245	35.3	5.65	40.2	8.91	3.55	1.08	5.54	1.30	13.5	0.358	405
22	7.46	53.3	199	29.0	5.54	33.2	7.00	2.80	1.04	4.39	1.27	13.4	0.208	314



(a) Braced Frames

(b) Unbraced Frames

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

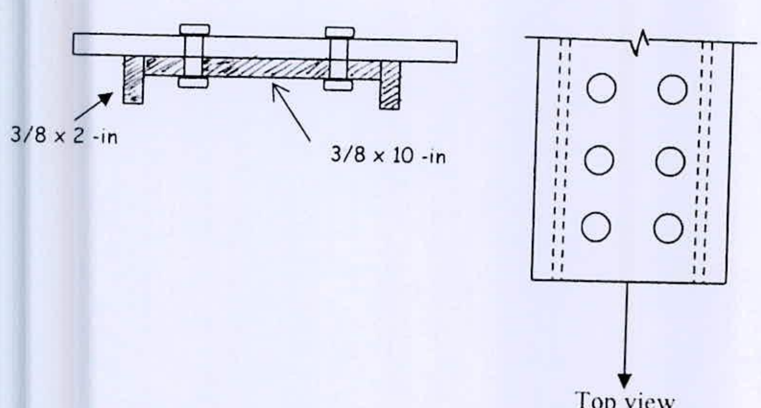


Figure 4

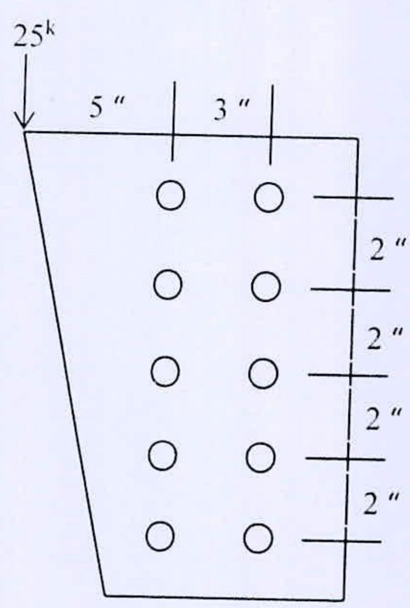


Figure 5

SOME OF THE REQUIRED EXPRESSIONS:

$$P_n = A_g F_{cr}$$

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

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

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

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

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

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

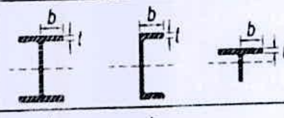
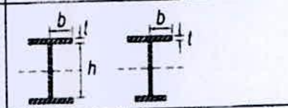
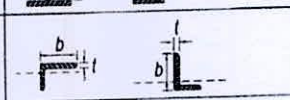
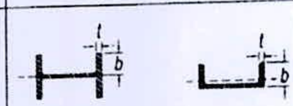
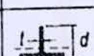
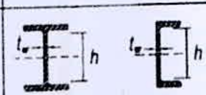
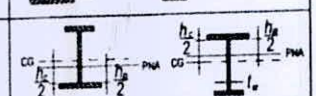
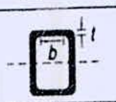
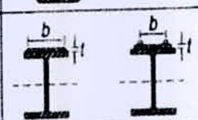
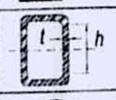
$$C_b = \frac{12.5M_{max}}{2.5M_{max} + 3M_A + 4M_B + 3M_C} R_m$$

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

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

=10=

TABLE B4.1b
Width-to-Thickness Ratios: Compression Elements Members Subject to Flexure

	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio: λ_p (compact/noncompact)	Limiting Width-to-Thickness Ratio: λ_r (noncompact/slender)	Examples
Unstiffened Elements	10	Flanges of rolled I-shaped sections, channels, and tees	b/t	$0.38\sqrt{\frac{E}{F_y}}$	$1.0\sqrt{\frac{E}{F_y}}$	
	11	Flanges of doubly and singly symmetric I-shaped built-up sections	b/t	$0.38\sqrt{\frac{E}{F_y}}$	$0.95\sqrt{\frac{k_cE}{F_L}}$ [a] [b]	
	12	Legs of single angles	b/t	$0.54\sqrt{\frac{E}{F_y}}$	$0.91\sqrt{\frac{E}{F_y}}$	
	13	Flanges of all I-shaped sections and channels in flexure about the weak axis	b/t	$0.38\sqrt{\frac{E}{F_y}}$	$1.0\sqrt{\frac{E}{F_y}}$	
	14	Stems of tees	d/t	$0.84\sqrt{\frac{E}{F_y}}$	$1.03\sqrt{\frac{E}{F_y}}$	
Stiffened Elements	15	Webs of doubly-symmetric I-shaped sections and channels	h/t_w	$3.76\sqrt{\frac{E}{F_y}}$	$5.70\sqrt{\frac{E}{F_y}}$	
	16	Webs of singly-symmetric I-shaped sections	h_c/t_w	$\frac{\frac{h_c}{h_p}\sqrt{\frac{E}{F_y}}}{\left(0.54\frac{M_p}{M_y}-0.09\right)^2} \le \lambda_r$ [c]	$5.70\sqrt{\frac{E}{F_y}}$	
	17	Flanges of rectangular HSS and boxes of uniform thickness	b/t	$1.12\sqrt{\frac{E}{F_y}}$	$1.40\sqrt{\frac{E}{F_y}}$	
	18	Flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.12\sqrt{\frac{E}{F_y}}$	$1.40\sqrt{\frac{E}{F_y}}$	
	19	Webs of rectangular HSS and boxes	h/t	$2.42\sqrt{\frac{E}{F_y}}$	$5.70\sqrt{\frac{E}{F_y}}$	
	20	Round HSS	D/t	$0.07\frac{E}{F_y}$	$0.31\frac{E}{F_y}$	

[a] $k_c = 4/\sqrt{h/t_w}$ but shall not be taken less than 0.35 nor greater than 0.76 for calculation purposes.
[b] $F_L = 0.7F_y$ for major axis bending of compact and noncompact web built-up I-shaped members with $S_{xt}/S_{xc} \ge 0.7$.
$F_L = F_yS_{xt}/S_{xc} \ge 0.5F_y$ for major axis bending of compact and noncompact web built-up I-shaped members with $S_{xt}/S_{xc} < 0.7$.
[c] M_y is the moment at yielding of the extreme fiber. M_p = plastic bending moment, kip-in. (N-mm)
E = modulus of elasticity of steel = 29,000 ksi (200 000 MPa)
F_y = specified minimum yield stress, ksi (MPa)

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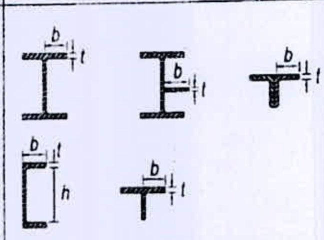
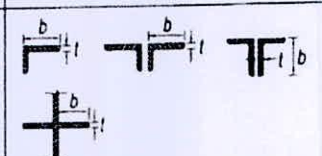
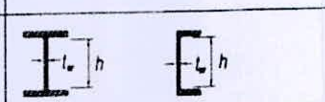
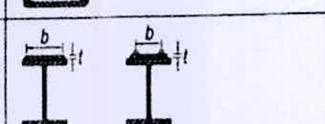
TABLE B4.1a
Width-to-Thickness Ratios: Compression Elements Members Subject to Axial Compression

	Case	Description of Element	Width-to-Thickness Ratio	Limiting Width-to-Thickness Ratio λ_r (nonslender/slender)	Examples
Unstiffened Elements	1	Flanges of rolled I-shaped sections, plates projecting from rolled I-shaped sections; outstanding legs of pairs of angles connected with continuous contact, flanges of channels, and flanges of tees	b/t	$0.56\sqrt{\frac{E}{F_y}}$	
	2	Flanges of built-up I-shaped sections and plates or angle legs projecting from built-up I-shaped sections	b/t	[a] $0.64\sqrt{\frac{k_cE}{F_y}}$	
	3	Legs of single angles, legs of double angles with separators, and all other unstiffened elements	b/t	$0.45\sqrt{\frac{E}{F_y}}$	
	4	Stems of tees	d/t	$0.75\sqrt{\frac{E}{F_y}}$	
Stiffened Elements	5	Webs of doubly-symmetric I-shaped sections and channels	h/t_w	$1.49\sqrt{\frac{E}{F_y}}$	
	6	Walls of rectangular HSS and boxes of uniform thickness	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	7	Flange cover plates and diaphragm plates between lines of fasteners or welds	b/t	$1.40\sqrt{\frac{E}{F_y}}$	
	8	All other stiffened elements	b/t	$1.49\sqrt{\frac{E}{F_y}}$	
	9	Round HSS	D/t	$0.11\frac{E}{F_y}$	

