CDF
CMEX
UPGRADE

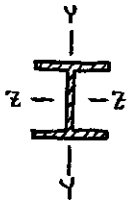
STRUCTURAL
AND
MECHANICAL
DESIGN

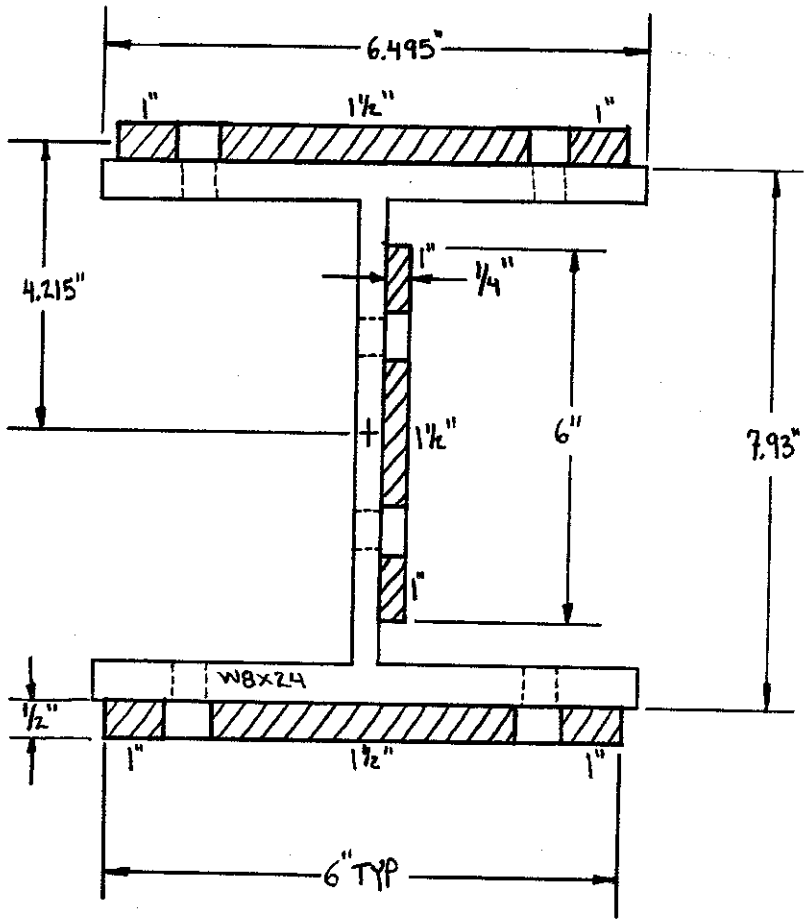
W8X24
CONNECTION
JOINTS

W8x24 Connection Joints

A system of three plates, two 1/2" thick plates and one 1/4" thick plate were used to connect adjoining frames of the inner, conical frame. These bolted on plates must be able to resist the forces and moments exerted on them. The weakest portion of each plate is through a plane passing through the bolt hole locations of each plate.

The moment of inertia and the section modulus were calculated for the cross section of the three plates. Maximum combined stress were calculated for all joints where "Frame Analysis" had indicated high stress. The maximum combined stress was 17,714 psi which is lower than the allowable 21,600 psi.





$I_z = 65.4923\ in^4$

$I_y = 13.008\ in^4$

$C_z = 4.465"$

$C_y = 3"$

$S = \frac{I}{C}$

$S_z = 14.667\ in^3$

$S_y = 4.336\ in^3$

$Area_{Top\ \&\ Bot.\ Plate} = 1.75\ in^2$

$A_{Total} = 4.375\ in^2$

FORCES & MOMENTS

Highest Stressed Elements

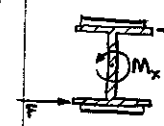
Element #	F_x	F_y	F_z	Torsion	M_y	M_z
19	-14840	-1691	-1366	-4180	-11830	45370
20	-25130	-2738	-2332	-6601	-18240	70100
21	-14900	1230	1214	1419	-11550	45610
22	-25210	2198	2028	2042	-17790	70490
39	-13540	-2768	-1552	-7842	-10320	61450
40	-23550	-3626	-3250	-14270	-14190	96260
41	-13880	-78	824	901	-9637	62050
42	-24010	1030	862	-152	-12780	97510
59	-16580	-1974	-1463	-9273	-12070	90490
60 worst	-24750	-1981	-2166	-12670	-14860	125100
61	-16650	1300	1428	4180	-11560	90930
62	-24670	2846	2097	6134	-14220	125700

