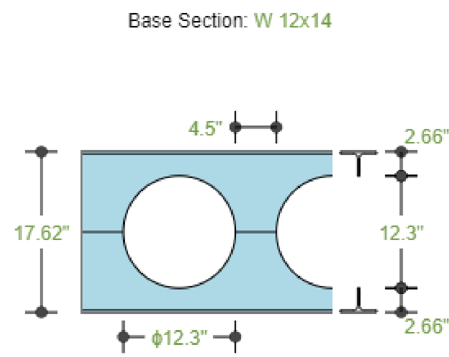
1.0 INPUT

1.1 Design Options



Design Code	**American Standard LRFD**
Unit	**English Unit**
Code	**ANSI/AISC 360-16**

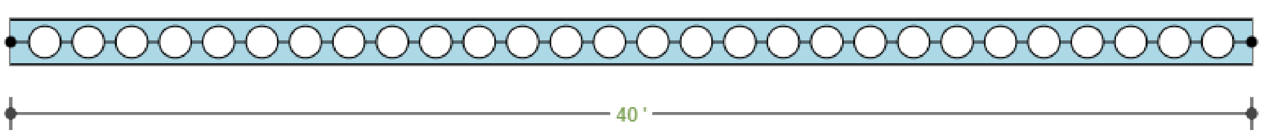
1.2 Section and Span

1.2.1 Base Section

Profile	Type	=	**Standard**
Section		=	**W 12x14**
Overall Depth	D	=	**12.0** in
Overall Height	H	=	**11.9** in
Width of Flange	B	=	**3.97** in
Thickness of Flange	T	=	**0.23** in
Thickness of Web	t	=	**0.2** in

1.2.2 Span

Shape		=	**Straight**
Beam Span	BL	=	**40** ft



1.3 Supports and Restraints

1.3.1 Supports

Left Support	LS	=	**Pinned**
Right Support	RS	=	**Pinned**
Effective Buckling Length	L_b	=	**8** ft

1.4 Fabrication

Fabrication Type	=	**Cellular Beam**

1.4.1 Details

Spacing Width	e	= **4.5** in
Opening Diameter	Do	= **12.3** in

1.4.2 Serviceability Load Combinations

No	Combination
SLS 1	DL + LL

1.4.3 Ultimate Load Combinations

No	Combination
ULS 1	1.2DL + 1.6LL

1.5 Loads and Combinations

1.5.1 Basic Load Cases

Collateral Loads (CL)		**No**
Snow Loads (SL)		**No**
No of Wind Cases	WL	= **0**

1.5.2 Loads and Combinations

Load No	Load Case	Load Type	Intensity (kips/ft)	Start Location (ft)	End Location (ft)
L1	DL	Distributed	0.125	0	40
L2	LL	Distributed	0.1	0	40

Auto Load Combinations **No**

1.6 Material Properties

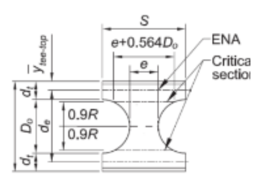
Steel Grade		**A992-Gr50**
Minimum Yield Stress	F_y	= **50** ksi
Tensile Stress	Fu	= **65** ksi

1.7 Deflection Limits

Live Load	DFL	= **240**
Total Load	DFT	= **180**

2.0 OUTPUT ANSI/AISC 360-16

2.1 Section Details



Spacing of Openings S $= e + D_o =$ **16.8** in

loss loss $= D_o / 2 - \text{SQRT}((D_o / 2)^2 - ((S - D_o) / 2)^2)$

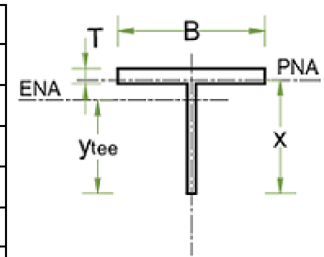
$=$ **0.43** in

Depth of Expanded Beam	d_g = d + D_o / 2 - loss = **17.62** in
Net Depth of Tee	$d_{t,net}$ = (d_g - D_o) / 2 = **2.66** in
	y = SQRT((0.5 * D_o)^2 - (0.225 * D_o)^2)
	= **5.49** in
Critical Depth of Tee	$d_{t,crit}$ = D_o / 2 - y + $d_{t,net}$ = **3.32** in