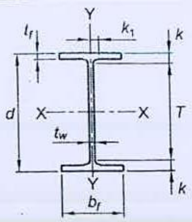


Table 1-1 (continued)
W-Shapes
Dimensions

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.
W27×129[c]	37.8	27.6	27 5/8	0.610	5/8	5/16	10.0	10	1.10	1 1/8	1.70	2 5/16	1 1/2	23	5 1/2
×114[c]	33.6	27.3	27 1/4	0.570	9/16	5/16	10.1	10 1/8	0.930	15/16	1.53	2 1/8	1 1/2		
×102[c]	30.0	27.1	27 1/8	0.515	1/2	1/4	10.0	10	0.830	13/16	1.43	2 1/16	1 7/16		
×94[c]	27.6	26.9	26 7/8	0.490	1/2	1/4	10.0	10	0.745	3/4	1.34	1 15/16	1 7/16		
×84[c]	24.7	26.7	26 3/4	0.460	7/16	1/4	10.0	10	0.640	5/8	1.24	1 7/8	1 7/16		
W24×370[h]	109	28.0	28	1.52	1 1/2	3/4	13.7	13 5/8	2.72	2 3/4	3.22	4	2	20	5 1/2
×335[h]	98.3	27.5	27 1/2	1.38	1 3/8	11/16	13.5	13 1/2	2.48	2 1/2	2.98	3 3/4	1 7/8		
×306[h]	89.7	27.1	27 1/8	1.26	1 1/4	5/8	13.4	13 3/8	2.28	2 1/4	2.78	3 9/16	1 13/16		
×279[h]	81.9	26.7	26 3/4	1.16	1 3/16	5/8	13.3	13 1/4	2.09	2 1/16	2.59	3 3/8	1 13/16		
×250	73.5	26.3	26 3/8	1.04	1 1/16	9/16	13.2	13 1/8	1.89	1 7/8	2.39	3 1/8	1 3/4		
×229	67.2	26.0	26	0.960	15/16	1/2	13.1	13 1/8	1.73	1 3/4	2.23	3	1 11/16		
×207	60.7	25.7	25 3/4	0.870	7/8	7/16	13.0	13	1.57	1 9/16	2.07	2 7/8	1 5/8		
×192	56.5	25.5	25 1/2	0.810	13/16	7/16	13.0	13	1.46	1 7/16	1.96	2 3/4	1 5/8		
×176	51.7	25.2	25 1/4	0.750	3/4	3/8	12.9	12 7/8	1.34	1 5/16	1.84	2 5/8	1 9/16		
×162	47.8	25.0	25	0.705	11/16	3/8	13.0	13	1.22	1 1/4	1.72	2 1/2	1 9/16		
×146	43.0	24.7	24 3/4	0.650	5/8	5/16	12.9	12 7/8	1.09	1 1/16	1.59	2 3/8	1 9/16		
×131	38.6	24.5	24 1/2	0.605	5/8	5/16	12.9	12 7/8	0.960	15/16	1.46	2 1/4	1 1/2		
×117[c]	34.4	24.3	24 1/4	0.550	9/16	5/16	12.8	12 3/4	0.850	7/8	1.35	2 1/8	1 1/2		
×104[c]	30.7	24.1	24	0.500	1/2	1/4	12.8	12 3/4	0.750	3/4	1.25	2 1/16	1 7/16		
W24×103[c]	30.3	24.5	24 1/2	0.550	9/16	5/16	9.00	9	0.980	1	1.48	2 1/4	1 1/2	20	5 1/2
×94[c]	27.7	24.3	24 1/4	0.515	1/2	1/4	9.07	9 1/8	0.875	7/8	1.38	2 1/8	1 7/16		
×84[c]	24.7	24.1	24 1/8	0.470	1/2	1/4	9.02	9	0.770	3/4	1.27	2 1/16	1 7/16		
×76[c]	22.4	23.9	23 7/8	0.440	7/16	1/4	8.99	9	0.680	11/16	1.18	1 15/16	1 7/16		
×68[c]	20.1	23.7	23 3/4	0.415	7/16	1/4	8.97	9	0.585	9/16	1.09	1 7/8	1 7/16		
W24×62[c]	18.2	23.7	23 3/4	0.430	7/16	1/4	7.04	7	0.590	9/16	1.09	1 1/2	1 1/16	20 3/4	3 1/2[g]
×55[c,v]	16.2	23.6	23 5/8	0.395	3/8	3/16	7.01	7	0.505	1/2	1.01	1 7/16	1	20 3/4	3 1/2[g]

[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

W27–W24

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}
129	4.55	39.7	4760	345	11.2	395	184	36.8	2.21	57.6	2.66	26.5	11.1	32500
114	5.41	42.5	4080	299	11.0	343	159	31.5	2.18	49.3	2.65	26.4	7.33	27600
102	6.03	47.1	3620	267	11.0	305	139	27.8	2.15	43.4	2.62	26.3	5.28	24000
94	6.70	49.5	3270	243	10.9	278	124	24.8	2.12	38.8	2.59	26.2	4.03	21300
84	7.78	52.7	2850	213	10.7	244	106	21.2	2.07	33.2	2.54	26.1	2.81	17900
370	2.51	14.2	13400	957	11.1	1130	1160	170	3.27	267	3.92	25.3	201	186000
335	2.73	15.6	11900	864	11.0	1020	1030	152	3.23	238	3.86	25.0	152	161000
306	2.94	17.1	10700	789	10.9	922	919	137	3.20	214	3.81	24.8	117	142000
279	3.18	18.6	9600	718	10.8	835	823	124	3.17	193	3.76	24.6	90.5	125000
250	3.49	20.7	8490	644	10.7	744	724	110	3.14	171	3.71	24.4	66.6	108000
229	3.79	22.5	7650	588	10.7	675	651	99.4	3.11	154	3.67	24.3	51.3	96100
207	4.14	24.8	6820	531	10.6	606	578	88.8	3.08	137	3.62	24.1	38.3	84100
192	4.43	26.6	6260	491	10.5	559	530	81.8	3.07	126	3.60	24.0	30.8	76300
176	4.81	28.7	5680	450	10.5	511	479	74.3	3.04	115	3.57	23.9	23.9	68400
162	5.31	30.6	5170	414	10.4	468	443	68.4	3.05	105	3.57	23.8	18.5	62600
146	5.92	33.2	4580	371	10.3	418	391	60.5	3.01	93.2	3.53	23.6	13.4	54600
131	6.70	35.6	4020	329	10.2	370	340	53.0	2.97	81.5	3.49	23.5	9.50	47100
117	7.53	39.2	3540	291	10.1	327	297	46.5	2.94	71.4	3.46	23.5	6.72	40800
104	8.50	43.1	3100	258	10.1	289	259	40.7	2.91	62.4	3.42	23.4	4.72	35200
103	4.59	39.2	3000	245	10.0	280	119	26.5	1.99	41.5	2.40	23.5	7.07	16600
94	5.18	41.9	2700	222	9.87	254	109	24.0	1.98	37.5	2.40	23.4	5.26	15000
84	5.86	45.9	2370	196	9.79	224	94.4	20.9	1.95	32.6	2.37	23.3	3.70	12800
76	6.61	49.0	2100	176	9.69	200	82.5	18.4	1.92	28.6	2.33	23.2	2.68	11100
68	7.66	52.0	1830	154	9.55	177	70.4	15.7	1.87	24.5	2.30	23.1	1.87	9430
62	5.97	50.1	1550	131	9.23	153	34.5	9.80	1.38	15.7	1.75	23.1	1.71	4620
55	6.94	54.6	1350	114	9.11	134	29.1	8.30	1.34	13.3	1.72	23.1	1.18	3870