Units: lbs, in-lb

STRESSES

Element #	(lbs) Torsion Force Couple	Torsion Shear $\tau_{y'} = \tau_{z'}$	P/A (σ_x)	σ_y	σ_z	τ_y	τ_z
19	496	283	3392	2728	3093	387	31
20	783	447	5744	4207	4779	626	533
21	168	96	3406	2664	3110	281	277
22	242	138	5762	4103	4806	502	464
39	930	532	3095	2380	4190	633	355
40	1693	967	5383	3273	6563	829	743
41	107	61	3173	2223	4231	18	188
42	18	10	5488	2947	6648	235	197
59	1100	629	3790	2784	6169	451	334
60	1503	859	5657	3427	8529	453	495
61	496	283	3806	2666	6199	297	326
62	728	416	5639	3280	8570	651	479

Stress in



COMBINED STRESS

$$\sigma_{Comb.} = \sqrt{(\sigma_x + \sigma_y + \sigma_z)^2 + (\tau_y + \tau_{y'})^2 + (\tau_z + \tau_{z'})^2}$$

Element #	Stress
19	9243
20	14802
21	9195
22	14697
39	9775
40	15420
41	9631
42	15086
59	12825
60	17,714
61	12699
62	17544

← Max. Stress < .6Fy = 21,600 psi

∴ Joint Connection Plates are adequate.

9 Chamber Frame

Question: Can the bolts that hold together the W8X24 joints withstand the forces and moments if the joint is looked at as a bearing type connection rather than a friction type connection?

Solution: The worst case joint is located at NODE # 11.

The forces and moments at this joint are:

$F_x = 24750$ lbs $\quad M_x = 12670$ in-lb

$F_y = 1981$ lbs $\quad M_y = 14860$ in-lb

$F_z = 2166$ lbs $\quad M_z = 125100$ in-lb

The moments are broken down into "couple forces" which either apply tensile or shear forces.

These forces acting on a A325, 3/4" Bolt create tensile or shear stresses.

The calculated stress per bolt is then compared to the allowable stress.

(Calculations are shown on the next two pages)

Conclusion:

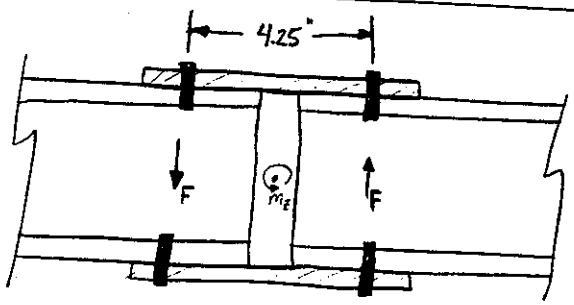
The maximum tensile stress is: 22,992 psi
The allowable tensile stress is: 35,291 psi } OK

The maximum shear stress is: 12,542 psi
The allowable shear stress is: 20,400 psi } OK

Tension Load = 10,158 lbs
Allowable tension Load = 19,400 lbs } OK

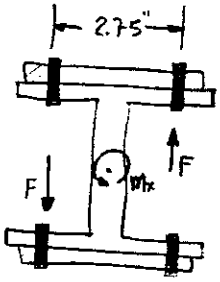
Shear Load = 5,541 lbs
Allowable shear load = 9,300 lbs } OK

∴ A325 3/4" UNC Bolts are adequate for a bearing type connection.



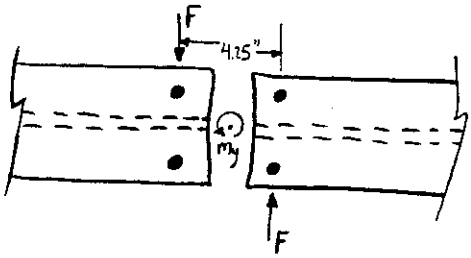
$$F = \frac{M_z}{D} = \frac{125100 \text{ in-lb}}{4.25 \text{ in}} = 29{,}435 \#$$

Divided by four bolts yields 7359 lbs/bolt (tension/compression)



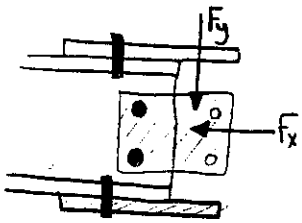
$$F = \frac{M_x}{D} = \frac{12670}{2.75} = 4{,}607 \#$$

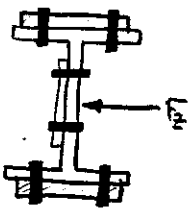
Divided by 2 bolts yields 2304 lbs/bolt (tension/compression)



$$F = \frac{M_y}{D} = \frac{14860}{4.25} = 3496 \#$$

Divided by four bolts yields 874 lbs/bolt (shear)





$$\frac{F_y}{4} = \frac{1981}{4} = 495 \# \text{ (tens./Comp)}$$

$$\frac{F_x}{6} = \frac{24750}{6} = 4125 \# \text{ (Shear)}$$

$$\frac{F_z}{4} = \frac{2166}{4} = 542 \# \text{ (Shear)}$$

Total Shear and Tension Loads: (per bolt)

tension

$7359 + 2304 + 495 = 10{,}158\ \#$

Shear

$8741 + 4125 + 542 = 5{,}541\ \#$

tension load = 10,158 #
Shear load = 5,541 #

From the "Manual of Steel Construction", 9th ed., the allowable loads for shear and tension on a A325, 3/4" Bolt, Standard Bearing Connection, are:

tensile load (max) = 19,400 #

Shear load (max) = 9,300 #

The applied loads are less than the allowable loads. ∴ Bolts are adequate under this loading check. But, are maximum bolt stresses below the allowable?