2.2 Top and Bottom Tee Section Properties

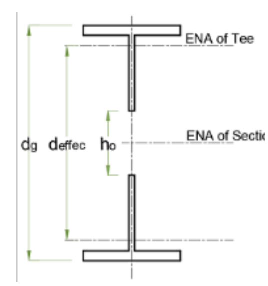
At Center of Opening		
$A_{tee\text{-}net}$ = **1.38** in^2	x_{net} = **2.53** in	$r_{x\text{-}net}$ = **0.76** in
$r_{y\text{-}net}$ = **0.92** in	$y_{tee\text{-}net}$ = **2.08** in	$S_{xtop\text{-}net}$ = **1.38** in^3
$S_{xbot\text{-}net}$ = **0.39** in^3	$Z_{x\text{-}net}$ = **0.68** in^3	$I_{xtee\text{-}net}$ = **0.803** in^4
$I_{ytee\text{-}net}$ = **1.175** in^4	J_{net} = **0.022** in^4	$y_{o\text{-}net}$ = **1.97** in
At Critical Section		
$A_{tee\text{-}crit}$ = **1.51** in^2	x_{crit} = **3.16** in	$r_{x\text{-}crit}$ = **1.51** in
$r_{y\text{-}crit}$ = **1.18** in	$y_{tee\text{-}crit}$ = **2.53** in	$S_{xtop\text{-}crit}$ = **1.9** in^3
$S_{xbot\text{-}crit}$ = **0.6** in^3	$Z_{x\text{-}crit}$ = **1.05** in^3	$I_{xtee\text{-}crit}$ = **1.505** in^4
$I_{ytee\text{-}crit}$ = **1.175** in^4	J_{crit} = **0.024** in^4	$y_{o\text{-}crit}$ = **2.42** in

A_{tee} Area of Tee, **x:** Plastic Neutral Axis, **r_x** Radius of Gyration - X Axis, **r_y** Radius of Gyration - Y Axis,
S_{xtop} Elastic Section Modulus - Top, **S_{xbot}** Elastic Section Modulus - Bottom, **Z_x** Plastic Section Modulus,
I_{xtee} Moment of Inertia - X Axis, **I_{ytee}** Moment of Inertia - Y Axis, **J** Polar Moment of Inertia,
y_o Shear Center from Centroid,



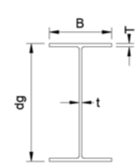
2.3 Net Section Properties

At Center of Opening		
A_{net} = **2.76** in^2	$d_{effecnet}$ = **16.46** in	I_{xnet} = **188.61** in^4
S_{xnet} = **21.404** in^3	Z_{xnet} = **22.724** in^3	
At Critical Section		
A_{crit} = **3.02** in^2	$d_{effec\text{-}crit}$ = **16.04** in	$I_{x\text{-}crit}$ = **197.536** in^4
$S_{x\text{-}crit}$ = **22.417** in^3	$Z_{x\text{-}crit}$ = **24.255** in^3	



2.4 Gross Section Properties

Gross Area	A_{gross} = A_{net} + D_o * t = **5.22** in^2
Gross Moment of Inertia	I_{xgross} = $I_{x\text{-}net}$ + (t * D_o^3 / 12) = **219.625** in^4
Gross Elastic Section Modulus	S_{xgross} = I_{xgross} / (d_g / 2) = **24.924** in^3



2.5 Capacity of Tee Section

2.5.1 Section Classification

Axial Compression (*Table B4.1.a*)				
Element	Slenderness Limit	Actual	Local Classification	Section Classification
Flange	$0.56(E_s/F_y)^{1/2}$ = **13.5**	(B/2)/T = **8.8**	Non-Slender	Non-Slender
Tee Stem	$0.75(E_s/F_y)^{1/2}$ = **18.1**	d_t/t = **16.6**	Non-Slender	

Flexure (*Table B4.1.b*)

Flexure *(Table B4.1 b)*

Element	Compact Limit	Non-Compact Limit	Actual	Local Classification	Section Classification
Flange	$0.38(E_s/F_y)^{1/2}$ = **9.2**	$1.0(E_s/F_y)^{1/2}$ = **24.1**	$(B/2)/T$ = **8.8**	Compact	**Compact**
Tee Stem	$0.84(E_s/F_y)^{1/2}$ = **20.2**	$1.03(E_s/F_y)^{1/2}$ = **36.6**	d_t/t = **16.6**	Compact	

Element | Compact Limit | Non-Compact Limit | Actual | Local Classification | Section Classification