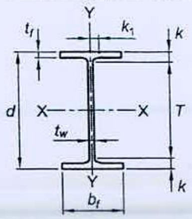


Table 1-1 (continued)
W-Shapes
Dimensions

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.
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

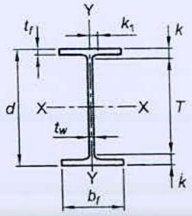


Table 1-1 (continued)
W-Shapes
Dimensions

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.
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

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}
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

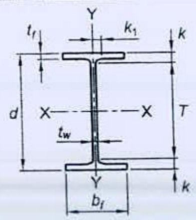


Table 1-1 (continued)
W-Shapes
Dimensions

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.
W14×873[h]	257	23.6	23 5/8	3.94	3 15/16	2	18.8	18 3/4	5.51	5 1/2	6.10	6 3/16	2 9/16	11 1/4	3-8 1/2-3[g]
×808[h]	238	22.8	22 3/4	3.74	3 3/4	1 7/8	18.6	18 5/8	5.12	5 1/8	5.71	5 3/4	2 1/2	11 1/4	3-8 1/2-3[g]
×730[h]	215	22.4	22 3/8	3.07	3 1/16	1 9/16	17.9	17 7/8	4.91	4 15/16	5.51	6 3/16	2 3/4	10	3-7 1/2-3[g]
×665[h]	196	21.6	21 5/8	2.83	2 13/16	1 7/16	17.7	17 5/8	4.52	4 1/2	5.12	5 13/16	2 5/8		3-7 1/2-3[g]
×605[h]	178	20.9	20 7/8	2.60	2 5/8	1 5/16	17.4	17 3/8	4.16	4 3/16	4.76	5 7/16	2 1/2		3-7 1/2-3
×550[h]	162	20.2	20 1/4	2.38	2 3/8	1 3/16	17.2	17 1/4	3.82	3 13/16	4.42	5 1/8	2 3/8		
×500[h]	147	19.6	19 5/8	2.19	2 3/16	1 1/8	17.0	17	3.50	3 1/2	4.10	4 13/16	2 5/16		
×455[h]	134	19.0	19	2.02	2	1	16.8	16 7/8	3.21	3 3/16	3.81	4 1/2	2 1/4		
×426[h]	125	18.7	18 5/8	1.88	1 7/8	15/16	16.7	16 3/4	3.04	3 1/16	3.63	4 5/16	2 1/8		
×398[h]	117	18.3	18 1/4	1.77	1 3/4	7/8	16.6	16 5/8	2.85	2 7/8	3.44	4 1/8	2 1/8		
×370[h]	109	17.9	17 7/8	1.66	1 11/16	13/16	16.5	16 1/2	2.66	2 11/16	3.26	3 15/16	2 1/16		
×342[h]	101	17.5	17 1/2	1.54	1 9/16	13/16	16.4	16 3/8	2.47	2 1/2	3.07	3 3/4	2		
×311[h]	91.4	17.1	17 1/8	1.41	1 7/16	3/4	16.2	16 1/4	2.26	2 1/4	2.86	3 9/16	1 15/16		
×283[h]	83.3	16.7	16 3/4	1.29	1 5/16	11/16	16.1	16 1/8	2.07	2 1/16	2.67	3 3/8	1 7/8		
×257	75.6	16.4	16 3/8	1.18	1 3/16	5/8	16.0	16	1.89	1 7/8	2.49	3 3/16	1 13/16		
×233	68.5	16.0	16	1.07	1 1/16	9/16	15.9	15 7/8	1.72	1 3/4	2.32	3	1 3/4		
×211	62.0	15.7	15 3/4	0.980	1	1/2	15.8	15 3/4	1.56	1 9/16	2.16	2 7/8	1 11/16		
×193	56.8	15.5	15 1/2	0.890	7/8	7/16	15.7	15 3/4	1.44	1 7/16	2.04	2 3/4	1 11/16		
×176	51.8	15.2	15 1/4	0.830	13/16	7/16	15.7	15 5/8	1.31	1 5/16	1.91	2 5/8	1 5/8		
×159	46.7	15.0	15	0.745	3/4	3/8	15.6	15 5/8	1.19	1 3/16	1.79	2 1/2	1 9/16		
×145	42.7	14.8	14 3/4	0.680	11/16	3/8	15.5	15 1/2	1.09	1 1/16	1.69	2 3/8	1 9/16		
W14×132	38.8	14.7	14 5/8	0.645	5/8	5/16	14.7	14 3/4	1.03	1	1.63	2 5/16	1 9/16	10	5 1/2
×120	35.3	14.5	14 1/2	0.590	9/16	5/16	14.7	14 5/8	0.940	15/16	1.54	2 1/4	1 1/2		
×109	32.0	14.3	14 3/8	0.525	1/2	1/4	14.6	14 5/8	0.860	7/8	1.46	2 3/16	1 1/2		
×99[f]	29.1	14.2	14 1/8	0.485	1/2	1/4	14.6	14 5/8	0.780	3/4	1.38	2 1/16	1 7/16		
×90[f]	26.5	14.0	14	0.440	7/16	1/4	14.5	14 1/2	0.710	11/16	1.31	2	1 7/16		
W14×82	24.0	14.3	14 1/4	0.510	1/2	1/4	10.1	10 1/8	0.855	7/8	1.45	1 11/16	1 1/16	10 7/8	5 1/2
×74	21.8	14.2	14 1/8	0.450	7/16	1/4	10.1	10 1/8	0.785	13/16	1.38	1 5/8	1 1/16		
×68	20.0	14.0	14	0.415	7/16	1/4	10.0	10	0.720	3/4	1.31	1 9/16	1 1/16		
×61	17.9	13.9	13 7/8	0.375	3/8	3/16	10.0	10	0.645	5/8	1.24	1 1/2	1		
W14×53	15.6	13.9	13 7/8	0.370	3/8	3/16	8.06	8	0.660	11/16	1.25	1 1/2	1	10 7/8	5 1/2
×48	14.1	13.8	13 3/4	0.340	5/16	3/16	8.03	8	0.595	5/8	1.19	1 7/16	1		
×43[c]	12.6	13.7	13 5/8	0.305	5/16	3/16	8.00	8	0.530	1/2	1.12	1 3/8	1		

[c] Shape is slender for compression with $F_y = 50$ ksi.
[f] Shape exceeds compact limit for flexure 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.