Maximum Bolt stress:

Tensile stress: $\frac{F_t}{\text{Bolt Area}} = f_{t_{max}} = \frac{10{,}158\ \#}{.4418\ in^2} = 22{,}992.3$ psi

Shear Stress: $\frac{F_v}{\text{Area}} = f_{v_{max}} = \frac{5541\ \#}{.4418\ in^2} = 12{,}541.9$ psi

Allowable Stress:

Allowable tensile stress $= \sqrt{(44)^2 - 4.39 f_v^2}$

$= \sqrt{(44)^2 - 4.39(12.54)^2}$

$= 35.291$ KSI $= \underline{35{,}291}$ psi

Allowable Shear stress $= .17 F_u = (.17)(120{,}000\ psi) = \underline{20{,}400\ psi}$

The actual stresses are below the allowables, therefore the Bolts are adequate.

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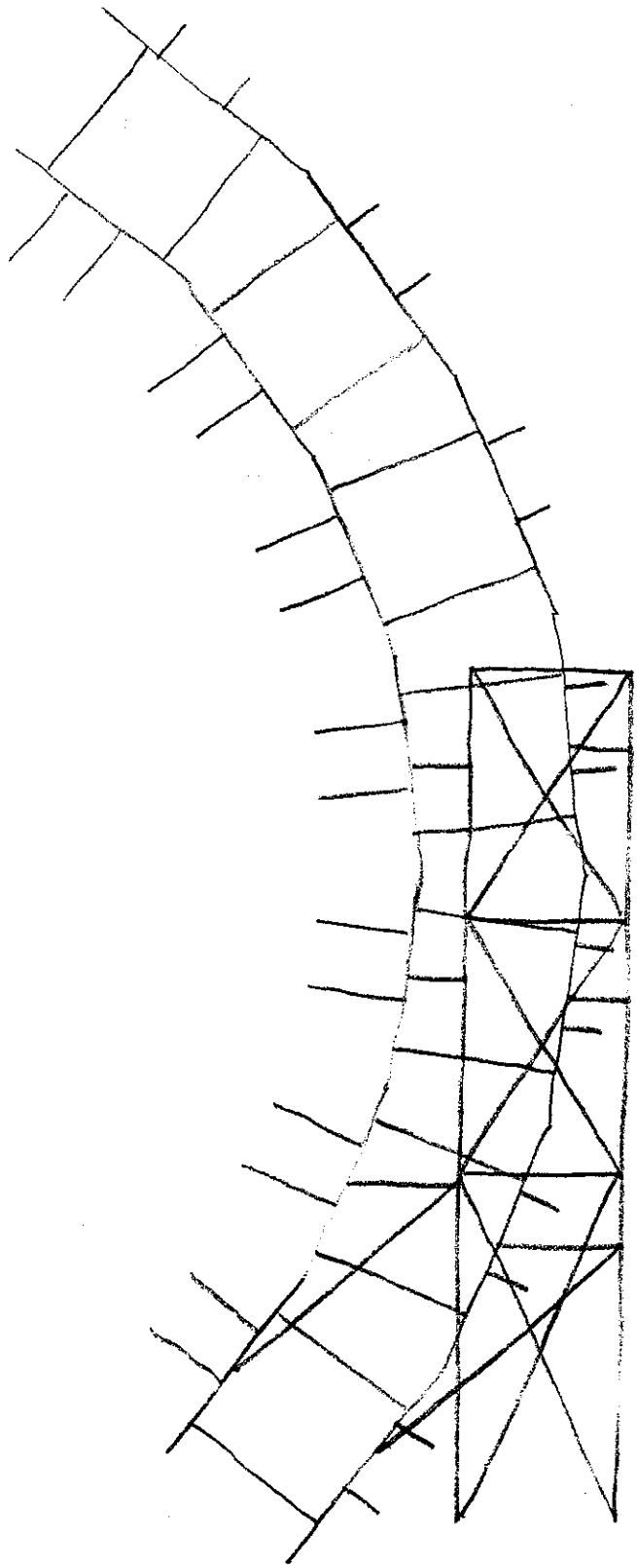
7 Chamber Stress Analysis,
Bolt Analysis,
and Connection Plate Analysis
without Super-Structure Support Frame

7 Chamber Frame



A stress analysis was performed on the CMEX conical frame with 9 chambers and was presented to the safety panel. These 9 chambers were supported by an outer supporting frame which connects to each section of the inner conical frame.

