SLSF LOOP HANDLING SYSTEM

Volume III

AISC Code Evaluations and Analysis
of Critical Attachments

by

MASTER

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A. Rafer, D. Ma, and F. Tebo

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**Prepared for the U. S. DEPARTMENT OF ENERGY
under Contract W-31-109-Eng-38**

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October 1978

ABSTRACT

SLSF loop handling system was analyzed for deadweight and postulated dynamic loading conditions, identified in Chapters II and III in Volume I of this report, using a linear elastic static equivalent method of stress analysis. Stress analysis of the loop handling machine is presented in Volume I of this report. Chapter VII in Volume I of this report is a contribution by EG & G Co., who performed the work under ANL supervision. Stress analysis of SLSF-LHS cradle structure is performed in Volume II and Volume III of this report; Volume II consists of computer modeling of LHM-Cradle-transporter system and Volume III consists of stress computations of Cradle and critical attachments per AISC Code guidelines. HFEEF is credited with in-depth review of initial phase of work in Volume III of this report. A summary of results with conclusions and recommendations is presented in Chapter XV in volume III of this report. Volume IV of this report contains some relevant backup appendices for the report.

Acknowledgements

Project Manager: B. LaMar, D. Lennox, R. Noland, C. Bolta,
W. Kaspic, D. Hillis, F. Tebo

Consultants: R. A. Malek J. M. Leonard, D. Kracinovic,
F. D'Souza

Designers: J. Martich, J. McKinney

Discussions and part
contributions: H. L. Magelby et al of EG&G Co.

Significant Contributions: EG&G Co. for work on Chapter VII of this
document.

W. A. Kaspic, J. Martich, J. Waters, and
R. Sacks for compiling Chapter V.

R. A. Malek for review of section VI.2.6
of Volume III of this document.

D. McGee of HFEF for useful reviews of some
aspects of Volume III of this document.

F. D' Souza for providing information on
truck tires.

J. Waters and R. Sacks for work on section
VI.2.2.

W. Kaspic for general assistance throughout
the report.

R. Pentz who compiled coordinate and
connectivity data for finite element compute
program model of loop handling system in
Volume II. Development and concept of
computer modelling and calculations of all
section properties were calculated by H.
Ahmed, A. Cowie and R. A. Malek
F. Tebo for editing this report

Typing: K. Hutchinson, J. Featherstone, S. Janowski,
L. Watts, and V. Scott et.al.

The authors express their gratitude to the above-mentioned and several other individuals who have provided assistance during this work scope.

SLSF LOOP HANDLING SYSTEM

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X. Conformance to AISC Code Requirements

X.1 Introduction and Definitions

This section is devoted to checking the conformance of the LHM cradle structure to the AISC. The relevant sections of the AISC code are given in Appendix B for convenient reference. The following definitions are rather important in the conformance investigation and will be used repeatedly throughout this chapter.

X.1.1 Unstiffened Elements under Compression

Unstiffened (projecting) compression elements, Fig X.1.1-1, are those having one free edge parallel to the direction of compression stress.

X.1.2 Stiffened Elements under Compression

Stiffened compression elements, Fig X.1.1-1, are those having lateral supports along both edges which are parallel to the direction of the compression stress.

FIG. X.1.1-1 Stiffened and Unstiffened Elements

X.2 Procedure for Conformance Check

A detailed outline for the step by step procedure to be used in checking the conformance and adequacy of the cradle structure design according to the AISC code is given below. Such procedure was the basis for a computer program that has been developed for checking the various components of the cradle structure for all the loading conditions previously defined in Chapter IX, Vol. 1.

X.2.1 Given Data

For each of the sections to be investigated, the following data has to be furnished in order to carry out the conformance procedure:

- i) Section properties: This data is available in Appendix C
- ii) Effective length factors (K_{22} and K_{33}): This data is given in section X.3
- iii) Straining actions: The straining actions on each of the sections in the cradle structure are given in Appendix B.

X.2.2 Effective Section

- i) Compute the ratio b/t
- ii) Compute the stress reduction factor Q_s which is equal to 1.0 for sections having no unstiffened elements. For sections having unstiffened elements, obtain Q_s from Equations (3.3) or (3.4) of Appendix B.
- iii) Calculate $f = 0.6 F_y Q_s$
- iv) Calculate the effective width of the flanges in the 2-2 and 3-3 directions according to equations (3.7) or (3.8) of Appendix B.
- v) Compute the effective section properties using the effective widths computed in iv above.
- vi) Compute the form factor $Q_a = \frac{\text{Effective area}}{\text{Actual area}}$

X.2.3 Check of Stresses for Sections having Axial Torsion

Provisions of Section 6.2 of Appendix B must be satisfied which are:

- i) Satisfy the requirements of equation (6.16) in which both f_{bx} and f_{by} are the bending tension stresses in the 3-3 and 2-2 directions respectively.
- ii) Satisfy the requirements of equation (6.16) where only the bending compressive stresses are taken into account. Thus the equation is modified as follows:

$$\frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0$$

in which f_{bx} and f_{by} are the bending compression stresses.