Table 1-1 (continued)
W-Shapes
Properties

W14

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]
873	1.71	2.89	18100	1530	8.39	2030	6170	656	4.90	1020	6.04	18.1	2270	505000
808	1.82	3.04	15900	1390	8.17	1830	5550	597	4.83	930	5.94	17.7	1840	434000
730	1.82	3.71	14300	1280	8.17	1660	4720	527	4.69	816	5.68	17.5	1450	362000
665	1.95	4.03	12400	1150	7.98	1480	4170	472	4.62	730	5.57	17.1	1120	305000
605	2.09	4.39	10800	1040	7.80	1320	3680	423	4.55	652	5.44	16.7	869	258000
550	2.25	4.79	9430	931	7.63	1180	3250	378	4.49	583	5.35	16.4	669	219000
500	2.43	5.21	8210	838	7.48	1050	2880	339	4.43	522	5.26	16.1	514	187000
455	2.62	5.66	7190	756	7.33	936	2560	304	4.38	468	5.17	15.8	395	160000
426	2.75	6.08	6600	706	7.26	869	2360	283	4.34	434	5.11	15.7	331	144000
398	2.92	6.44	6000	656	7.16	801	2170	262	4.31	402	5.05	15.5	273	129000
370	3.10	6.89	5440	607	7.07	736	1990	241	4.27	370	5.00	15.2	222	116000
342	3.31	7.41	4900	558	6.98	672	1810	221	4.24	338	4.95	15.0	178	103000
311	3.59	8.09	4330	506	6.88	603	1610	199	4.20	304	4.87	14.8	136	89100
283	3.89	8.84	3840	459	6.79	542	1440	179	4.17	274	4.80	14.6	104	77700
257	4.23	9.71	3400	415	6.71	487	1290	161	4.13	246	4.75	14.5	79.1	67800
233	4.62	10.7	3010	375	6.63	436	1150	145	4.10	221	4.69	14.3	59.5	59000
211	5.06	11.6	2660	338	6.55	390	1030	130	4.07	198	4.64	14.1	44.6	51500
193	5.45	12.8	2400	310	6.50	355	931	119	4.05	180	4.59	14.1	34.8	45900
176	5.97	13.7	2140	281	6.43	320	838	107	4.02	163	4.55	13.9	26.5	40500
159	6.54	15.3	1900	254	6.38	287	748	96.2	4.00	146	4.51	13.8	19.7	35600
145	7.11	16.8	1710	232	6.33	260	677	87.3	3.98	133	4.47	13.7	15.2	31700
132	7.15	17.7	1530	209	6.28	234	548	74.5	3.76	113	4.23	13.7	12.3	25500
120	7.80	19.3	1380	190	6.24	212	495	67.5	3.74	102	4.20	13.6	9.37	22700
109	8.49	21.7	1240	173	6.22	192	447	61.2	3.73	92.7	4.17	13.4	7.12	20200
99	9.34	23.5	1110	157	6.17	173	402	55.2	3.71	83.6	4.14	13.4	5.37	18000
90	10.2	25.9	999	143	6.14	157	362	49.9	3.70	75.6	4.10	13.3	4.06	16000
82	5.92	22.4	881	123	6.05	139	148	29.3	2.48	44.8	2.85	13.4	5.07	6710
74	6.41	25.4	795	112	6.04	126	134	26.6	2.48	40.5	2.83	13.4	3.87	5990
68	6.97	27.5	722	103	6.01	115	121	24.2	2.46	36.9	2.80	13.3	3.01	5380
61	7.75	30.4	640	92.1	5.98	102	107	21.5	2.45	32.8	2.78	13.3	2.19	4710
53	6.11	30.9	541	77.8	5.89	87.1	57.7	14.3	1.92	22.0	2.22	13.2	1.94	2540
48	6.75	33.6	484	70.2	5.85	78.4	51.4	12.8	1.91	19.6	2.20	13.2	1.45	2240
43	7.54	37.4	428	62.6	5.82	69.6	45.2	11.3	1.89	17.3	2.18	13.2	1.05	1950

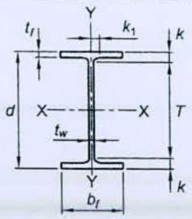


Table 1-1 (continued)
W-Shapes
Dimensions

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	Distance Workable Gage
	in.^{2}	in.		in.		in.	in.		in.		in.	in.	in.	in.	in.
W14×38[c]	11.2	14.1	14 1/8	0.310	5/16	3/16	6.77	6 3/4	0.515	1/2	0.915	1 1/4	13/16	11 5/8	3 1/2[g]
×34[c]	10.0	14.0	14	0.285	5/16	3/16	6.75	6 3/4	0.455	7/16	0.855	1 3/16	3/4	↓	3 1/2
×30[c]	8.85	13.8	13 7/8	0.270	1/4	1/8	6.73	6 3/4	0.385	3/8	0.785	1 1/8	3/4		3 1/2
W14×26[c]	7.69	13.9	13 7/8	0.255	1/4	1/8	5.03	5	0.420	7/16	0.820	1 1/8	3/4	11 5/8	2 3/4[g]
×22[c]	6.49	13.7	13 3/4	0.230	1/4	1/8	5.00	5	0.335	5/16	0.735	1 1/16	3/4	11 5/8	2 3/4[g]
W12×336[h]	98.9	16.8	16 7/8	1.78	1 3/4	7/8	13.4	13 3/8	2.96	2 15/16	3.55	3 7/8	1 11/16	9 1/8	5 1/2
×305[h]	89.5	16.3	16 3/8	1.63	1 5/8	13/16	13.2	13 1/4	2.71	2 11/16	3.30	3 5/8	1 5/8		
×279[h]	81.9	15.9	15 7/8	1.53	1 1/2	3/4	13.1	13 1/8	2.47	2 1/2	3.07	3 3/8	1 5/8		
×252[h]	74.1	15.4	15 3/8	1.40	1 3/8	11/16	13.0	13	2.25	2 1/4	2.85	3 1/8	1 1/2		
×230[h]	67.7	15.1	15	1.29	1 5/16	11/16	12.9	12 7/8	2.07	2 1/16	2.67	2 15/16	1 1/2		
×210	61.8	14.7	14 3/4	1.18	1 3/16	5/8	12.8	12 3/4	1.90	1 7/8	2.50	2 13/16	1 7/16		
×190	56.0	14.4	14 3/8	1.06	1 1/16	9/16	12.7	12 5/8	1.74	1 3/4	2.33	2 5/8	1 3/8		
×170	50.0	14.0	14	0.960	15/16	1/2	12.6	12 5/8	1.56	1 9/16	2.16	2 7/16	1 5/16		
×152	44.7	13.7	13 3/4	0.870	7/8	7/16	12.5	12 1/2	1.40	1 3/8	2.00	2 5/16	1 1/4		
×136	39.9	13.4	13 3/8	0.790	13/16	7/16	12.4	12 3/8	1.25	1 1/4	1.85	2 1/8	1 1/4		
×120	35.2	13.1	13 1/8	0.710	11/16	3/8	12.3	12 3/8	1.11	1 1/8	1.70	2	1 3/16		
×106	31.2	12.9	12 7/8	0.610	5/8	5/16	12.2	12 1/4	0.990	1	1.59	1 7/8	1 1/8		
×96	28.2	12.7	12 3/4	0.550	9/16	5/16	12.2	12 1/8	0.900	7/8	1.50	1 13/16	1 1/8		
×87	25.6	12.5	12 1/2	0.515	1/2	1/4	12.1	12 1/8	0.810	13/16	1.41	1 11/16	1 1/16		
×79	23.2	12.4	12 3/8	0.470	1/2	1/4	12.1	12 1/8	0.735	3/4	1.33	1 5/8	1 1/16		
×72	21.1	12.3	12 1/4	0.430	7/16	1/4	12.0	12	0.670	11/16	1.27	1 9/16	1 1/16		
×65[f]	19.1	12.1	12 1/8	0.390	3/8	3/16	12.0	12	0.605	5/8	1.20	1 1/2	1	↓	↓
W12×58	17.0	12.2	12 1/4	0.360	3/8	3/16	10.0	10	0.640	5/8	1.24	1 1/2	15/16	9 1/4	5 1/2
×53	15.6	12.1	12	0.345	3/8	3/16	10.0	10	0.575	9/16	1.18	1 3/8	15/16	9 1/4	5 1/2
W12×50	14.6	12.2	12 1/4	0.370	3/8	3/16	8.08	8 1/8	0.640	5/8	1.14	1 1/2	15/16	9 1/4	5 1/2
×45	13.1	12.1	12	0.335	5/16	3/16	8.05	8	0.575	9/16	1.08	1 3/8	15/16		
×40	11.7	11.9	12	0.295	5/16	3/16	8.01	8	0.515	1/2	1.02	1 3/8	7/8	↓	↓
W12×35[c]	10.3	12.5	12 1/2	0.300	5/16	3/16	6.56	6 1/2	0.520	1/2	0.820	1 3/16	3/4	10 1/8	3 1/2
×30[c]	8.79	12.3	12 3/8	0.260	1/4	1/8	6.52	6 1/2	0.440	7/16	0.740	1 1/8	3/4		
×26[c]	7.65	12.2	12 1/4	0.230	1/4	1/8	6.49	6 1/2	0.380	3/8	0.680	1 1/16	3/4	↓	↓
W12×22[c]	6.48	12.3	12 1/4	0.260	1/4	1/8	4.03	4	0.425	7/16	0.725	15/16	5/8	10 3/8	2 1/4[g]
×19[c]	5.57	12.2	12 1/8	0.235	1/4	1/8	4.01	4	0.350	3/8	0.650	7/8	9/16		
×16[c]	4.71	12.0	12	0.220	1/4	1/8	3.99	4	0.265	1/4	0.565	13/16	9/16		
×14[c,v]	4.16	11.9	11 7/8	0.200	3/16	1/8	3.97	4	0.225	1/4	0.525	3/4	9/16	↓	↓