2.5.2 Axial Compression Strength of Tee

a. Flexural Buckling :

Note: Design Assumptions are per Clause 3.2.2.1 of AISC Steel Design Guide 31

Slenderness x - axis L_c/r_x = 0.65 * e / r_x = **4.01**

Slenderness y - axis L_c/r_y = e / r_y = **6.98**

Critical Slenderness L_c/r = **6.98**

Elastic Buckling Stress F_e = π^2 * E_s / $(L_c/r)^2$ = **5881.4** ksi *Eq. E3-4*

Limiting Elastic Slenderness $(L_c/r)_l$ = 4.71 * (E_s / F_y $)^{0.5}$ = **113.4**

Critical Stress F_{cr1} = $0.658^{(F_y/F_e)}$ * F_y = **49.9** ksi

b. Flexural Torsional Buckling :

Shear Modulus of Elasticity of Steel G = **11200.0** ksi

Elastic Critical Buckling Stress about Minor Axis F_{ey} = (π^2 * E_s) / (e / r_y $)^2$ = **5881.4** ksi

Polar Radius of Gyration about the Shear Center r_o = (y_o^2 + (($I_{xtee-crit}$ + I_{ytee}) / $A_{tee-crit}$))$^{0.5}$ = **2.8** in *Eq. E4-9*

Elastic Critical Torsional Buckling Stress F_{ez} = ((π^2 * E_s / e^2) + G * J) * (1 / ($A_{tee-crit}$ * r_o^2))
= **679.3** ksi

Flexural Constant H_c = 1 - (y_o^2 / r_o^2) = **0.2** *Eq. E4-8*

Elastic Critical Buckling Stress F_{et} = (F_{ey} + F_{ez}) / (2.0 * H_c) * (1.0 - ((1.0 - (4.0 * F_{ey} * F_{ez} * H_c / (Fey + Fez$)^2$))$^{0.5}$)) = **622.7** ksi

Critical Stress F_{cr2} = $0.658^{(F_y / F_{et})}$ * F_y = **48.4** ksi *Eq. E3-2*

c. Compressive Strength

Critical Stress F_{cr} = min(F_{cr1}, F_{cr2}) = **48.4** ksi

Effective Flange Width b_e = **3.97** in (Non-Slender) *Eq. E7-1*

Effective Tee Stem Depth d_e = **3.32** in (Non-Slender) *Eq. E7-1*

Effective Sectional Area A_e = b_e * T + (d_e - T) * t = **1.51** in^2

Nominal Compressive Strength P_n = A_e * F_{cr} = **73.2** Kips

Available Compressive Strength P_u = φ_c * P_n = **65.9** Kips

2.5.3 Flexure Strength of Tee

a. Yielding

Yield Moment about Axis of Bending M_y = F_y * $S_{xbot-crit}$ = **29.8** kips-in *Eq. F9-3*

Plastic Bending Moment M_p = M_y = **29.8** kips-in *Eq. F9-4*

b. Lateral-torsional Buckling

Lateral Torsional Buckling Factor B_{tee} = -2.3 * (d_{t-net} / L_b) * ($I_{ytee-net}$ / J $)^{0.5}$ = **-0.5** *Eq. F9-12*

Nominal Flexural Strength based on Lateral Torsional Buckling M_{cr} = 1.95 * E_s / L_b * ($I_{ytee-net}$ * J $)^{0.5}$ * (B_{tee} + (1 + $B_{tee}^2)^{0.5}$)
= **60.2** kips-in *Eq. F9-10*

c. Local Buckling of Tee Stem

The Tee Stem is compact, local buckling of Tee Stem is not applicable.

d. Local Buckling of Tee Flange

The Tee Flange is compact, local buckling of Tee Flange is not applicable.

e. Flexural Strength:

Available Flexural Strength M_a = $\varphi b * Min(a, b, c, d)$ = **26.8** kips-in

2.6 Flexural Strength of Web Post

Note: The calculation of web post flexural strength is per Clause 3.4.2 of AISC Steel Design Guide 31

Elastic Moment M_e = $t * (S - D_o + 0.564 * D_o)^2 / 6.0 * F_y$ = **218.0** kips-in

Allowable / Elastic Moment Ratio M_{al}/M_e = **0.425**

Available Flexural Strength φM_n = $\varphi_b * (M_{al}/M_e) * M_e$ = **83.3** kips-in