In this 7 chamber frame analysis, only the first four inner frame sections will be supported by the outer support frame. This means that the super structure needed to support 9 chambers will not be used to support 7 chambers. In other words, in this 7 chamber analysis, the top 3 chambers will be connected to each other ONLY and <u>not</u> to an outer supporting frame.

<u>Question #1</u>: Are the stresses in the inner conical frame below the allowable stress?

<u>Question #2</u>: Can the bolted joint connections handle the load if the slip-critical connection was actually a bearing type connection?

<u>Question #3</u>: Are the plates in the bolted joint connections below the allowable stress?

In the 9 chamber configuration, the answers to these questions was "Yes." However, in the 7 chamber scheme since the super structure will not be used and 3 chambers will be partially un-supported, the answers to these questions is not intuitive.

The analysis will begin with a conservative look at the stresses in the 7 chamber inner conical frame.

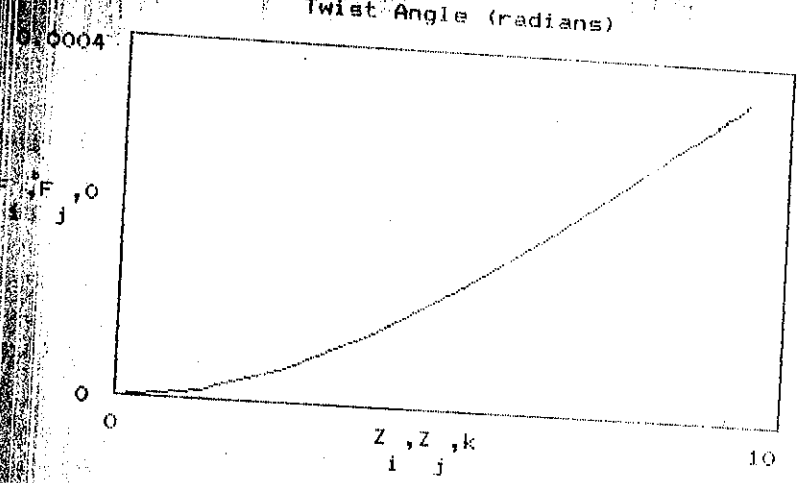
<u>Wide-flange Stress Calculations</u>: (Question #1 solution)

Instead of calculating stresses for each wide-flange, the maximum forces and moments out of all the wide-flange members will be used and assumed to be acting all on one beam. If the combined stress is below the allowable stress of 21,600 psi, then it can be assumed that all wide-flange elements are below the allowable stress. If not, an individual analysis of each beam will be performed.

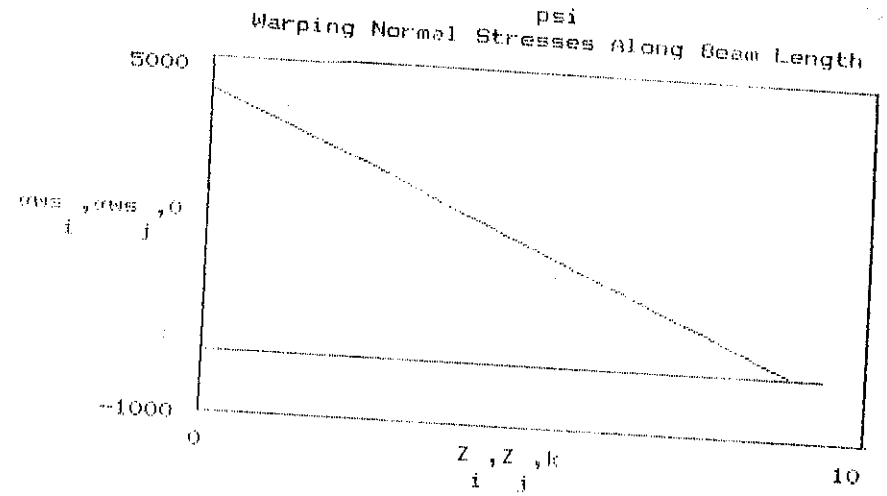
7 Chamber Frame
Torsional Analysis
on
W8x24 Beam