[c] Shape is slender for compression with $F_y = 50$ ksi.
[f] Shape exceeds compact limit for flexure 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

W14–W12

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}
38	6.57	39.6	385	54.6	5.87	61.5	26.7	7.88	1.55	12.1	1.82	13.6	0.798	1230
34	7.41	43.1	340	48.6	5.83	54.6	23.3	6.91	1.53	10.6	1.80	13.5	0.569	1070
30	8.74	45.4	291	42.0	5.73	47.3	19.6	5.82	1.49	8.99	1.77	13.4	0.380	887
26	5.98	48.1	245	35.3	5.65	40.2	8.91	3.55	1.08	5.54	1.30	13.5	0.358	405
22	7.46	53.3	199	29.0	5.54	33.2	7.00	2.80	1.04	4.39	1.27	13.4	0.208	314
336	2.26	5.47	4060	483	6.41	603	1190	177	3.47	274	4.13	13.8	243	57000
305	2.45	5.98	3550	435	6.29	537	1050	159	3.42	244	4.05	13.6	185	48600
279	2.66	6.35	3110	393	6.16	481	937	143	3.38	220	4.00	13.4	143	42000
252	2.89	6.96	2720	353	6.06	428	828	127	3.34	196	3.93	13.2	108	35800
230	3.11	7.56	2420	321	5.97	386	742	115	3.31	177	3.87	13.0	83.8	31200
210	3.37	8.23	2140	292	5.89	348	664	104	3.28	159	3.81	12.8	64.7	27200
190	3.65	9.16	1890	263	5.82	311	589	93.0	3.25	143	3.77	12.7	48.8	23600
170	4.03	10.1	1650	235	5.74	275	517	82.3	3.22	126	3.70	12.4	35.6	20100
152	4.46	11.2	1430	209	5.66	243	454	72.8	3.19	111	3.66	12.3	25.8	17200
136	4.96	12.3	1240	186	5.58	214	398	64.2	3.16	98.0	3.61	12.2	18.5	14700
120	5.57	13.7	1070	163	5.51	186	345	56.0	3.13	85.4	3.56	12.0	12.9	12400
106	6.17	15.9	933	145	5.47	164	301	49.3	3.11	75.1	3.52	11.9	9.13	10700
96	6.76	17.7	833	131	5.44	147	270	44.4	3.09	67.5	3.49	11.8	6.85	9410
87	7.48	18.9	740	118	5.38	132	241	39.7	3.07	60.4	3.46	11.7	5.10	8270
79	8.22	20.7	662	107	5.34	119	216	35.8	3.05	54.3	3.43	11.7	3.84	7330
72	8.99	22.6	597	97.4	5.31	108	195	32.4	3.04	49.2	3.41	11.6	2.93	6540
65	9.92	24.9	533	87.9	5.28	96.8	174	29.1	3.02	44.1	3.38	11.5	2.18	5780
58	7.82	27.0	475	78.0	5.28	86.4	107	21.4	2.51	32.5	2.81	11.6	2.10	3570
53	8.69	28.1	425	70.6	5.23	77.9	95.8	19.2	2.48	29.1	2.79	11.5	1.58	3160
50	6.31	26.8	391	64.2	5.18	71.9	56.3	13.9	1.96	21.3	2.25	11.6	1.71	1880
45	7.00	29.6	348	57.7	5.15	64.2	50.0	12.4	1.95	19.0	2.23	11.5	1.26	1650
40	7.77	33.6	307	51.5	5.13	57.0	44,1	11.0	1.94	16.8	2.21	11.4	0.906	1440
35	6.31	36.2	285	45.6	5.25	51.2	24.5	7.47	1.54	11.5	1.79	12.0	0.741	879
30	7.41	41.8	238	38.6	5.21	43.1	20.3	6.24	1.52	9.56	1.77	11.9	0.457	720
26	8.54	47.2	204	33.4	5.17	37.2	17.3	5.34	1.51	8.17	1.75	11.8	0.300	607
22	4.74	41.8	156	25.4	4.91	29.3	4.66	2.31	0.848	3.66	1.04	11.9	0.293	164
19	5.72	46.2	130	21.3	4.82	24.7	3.76	1.88	0.822	2.98	1.02	11.9	0.180	131
16	7.53	49.4	103	17.1	4.67	20.1	2.82	1.41	0.773	2.26	0.983	11.7	0.103	96.9
14	8.82	54.3	88.6	14.9	4.62	17.4	2.36	1.19	0.753	1.90	0.961	11.7	0.0704	80.4

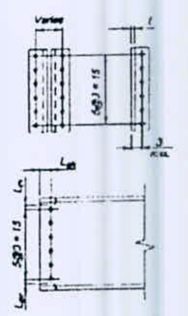
= 17 =

Beam	Angle
F_y = 50 ksi, F_u = 65 ksi	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.	1 1/2		1 3/4		1 1/2		1 3/4		1 1/2		1 3/4	
L_{ev}, in.		ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	LRFD	ASD	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.

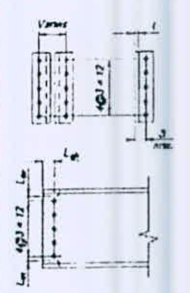
= 18 =

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	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	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 Stren th per Inch Thic ness, ips/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	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, ips/in.

Hole Type	ASD	LRFD
STD/ OVS/ SSLT	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.

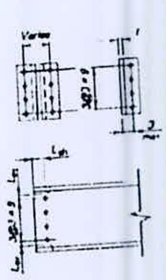
Beam	F_y = 50 ksi, F_u = 65 ksi
Angle	F_y = 36 ksi, F_u = 58 ksi

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

3/4-in. Bolts

4 Rows

W24, 21, 18, 16



Bolt and Angle Available Strength, kips

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	50.8	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	105	158
	SC Class B	STD	67.1	101	83.9	126	101	151	89.9	134
		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

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

Hole Type		STD				OVS				SSLT			
	L_{eh}*, in.	$1^1/_2$		$1^3/_4$		$1^1/_2$		$1^3/_4$		$1^1/_2$		$1^3/_4$	
	L_{ev}, in.	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 : 18/10/2023

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2021-2022

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**.

1. (a) Briefly describe the importance of Traffic Engineering. Name the common tools that are available to traffic engineer to tackle congestion and road safety problems. **(3+4=7)**

(b) State the objectives and methods of collecting data for the following surveys: (i) Volume, (ii) Speed, (iii) Origin – destination (O-D) **(3×4=12)**

(c) Following data was collected while conducting spot speed studies at a certain stretch of a road within the urban area. Determine: **(12)**

(i) Average speed of traffic stream,

(ii) Modal speed,

(iii) Upper and lower speed limits,

(iv) Design speed

Speed range (kmph)	Frequency
0-5	0
5-10	12
10-15	36
15-20	54
20-25	108
25-30	205
30-35	240
35-40	110
40-45	65
45-50	25
50-55	11
55-60	5
60-65	3
65-70	0

(d) A freeway detector records an occupancy of 0.255 for a 15-minute period. If the detector is 3.5 ft. long, and the average vehicle has a length of 20 ft, what is the density implied by this measurement? **(4)**

Contd P/2

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2. (a) Differentiate between: **(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) Name four sea ports of Bangladesh with their location, type and operational status. With proper labelling draw a cross-section of LGED road having a hill-cut at one side at inward curvature to hill (CVD 0 to 300). **(4+5=9)**

(c) The following travel times were measured for vehicles as they traversed a 2.0-mile segment of highway. Compute the time mean speed (TMS) and space mean speed (SMS) for this data. **(8)**

Vehicle	Travel time(s)
1	155
2	145
3	144
4	168
5	126
6	132

(d) A motorist traveling at 80 km/h up a grade of 2% on a highway observes a crash ahead of him, involving an overturned truck that is completely blocking the road. If the motorist was able to stop his vehicle 5 m from the overturned truck, what was his distance from the truck when he first observed the crash? Assume comfortable deceleration rate as 3.4 m/sec^2 and appropriate PIEV time. **(9)**

3. (a) 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. **(3×4=12)**

(b) Write short notes on: (i) PCU/PCE (ii) CVD, (iii) Pace. **(3×3=9)**

(c) 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. **(7)**

U_1 = 34.0 kmph	U_2 = 37.0 kmph
S_1 = 6.0 kmph	S_2 = 7.0 kmph
N_1 = 250 nos.	N_2 = 260 nos.