2.7 Vertical Shear Capacity of Net Section

Depth to Thickness Ratio h/t = $d_{t,net} / t$ = **13.3**

Web plate buckling coefficient k_v = **1.2**

Web Shear Buckling Coefficient C_{v2} = **1.0**

Nominal Shear Strength φ_{vVnnet} = $\varphi_v * 0.6 * F_y * (2 * d_{t,net} * t) * C_{v2}$ = **31.9** Kips *Eq. G3-1*

2.8 Horizontal Shear Capacity of Web Post

φ_v = **1.0**

Available Shear Strength $\varphi_{vVnhori}$ = $\varphi_v * 0.6 * F_y * (e * t)$ = **27.0** Kips *Eq. J4-3*

2.9 Vertical Shear Capacity of Beam Gross Section

Depth to Thickness Ratio h/t = $(d_g - 2 * T) / t$ = **85.9**

Web Plate Shear Buckling Coefficient k_{v2} = **5.3**

Web Shear Strength Coefficient C_{v1} = **0.7**

φ_{v2} = **0.9**

Nominal Shear Strength $\varphi_{vVngross}$ = $\varphi_{v2} * 0.6 * F_y * (d_g * t) * C_{v1}$ = **67.8** Kips *Eq. G2-1*

2.10 Design Forces action at the opening and web post

Tee Axial Force P_r = M_r / d_{effec}

Horizontal Shear V_h = $P_{r(i+1)} - P_{ri}$

Vierendeel Moment M_{vr} = $V_r / 2 * (e / 2)$

Web Post M_u = $V_h * h$

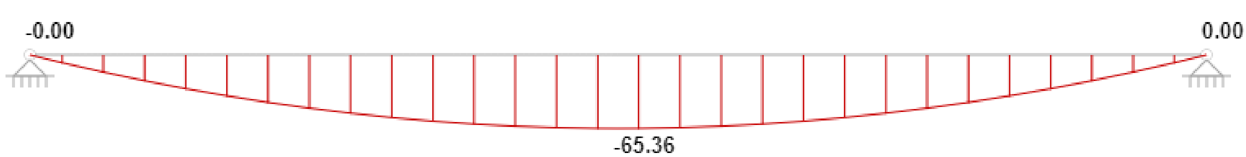
Axial Force and Moment Interaction

For $P_r/P_c >= 0.2$ = $(P_r / P_u) + (8 / 9) * (M_{vr} / M_a)$ *Eq. H1-1a*

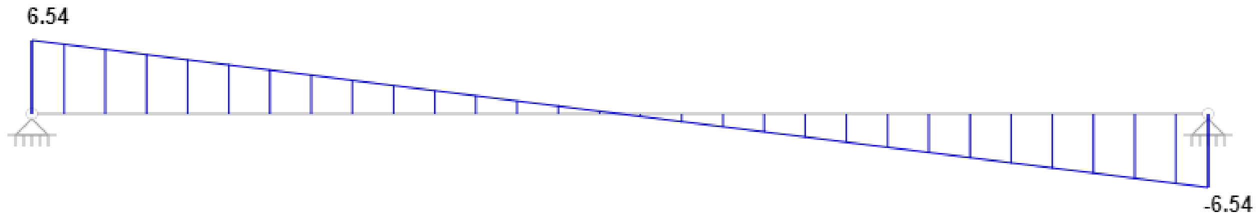
For $P_r/P_c < 0.2$ = $(P_r / P_u) / 2) * (M_{vr} / M_a)$ *Eq. H1-1b*

2.11 Beam Analysis and Design Forces

Combination: 1.2DL + 1.6LL



Bending Moment Diagram (Unit: Kips.ft)

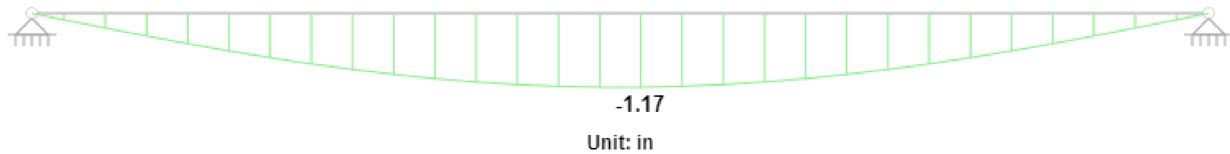


Shear Force Diagram (Unit: Kips)