TORSIOAL ANALYSIS OF WIDE-FLANGE MEMBER - α = 0.95

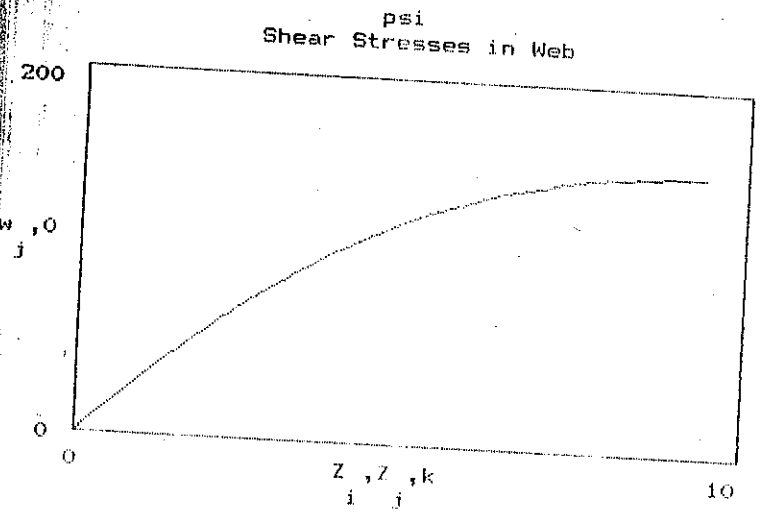
TWIST ANGLE AND ITS DERIVATIVES

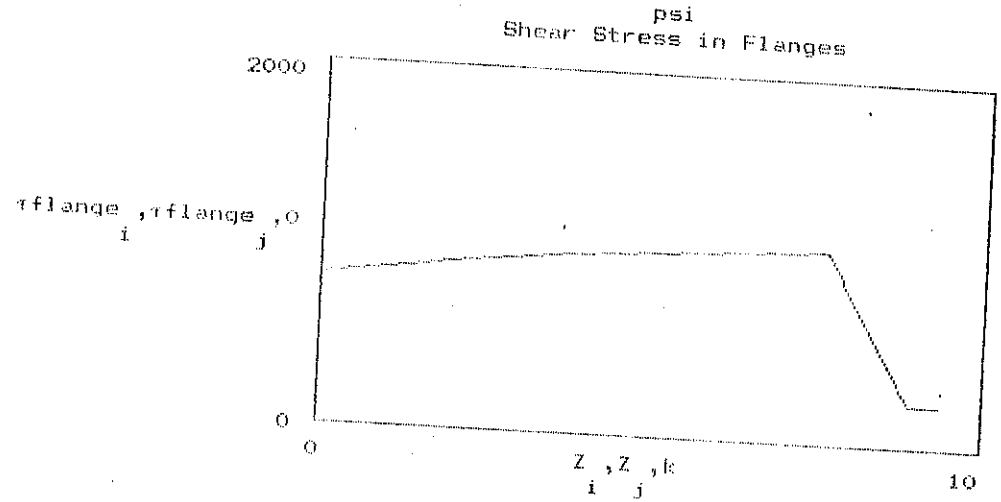


T O R S I O N A L S T R E S S E S



Torsional Shear Stresses Along Beam Length





fa = $1.551 \cdot 10^{3}$ psi (axial stress)

[illegible]	psi Web Shear Stress τtw m	psi Flange Shear Stress $\tau flange$ m	Radians Twist Angle F m	Position Z m
[illegible]	$4.57 \cdot 10^{-12}$	$8.207 \cdot 10^{2}$	0	0
[illegible]	$4.049 \cdot 10^{1}$	$8.824 \cdot 10^{2}$	$9.625 \cdot 10^{-6}$	1.272
[illegible]	$7.468 \cdot 10^{1}$	$9.346 \cdot 10^{2}$	$3.655 \cdot 10^{-5}$	2.543
[illegible]	$1.026 \cdot 10^{2}$	$9.771 \cdot 10^{2}$	$7.787 \cdot 10^{-5}$	3.815
[illegible]	2	3	$1.307 \cdot 10^{-4}$	5.087
[illegible]	$1.398 \cdot 10^{2}$	$1.034 \cdot 10^{3}$	$1.921 \cdot 10^{-4}$	6.358
[illegible]	$1.49 \cdot 10^{2}$	$1.048 \cdot 10^{3}$	$2.593 \cdot 10^{-4}$	7.63
[illegible]	$1.521 \cdot 10^{2}$	$2.318 \cdot 10^{2}$	$3.293 \cdot 10^{-4}$	8.902
[illegible]	$1.521 \cdot 10^{2}$	$2.318 \cdot 10^{2}$	$3.325 \cdot 10^{-4}$	8.96
[illegible]	$1.521 \cdot 10^{2}$	$2.318 \cdot 10^{2}$	$3.358 \cdot 10^{-4}$	9.077
[illegible]	$1.521 \cdot 10^{2}$	$2.318 \cdot 10^{2}$	$3.39 \cdot 10^{-4}$	9.136
[illegible]	$1.521 \cdot 10^{2}$	$2.318 \cdot 10^{2}$	$3.423 \cdot 10^{-4}$	9.194
[illegible]	$1.521 \cdot 10^{2}$	$2.318 \cdot 10^{2}$	$3.455 \cdot 10^{-4}$	9.253
[illegible]	$1.521 \cdot 10^{2}$	$2.318 \cdot 10^{2}$	$3.488 \cdot 10^{-4}$	9.311
[illegible]	$1.521 \cdot 10^{2}$	$2.318 \cdot 10^{2}$	$3.52 \cdot 10^{-4}$	9.37
[illegible]	$1.521 \cdot 10^{2}$	$2.318 \cdot 10^{2}$	$3.552 \cdot 10^{-4}$	