(d) The acceleration of a vehicle is specified as: $du_t/dt = 1 - 0.04\ u_t$ where u_t is the velocity in meter/second. If the vehicle is travelling at 80 km/hour, determine the velocity after 5 second of acceleration and distance travelled during that time. **(7)**

Contd P/3

4. (a) What are the advantages and disadvantages of "Water Transport"? Write short notes on DMTCL, CAAB and Bangladesh Railway. **(4+9=13)**

(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. **(9)**

(c) Name different roads operated, constructed and maintained by RHD and LGED. An existing 6.2 m regional road located on an embankment requires full reconstruction. CBR of the sub-grade beneath the existing road was 3%. A 24-hour classified traffic count was carried out on a typical weekday and it was found that the base year annual ESAL was 3,42,735. Design the road with a design period according to RHD standards (see Table 1). Note: For regional roads r = 7% and n = 20 years. **(3+5=8)**

(d) Where parking should be prohibited? Write a short note on "Truck Stops". **(2+3=5)**

SECTION – B

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

Assume any reasonable value for any missing data.

5. (a) Differentiate between cordon and screen line traffic count with an appropriate study area diagram. What variables are collected during a household interview survey? Name at least two variables each for household, person, vehicle, and trip category. **(6+8=14)**

(b) What do you understand by highway performance function? Two highways serve a busy corridor with a traffic demand of 6000 vehicles per hour during the peak period. The performance function for the two routes is given by $t_1 = 4 + 5(\frac{x1}{c1})$ and $t_2 = 3 + 7(\frac{x2}{c2})$. Here, time (t's) are in minutes and the flow (x's) and capacity (c's) are in thousands of vehicles per hour. If the capacities of routes 1 and 2 are 4400 veh/h and 5200 veh/h respectively, determine the amount of flow on routes 1 and 2 during the peak hour under the user equilibrium condition. Calculate the total vehicle-hour traveled on the two routes during the peak hour. **(4+12=16)**

(c) Under what circumstances would you prefer cross-classification analysis over regression for trip generation modeling? Explain with an example. **(5)**

6. (a) What do you understand by design hour volume (DHV)? How would you select the design vehicle for the geometric design of a facility as per AASHTO? **(4+5=9)**

(b) What do you understand by crowning of highway? Where would you provide a crowned section? Produce an appropriate diagram to show the transition of a crowned section to a superelevated section. You can assume that the cross-section is rotated about the center line of the pavement. Clearly identify the length of tangent runout and tangent runoff. **(3+2+7=12)**

Contd P/4

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(c) What will be the stopping sight distance for a design speed of 60 km per hour? You can assume a perception reaction time of 2.75 seconds and a friction coefficient of 0.32. **(7)**

(d) Draw a typical diamond interchange for left hand driving. Identify the upward and downward ramps. Clearly state how the left, through and right movements are facilitated for different approaches in a diamond interchange. **(7)**

7. (a) A mode choice model is developed to quantify the modal share between car, bus and metro rail, The utility equation of the three modes is provided below where 'tt' represents travel time in minute and 'tc' represents travel cost in taka. **(12)**

$$U_{car} = 2.5 - 0.4 * tt_{car} - 0.2 * tc_{car}$$
$$U_{bus} = -0.2 * tt_{bus} - 0.2 * tc_{bus}$$
$$U_{metro} = 0.3 - 0.3 * tt_{metro} - 0.2 * tc_{metro}$$

Calculate the modal share for the travel time and cost values provided in the following table. How will the modal share change if an operational subsidy by government reduces the metro rail fare by 10 takas?

Mode	Travel Time (min)	Travel Cost (Taka)
Car	30	40
Bus	50	20
Metro rail	35	30

(b) According to AASHTO what factors guide the requirement for separate bicycle facility? Define the class I, class II and class III bicycle facilities as per AASHTO. **(8)**

(c) Explain different attributes of the Transportation System with examples. What do you understand by EV, BEV and PHEV? **(6+9=15)**

8. (a) Describe the Characteristics of Automobile City, Walking City and Transit City. What are the key properties of commuter rail? **(9+6=15)**

(b) A bus transit system will to be set up between the BUET campus and the Gabtoli bus terminal covering 8.5 miles. The operating time will be 30 minutes. It has been estimated that the peak hour demand is 400 passengers/hour and 45-seater buses are available, which can safely accommodate 20 standees. Design the primary system and determine the fleet size, assuming the policy headway is 30 minutes, and the minimum terminal time is 7.5 minutes, which may be revised if necessary. **(10)**

(c) Write down the different applications of GPS in Transportation Engineering. **(10)**

Appendix

Table 1 for Question 4 (c)

mm	Surfacing (mm)		Roadbases (mm)* (Select one type)			Sub-bases (mm)** Subgrade CBR %		
Traffic ESA (mill)	Asphalt Wearing Course	Asphalt Base-Course	Cement-bound Granular	Granular Base Type I	Granular Base Type II	5	8 - 25	> 25
60 - 80	40	155	Refer to BRRL for design advice	N/A	N/A	300	150	0
40 - 60	↓	140	↓	↓	↓	↓	↓	↓
30 - 40	↓	125	↓	↓	↓	↓	↓	↓
25 - 30	↓	110	↓	250	300	250	↓	↓
17 - 25	↓	105	↓	↓	↓	↓	↓	↓
15 - 17	↓	95	↓	↓	↓	200	↓	↓
11 - 15	↓	90	↓	↓	↓	↓	↓	↓
9 - 11	↓	80	↓	200	250	↓	↓	↓
7 - 9	↓	70	↓	↓	↓	↓	↓	↓
6 - 7	↓	65	↓	↓	↓	↓	↓	↓
5 - 6	↓	60	↓	↓	↓	↓	↓	↓
4 - 5	↓	55	↓	↓	↓	↓	↓	↓
3 - 4	↓	45	↓	175	200	175	↓	↓
< 3	↓	35	↓	150	175	150	↓	↓

* CBR of granular base type I is min. 80%　　N/A. = not applicable

* CBR of granular base type II is min. 50%

** CBR of sub-base material is 25%

L-3/T-2/CE Date : 02/10/2023

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-2 B. Sc. Engineering Examinations 2021-2022

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

Full Marks : 280 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**.

Assume reasonable values if needed.

1. (a) For the following velocity distribution profile estimate the discharge per unit width of the channel. Also calculate the velocity distribution coefficients. **(20)**

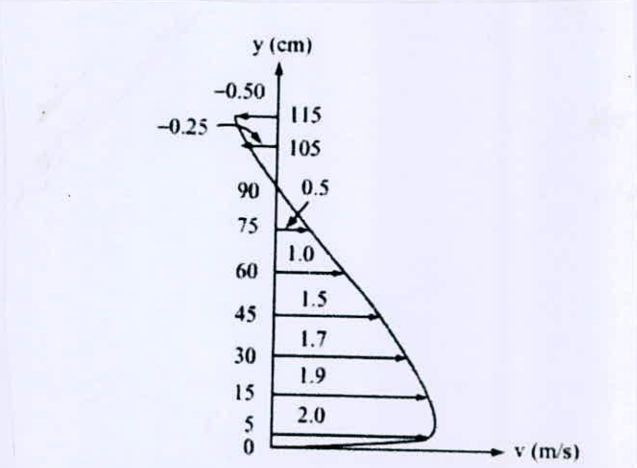

Figure 1 for question1(a)

(b) In a rectangular channel if the angle between the flow surface and horizontal axis is θ and the angle between the channel bottom and horizontal is ϕ, prove that the pressure intensity at the channel bottom is, $p = \frac{1}{1+\tan\theta\tan\phi^{\rho g y}}$, Where y is the flow depth measured vertically. **(10)**