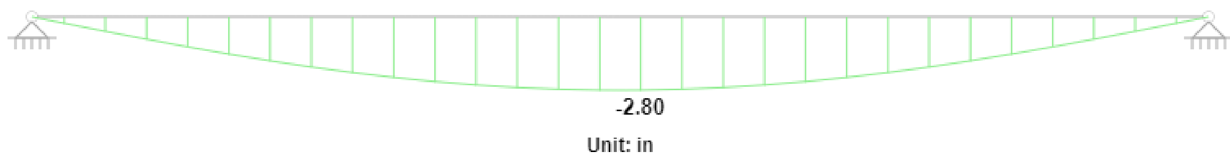
Opening	1 Global Shear V_r	2 Global Moment M_r	3 Tee Axial P_r M_r/d_{eff}	4 Hr. Shear V_h $P_{r(i+1)}-P_{r(i)}$	5 Vir. Mom. M_{vr} $V_r/2*(Do/4)$	6 Web Post M_u $V_h * h$	7 P_r/P_c	8 Interaction
1	6.25	5.64	4.22	6.29	9.60	34.84	0.064	0.390
2	5.79	14.05	10.51	5.82	8.90	32.23	0.160	0.412
3	5.33	21.84	16.34	5.34	8.20	29.58	0.248	0.520
4	4.87	28.98	21.68	4.86	7.49	26.93	0.329	0.578
5	4.42	35.48	26.55	4.39	6.79	24.27	0.403	0.628
6	3.96	41.35	30.93	3.91	6.09	21.62	0.470	0.671
7	3.50	46.57	34.84	3.43	5.38	18.97	0.529	0.707
8	3.04	51.15	38.27	2.95	4.68	16.32	0.581	0.736
9	2.59	55.09	41.21	2.47	3.98	13.66	0.626	0.757
10	2.13	58.39	43.68	1.99	3.27	11.01	0.663	0.772
11	1.67	61.05	45.67	1.51	2.57	8.36	0.693	0.778
12	1.21	63.07	47.18	1.03	1.87	5.71	0.716	0.778
13	0.76	64.44	48.21	0.55	1.16	3.05	0.732	0.770
14	0.30	65.18	48.77	0.11	0.46	0.62	0.740	0.755
15	0.08	65.33	48.88	0.21	0.12	1.14	0.742	0.746
16	0.39	65.06	48.67	0.65	0.60	3.58	0.739	0.759
17	0.85	64.19	48.03	1.13	1.30	6.23	0.729	0.772
18	1.30	62.69	46.90	1.60	2.00	8.88	0.712	0.778
19	1.76	60.54	45.30	2.08	2.71	11.53	0.688	0.777
20	2.22	57.76	43.21	2.56	3.41	14.19	0.656	0.769
21	2.68	54.33	40.65	3.04	4.11	16.84	0.617	0.753
22	3.13	50.27	37.61	3.52	4.82	19.49	0.571	0.731
23	3.59	45.56	34.09	4.00	5.52	22.14	0.517	0.701
24	4.05	40.21	30.09	4.48	6.22	24.80	0.457	0.663
25	4.51	34.23	25.61	4.96	6.93	27.45	0.389	0.618
26	4.96	27.60	20.65	5.44	7.63	30.10	0.313	0.567
27	5.42	20.33	15.21	5.92	8.33	32.75	0.231	0.507
28	5.88	12.42	9.29	5.92	9.04	32.75	0.141	0.408

2.12 Check Deflection

Live Load



Critical: DL + LL



Allowable Live Load Deflection	AD_{LL}	= BL / DFL = **2.00** in
Allowable Total Load Deflection	AD_{TL}	= BL / DFT = **2.67** in

3.0 SUMMARY

Description	Critical		Actual	Allowable	Status
	Comb.	Location (ft)			
Tee - Axial Force (*Kips*)	ULS 1	20.488	48.88	65.88	PASS
Tee - Moment (*kips-in*)	ULS 1	0.888	9.60	26.79	PASS
Tee - Compression + Moment Interaction	ULS 1	14.888	0.778	1.000	PASS
Web Post - Moment (*kips-in*)	ULS 1	0.888	34.84	83.32	PASS
Web Post - Horizontal Shear (*Kips*)	ULS 1	0.888	6.29	27.00	PASS
Net Section - Vertical Shear (*Kips*)	ULS 1	0.888	6.25	31.94	PASS
Deflection - Live Load (*in*)	LL	-	1.17	2.00	PASS
Deflection - Total Load (*in*)	SLS 1	-	2.80	2.67	FAIL