Situation Parameters

$E = 2.9 \cdot 10^{7}$ Modulus of Elasticity

$G = 1.12 \cdot 10^{7}$ Modulus of Rigidity

$P = 1.098 \cdot 10^{4}$ Axial Load (lb)

$M = 1.082 \cdot 10^{4}$ Torsional Moment (in-lb)

Wide-Flange Constants (from AISC handboo

$J = 0.35$ Torsional Constant

$a = 4.4 \cdot 10^{1}$ (ECw/GJ)

$Wno = 1.22 \cdot 10^{1}$ Normalized Warping Constant

$Sw = 7.94$ Warping Static Moment

$A = 7.08$ Area of Cross-Section

Wide-Flange Dimensions (inches)

$L = 9.37$ Unsupported Length of Beam

$tw = 0.245$ Web Thickness

$tf = 0.4$ Flange Thickness

$h = 7.93$ Overall Height of Wide-Flang

$w = 6.495$ Overall Width of Wide-Flange

$F_{x_{max}}$	$F_{y_{max}}$	$F_{z_{max}}$	$M_{x_{max}}$	$M_{y_{max}}$	$M_{z_{max}}$
10980 lbs	1487 lbs	1323 lbs	10820 in-lb torsion	10000 in-lb	106800 in-lb
σ_x	τ_y	τ_z	σ_{ws} τ_f	σ_y	σ_z
F_x/A	F_y/A	F_z/A		M_y/S_y	M_z/S_z
$10980/7.08\,in^2$	$1487/7.08\,in^2$	$1323/7.08\,in^2$		$10000/5.63\,in^3$	$106{,}800/20.9\,in^3$
1551 psi	210 psi	187 psi	4425 psi 1048 psi	1776 psi	5110 psi

Combined stress:

$$\sigma_{max} = \sqrt{(\sigma_x + \sigma_y + \sigma_z + \sigma_{ws})^2 + (\tau_y + \tau_f)^2 + (\tau_z + \tau_f)^2}$$

$$\sigma_{max} = \sqrt{(1551 + 1776 + 5110 + 4425)^2 + (210 + 1048)^2 + (187 + 1048)^2}$$

$$\boxed{\sigma_{max} = 12{,}982 \text{ psi}}$$

OK

$$F_a = .6 F_y = .6\,(36{,}000 \text{ psi}) = 21{,}600 \text{ psi}$$

$$\sigma_{max} < F_a$$

Therefore, it can be assumed that all wide-flange members are strong enough even in a #5, #6, #7 unsupported chamber configuration.

Bearing type bolted connection: (Question #2 Solution)

Similiar to the analysis of combined stress in the W8x24 members, this analysis of Bolt stress will use the maximum forces and maximum moments and assume that these forces and moments all act on one joint. If the bolts are strong enough to withstand these forces, then it can be assumed that all the bolted connections are adequate.

The maximum forces and moments are:

$F_x = 10980$ lbs

$F_y = 1487$ lbs

$F_z = 1323$ lbs

$M_x = 10,820$ in-lb (torsion)

$M_y = 10,000$ in-lb (bending)

$M_z = 106,800$ in-lb (bending)

The moments are broken down into "couple forces" which either apply tensile, compressive, or shear forces.

These forces acting on a A325, 3/4" bolt create tensile, compressive, or shear stresses.

The calculated stress per bolt is then compared to the allowable stress.

(Calculations are shown on the next two pages)

Conclusion: (Bolted Connections)

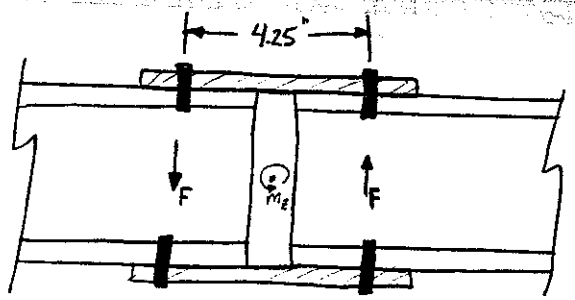
The maximum tensile stress is: 19,513 psi
The allowable tensile stress is: 42,020 psi } OK

The maximum shear stress is: 6,222 psi
The allowable shear stress is: 20,400 psi } OK

Tension Load = 8,621 lbs
allowable tensile load = 19,400 lbs } OK

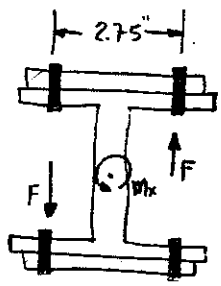
Shear Load = 2,749 lbs
allowable shear load = 9,300 lbs } OK

∴ A325, 3/4" Bolts are adequate for a bearing type connection even if the friction connection does not hold.