(c) While computing the bending moment and shear force acting on the sidewalls of a spillway chute shown in figure 2 a structural engineer assumed hydrostatic pressure distribution at the invert of the chute. What are the computed values of bending moment and shear force at the invert level? Are these computed results, correct? If not, compute the percentage error. **(16⅔)**

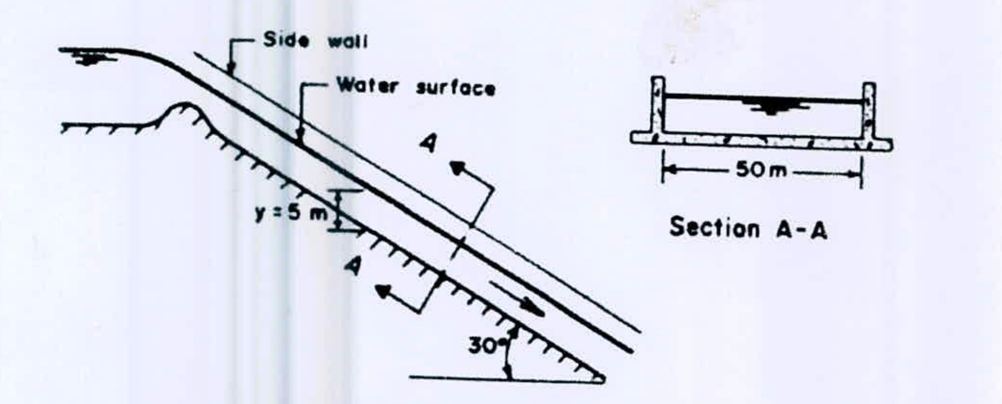

Figure 2 for question 1(c)

Contd P/2

2. (a) Driven an expression for hydraulic exponent for critical flow condition and calculate the value of this exponent for parabolic section. **(10)**

   (b) Water flows in a rectangular channel at upstream depth of 1.8m, with a hump. A 35cm high smooth hump produces a drop of 15cm in the water surface elevation. Estimate the discharge per unit width of the channel considering an energy loss of 15% of the approach velocity head. **(16)**

   (c) A 3.0 m wide rectangular channel carries a flow at 1.25 m depth. At a certain section the width is reduced to 2.5m and the bed is raised by 0.20 m through a hump. (i) Estimate the discharge in the channel when the water surface drops by 15cm over the hump. (ii) What change in bed elevation in the contracted section would make the water surface have the same elevation upstream and downstream of the contraction? The energy loss can be neglected. **(20⅔)**

3. (a) A sluice gate in a 3 m wide rectangular channel releases a discharge of 18 m^3/s. The gate opening is 0.67m and the coefficient of contraction can be assumed to be 0.6. If a hydraulic jump forms in this channel, determine the type of the jump when the tailwater depth is 5.00 m. Show necessary sketches. **(15)**

   (b) An overflow spillway is 40m high (shown in figure 3). At the design energy head of 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 the flow over spillway and assume C_d=0.738. **(16⅔)**

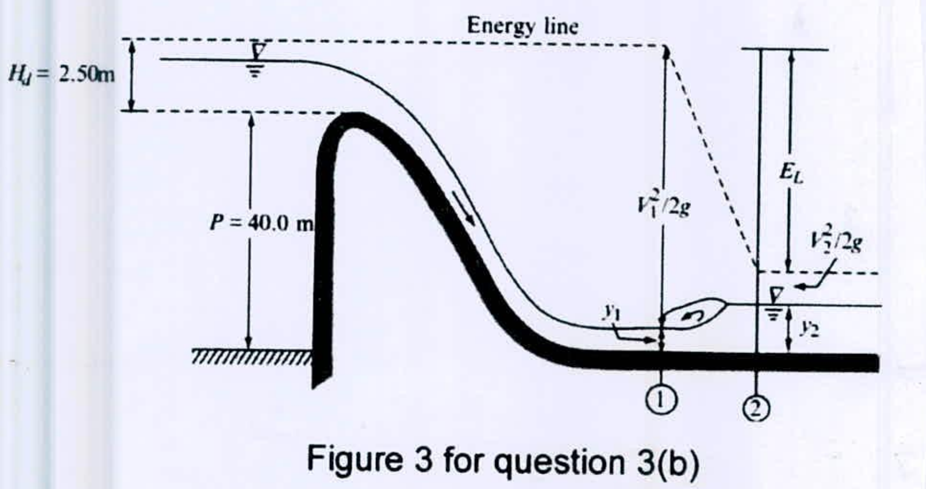

Figure 3 for question 3(b)

   (c) A rectangular channel is laid on a slope of 12° with the horizontal. When the channel carries a discharge of 15$m^3/s/m$ at a depth of 0.7 m, a hydraulic jump is known to occur at a section. Calculate the sequent depth of the jump, length of the jump and energy loss in the jump. Also determine the type of the jump with necessary sketch. **(15)**

Contd P/3

4. (a) Using the regime approach, design an alluvium channel for a design flow of 8 m^3/s. The sediment carried by water is 0.4 mm sand. Show necessary sketches. **(10)**

(b) Design an irrigation canal for a design discharge of 1100 ft^3/s. The general slope in the area is 2 ft per mile and Manning's roughness n is 0.025. Design the channel by the concept of best hydraulic section method. **($16\frac{2}{3}$)**

(c) A drainage channel has to be designed to carry a runoff from 200 km^2 area. If the flow per square kilometer is 0.5 $m^3/s/km^2$, design the drainage channel by tractive force method. The bottom slope is 0.00025 and the channel is excavated through fine gravel having particle size of 8mm. Assume particles are moderately rounded and the water **(20)**

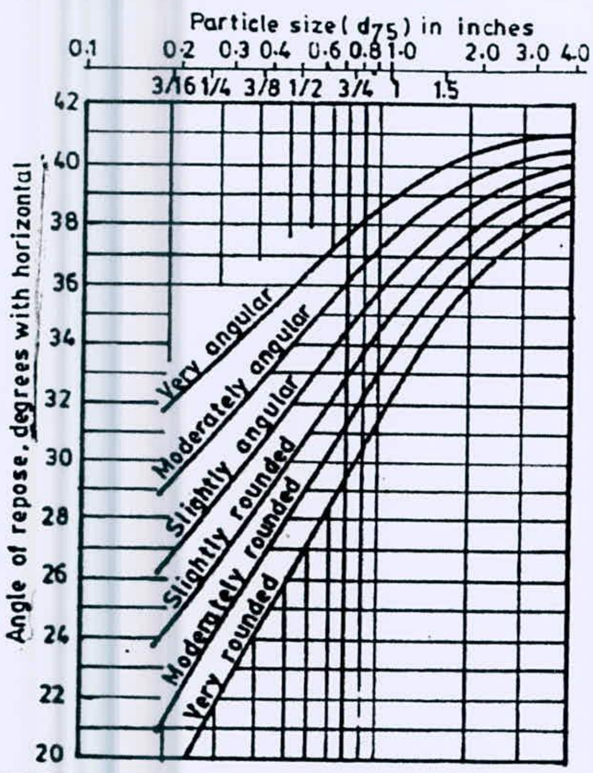

Figure 4 for question 4(c)

SECTION – B

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

The symbols and notations have their usual meanings.