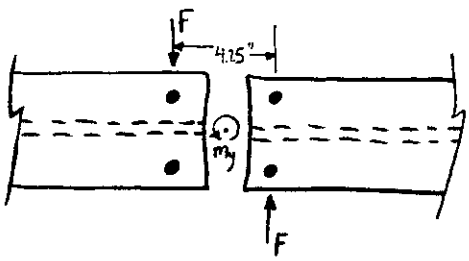
$$F = \frac{M_z}{D} = \frac{106{,}800 \text{ in-lb}}{4.25 \text{ in}} = 25{,}129 \text{ lbs}$$

Divided by 4 bolts yields **6,282 lbs/bolt** in tension/compression



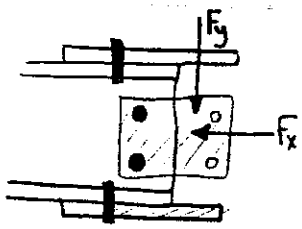
$$F = \frac{M_x}{D} = \frac{10{,}820 \text{ in-lb}}{2.75 \text{ in}} = 3935 \text{ lbs}$$

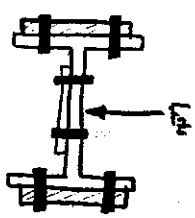
Divided by 2 bolts yields **1,967 lbs/bolt** in tension/compression



$$F = \frac{M_y}{D} = \frac{10{,}000 \text{ in-lb}}{4.25 \text{ in}} = 2353 \text{ lbs}$$

Divided by 4 bolts yields **588 lbs/bolt** in shear





$$\frac{F_y}{4} = \frac{1487 \text{ lbs}}{4} = 372 \text{ lbs (tens/comp)}$$

$$\frac{F_x}{6} = \frac{10980 \text{ lbs}}{6} = 1830 \text{ lbs (shear)}$$

$$\frac{F_z}{4} = \frac{1323 \text{ lbs}}{4} = 331 \text{ lbs (shear)}$$

Total shear and tension loads per bolt:

tension	shear
6282 + 1967 + 372 = 8621 lbs	588 + 1830 + 331 = 2749 lbs

tension load per bolt = 8,621 lbs
shear load per bolt = 2,749 lbs

From the "Manual of Steel Construction", 9th ed. the allowable loads for shear and tension on a A325, 3/4" bolt, Standard Bearing Connection, are:

tensile load (max) = 19,400 lbs
shear load (max) = 9,300 lbs

The applied loads are less than the allowable loads. Therefore, Bolts are adequate under this loading scheme. But, are maximum bolt stresses below the allowable?

Maximum Bolt Stress:

$(f_{t_{max}})$ Tensile stress: $\frac{F_t}{\text{Bolt Area}} = 8{,}621 \text{ lbs} / .4418 \text{ in}^2 = 19{,}513 \text{ psi}$

$(f_{v_{max}})$ Shear Stress: $\frac{F_v}{\text{Bolt Area}} = 2{,}749 \text{ lbs} / .4418 \text{ in}^2 = 6{,}222 \text{ psi}$

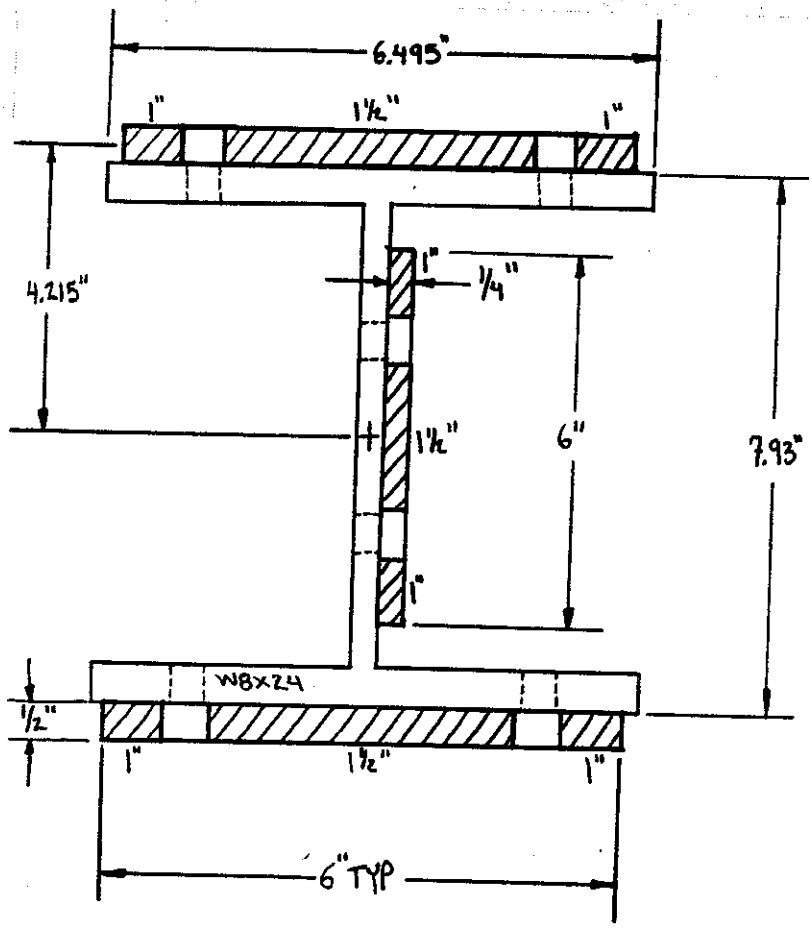
Allowable Bolt Stress:

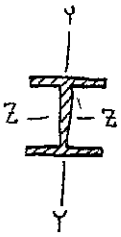
$$\text{Allowable tensile stress} = \sqrt{(44)^2 - 4.39 f_v^2}$$
$$= \sqrt{(44)^2 - 4.39(6.222)^2}$$
$$= 42.02 \text{ KSI} = 42{,}020 \text{ psi}$$

$$\text{Allowable shear stress} = .17 F_u = (.17)(120{,}000 \text{ psi})$$
$$= 20{,}400 \text{ psi}$$

The actual stresses are below the allowable stresses.

Therefore, for the 7 chamber (non super-structure support), the bolts are adequate even if the friction connections fail.





$I_z = 65.4923\ in^4$

$I_y = 13.008\ in^4$

$C_z = 4.465"$

$C_y = 3"$

$S = \frac{I}{C}$

$S_z = 14.667\ in^3$

$S_y = 4.336\ in^3$

$A_{Top\ \&\ Bot.\ Plate} = 1.75\ in^2$

$A_{Total} = 4.375\ in^2$

Plate Connection Stress Calculations: (Question #3 Solution)

Maximum forces and moments from all joints will be combined and assumed to act all on one joint. If the connection plates can withstand this load application then it will be assumed that all connection joints are strong enough.

Maximum Forces and Moments:

$F_x = 10980$ lbs

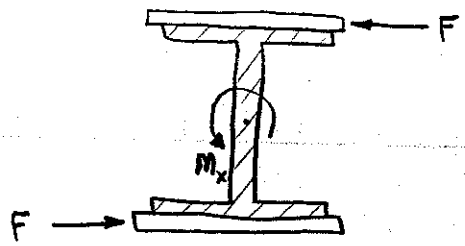
$F_y = 1487$ lbs

$F_z = 1323$ lbs

$M_x = 10820$ in-lb (torsion)

$M_y = 10000$ in-lb

$M_z = 106,800$ in-lb



$$F = \frac{M_x}{D} = \frac{10820}{7.93} = 1,364\ lbs$$

Torsion Shear: $\tau_{y'} = \tau_{z'}$

$$\tau_{y'} = \tau_{z'} = \frac{F}{A_{\text{Top plate}}} = \frac{1364 \text{ lbs}}{1.75 \text{ in}^2} = \underline{\underline{780 \text{ psi}}}$$

Axial Stress: σ_x

$$\sigma_x = \frac{F_x}{A} = \frac{10980 \text{ lbs}}{4.375 \text{ in}^2} = \underline{\underline{2,510 \text{ psi}}}$$

Bending Stress: σ_y, σ_z

$$\sigma_y = \frac{M_y}{S_y} = \frac{10\,000 \text{ in-lb}}{4.336 \text{ in}^3} = \underline{\underline{2,306 \text{ psi}}}$$

$$\sigma_z = \frac{M_z}{S_z} = \frac{106,800 \text{ in-lb}}{14.667 \text{ in}^3} = \underline{\underline{7,282 \text{ psi}}}$$

Shear Stress: τ_y, τ_z

$$\tau_y = \frac{F_y}{A} = \frac{1487 \text{ lbs}}{4.375 \text{ in}^2} = \underline{\underline{340 \text{ psi}}}$$

$$\tau_z = \frac{F_z}{A} = \frac{1323 \text{ lbs}}{4.375 \text{ in}^2} = \underline{\underline{302 \text{ psi}}}$$

Combined Stress:

$$\sigma_{comb.} = \sqrt{(\sigma_x + \sigma_y + \sigma_z)^2 + (\tau_y + \tau_{y'})^2 + (\tau_z + \tau_{z'})^2}$$

$$= \sqrt{(2510 + 2306 + 7282)^2 + (340 + 780)^2 + (302 + 780)^2}$$

$$= 12,198 \text{ psi}$$

$$\boxed{\text{Max. Combined Stress} = 12,198 \text{ psi}}$$

Max. Allowable Stress $= F_a = .6 F_y = (.6)(36,000 \text{ psi}) = 21,600 \text{ psi}$

$\sigma_{max} < F_a$ $\therefore$ all connection plates are adequate.