5. (a) Define spatially varied flow. Explain the type of flow in a roadside gutter 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. **(12)**

(c) A rectangular channel with a sharp crested weir is shown in Figure 5. If discharge per unit width of the weir is 4 $m^3/s/m$, estimate the energy loss due to 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. **($24\frac{2}{3}$)**

Contd P/4

WRE 311(CE)

6. (a) Explain why uniform flow seems to be self-adjusting and any deviation from the condition '$W\sin\theta = F_f$' tends to reestablish this condition. **(10)**

(b) Differentiate between normal slope and critical slope. A rectangular channel has a bottom width of 6 m, α=1.12 and n=0.02. Determine the critical slope if the normal depth of this channel is 1.50 m. **(12)**

(c) Compute the total discharge and the mean velocity of flow for the entire section of a channel that consists of a main section and two side sections with respective roughness, energy and momentum coefficients as shown in the Figure 6. Given, the bed slope is S_0=0.0008. Compute the numerical values of n, α, and β for the entire section. Comment on your results. **(24⅔)**

7. (a) Determine the value of hydraulic exponent for uniform flow computation N, for a trapezoidal channel section when conveyance is expressed by Chezy formula. **(15)**

(b) Draw qualitatively the possible flow profiles as a result of change in channel width in a mild slope channel followed by critical slope channel as shown in Figure 7. **(15)**

(c) A rectangular channel with b=6 m, α=1.13 and n=0.023, has two reaches arranged serially. The bottom slopes of these reaches are 0.0080 and 0.0030, respectively. For a discharge of 10 m^3/s in the channel, name and sketch qualitatively the resulting flow profiles. **(16⅔)**

8. (a) Derive the dynamic equation of steady gradually varied flow with necessary assumption. What is the implication of this equation? **(10)**

(b) Explain why zone-1 in horizontal slope channel is not possible in gradually varied flow. Draw a qualitative flow profile as a result of decrease in bed surface roughness in a steep slope channel. **(10)**

(c) A trapezoidal channel with bottom width of 6 m, s=2, n=0.02 is laid on a slope of 0.0007 and carries a discharge of 50 m^3/s. The depth produced by a dam immediately upstream of it is 2.80 m. Compute the resulting flow profile. Determine the depth of flow 100 m upstream of the dam using the fourth-order Runge-Kutta method. Consider the normal depth and critical depth as 1.90 m and 1.50 m, respectively. Given, the energy coefficient is 1.15. **(26⅔)**

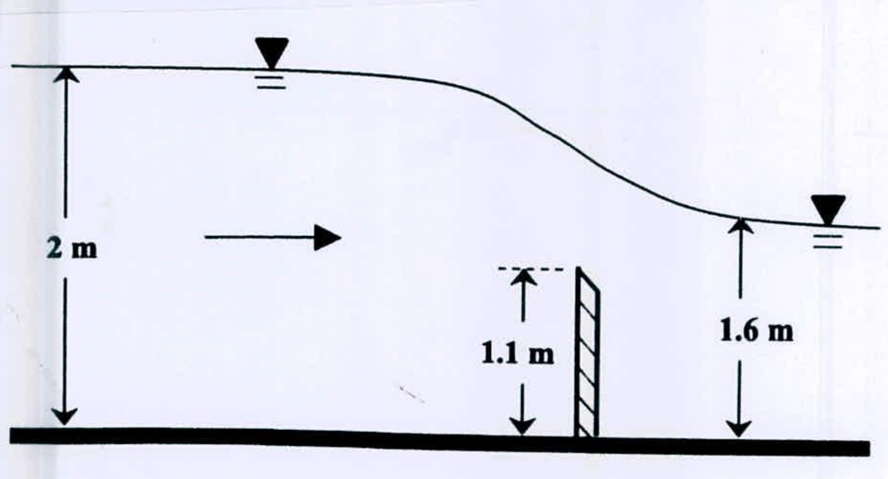

Figure 6 for Question 5(c)

5

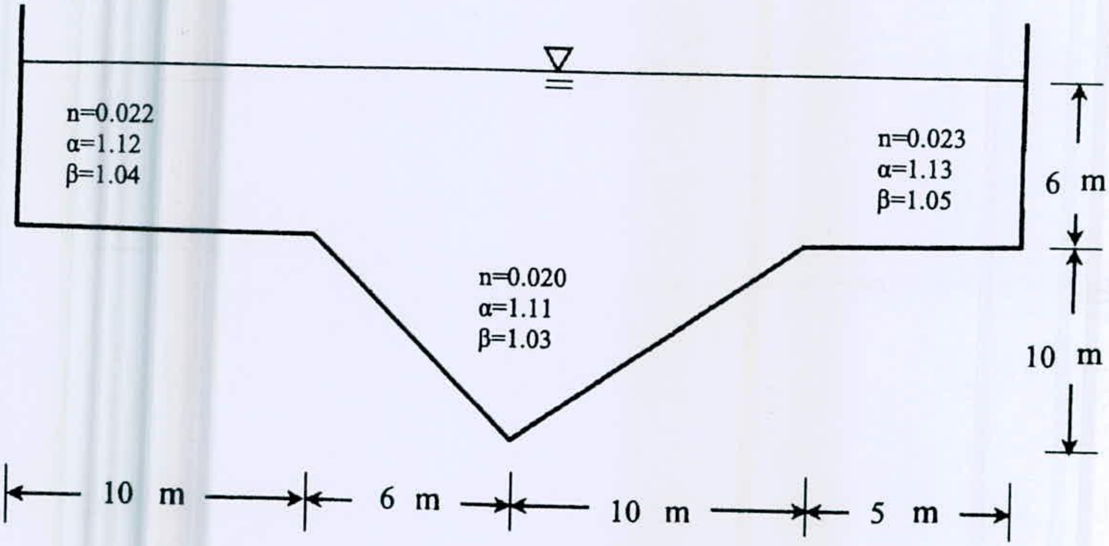

Figure 6 for Question 6(c)

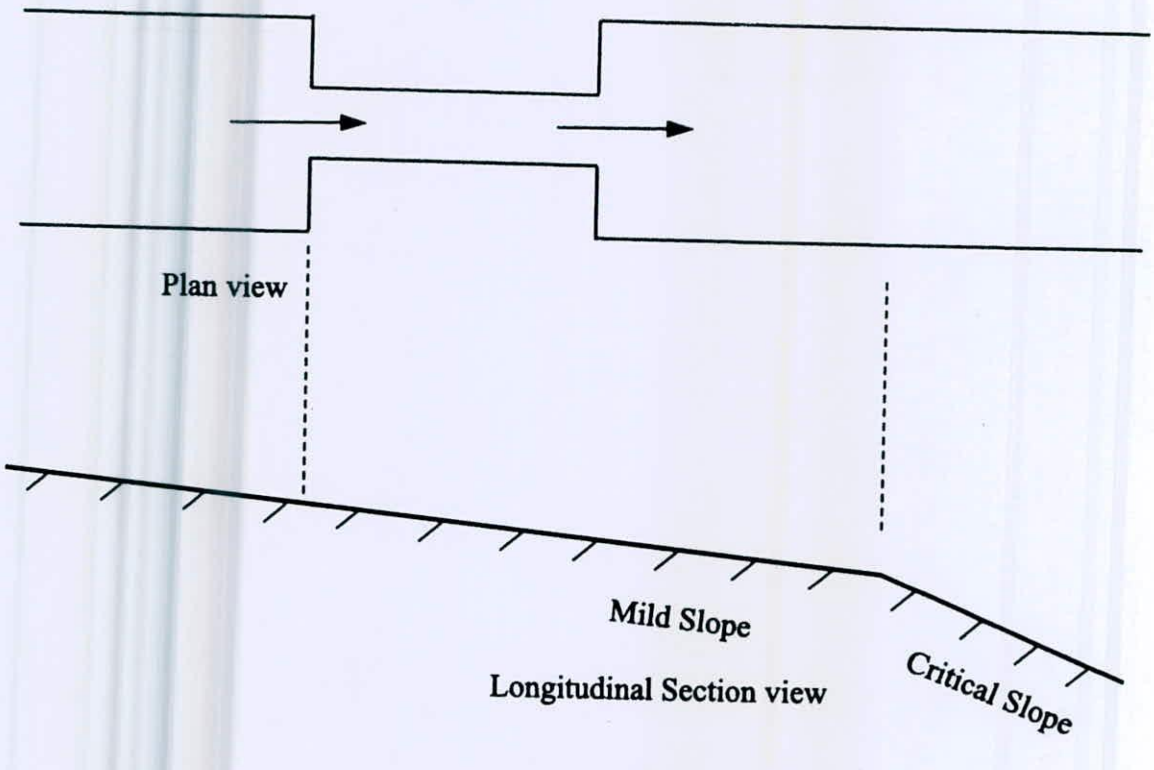

Figure 7 for Question 8(b)