- iii) The allowable bending stresses F_{bx} and F_{by} can be conservatively taken as $0.6 F_y$ for box sections whose depth/width ratio does not exceed 6 (which is the case for all the cradle box sections).

X.2.4 Check of Stresses for Sections having Axial Compression

Provisions of section 6.1 of Appendix B must be satisfied according to the following procedure:

- i) Compute the modified section slenderness ratio

$$C_c' = \sqrt{\frac{2\pi^2 E}{Q_s Q_a F_y}}$$

- ii) The allowable compressive stress F_a can be determined using equations 3.9, 5.2, or 5.3, whichever is applicable.
- iii) The allowable bending stresses F_{bx} and F_{by} can be conservatively taken equal to $0.6 F_y$ (see X.2.3 iii).
- iv) Compute the actual axial and bending compressive stresses f_a , f_{bx} and f_{by} .

v) For $\frac{f_a}{F_a} \leq 0.15$ equation (6.2) must be satisfied.

vi) For $\frac{f_a}{F_a} \geq 0.15$ equations (6.1a) and (6.1b) must be satisfied but first the following parameters must be computed:

$$C_{mx} = 0.85, \quad C_{my} = 0.6 - 0.4 \frac{M_1}{M_2} \geq 0.4 \quad \text{and}$$

$$F_{e_{xy}} = \frac{12\pi^2 E}{23(KL/r)_{xy}^2} \quad \text{in which } \frac{M_1}{M_2} \text{ is as defined in section 1.3.}$$

X.2.5 Check of Shear Stresses

- i) Determine average web shear stress f_{vx} and f_{vy} and torsion stress f_T
- ii) Determine the allowable shear stress F_v according to equation 4.1.

However, first the factor C_v needs to be computed as follows:

-obtain k equation 1.7 (a/h is always greater than 1.0)

-then find C_v from equation 1.4 or 1.5 whichever is applicable

- iii) Satisfy the following equations:

$$f_{vx} + f_T < F_v \quad \text{and} \quad f_{vy} + f_T < F_v$$

X.2.6 Check for Stiffeners

The box sections for the cradle structures have no stiffeners and hence the following provisions must be satisfied:

- i) $\frac{d}{t} < \frac{14,000}{\sqrt{F_y(F_y + 16.5)}}$
- ii) $\frac{h}{t} < 260$

X.2.7 Allowable Stresses

The allowable stresses for the normal loading conditions are as given in the previous sections and Appendix B. However, the allowable stresses for the accidental cases and the travel cases shall be increased by 33% and 25% respectively, over those allowable stresses specified for the normal condition.

X.2.8 Determination of Shear Stresses due to Torsion

It should be noted that the shear stresses due to Torsion in closed box sections is given by the formula

$$f_T = \frac{M_T}{2At}$$

in which f_T is the shear stress in a side of the box section having thickness t , and A is the area bounded by the centerline of the four sides of the box section. However, due to restrictions imposed by the computer program used for stress analysis, an equivalent Torsional section property has been determined to accommodate the computer algorithm which uses the torsion formula

$$f_T = \frac{M_T \cdot r}{J}$$

Thus, in Appendix C, equivalent values for J and r were computed to determine torsion stresses according to the more exact formula $f_T = \frac{M_T}{2At}$ for box sections. Therefore, for the sake of consistency throughout this report, these equivalent values will be used in favor of introducing new computations for the Torsional stiffnesses of the cradle elements. Note that r given in Appendix C corresponds to the side plate having the smallest thickness $t_{\min}$. In order to obtain the other r 's for other side plates having a thickness $\bar{t}$ use the following expression

$$\bar{r} = \frac{r t_{\min}}{\bar{t}}$$

Also, to eliminate any confusion with the radius of gyration, these values of r will be referred to as $\bar{r}$ in the following sections. Therefore, $\bar{r}_2$ and $\bar{r}_3$ will refer to the radius of the side plate parallel to the 2 and 3 axes respectively.

X.3. Slenderness Ratios

The effective length factor in the 3-3 direction, K_3 can be taken for all members equal to unity. For the effective length factor in the 2-2 direction consult Table X.3-1.

X.4. Conformance to AISC of Selected Sections

In the following section, the criteria outlined in Section X.2 is applied to several selected sections in the cradle structure in order to verify manually its applicability. Only one loading case is used for each, but in the process the various conditions of loading and therefore, the different variations in the analysis are illustrated. These calculations are intended to give only the maximum stresses that could possibly occur in a section for a selected load case. In order to determine which load case would govern, and how much the stress is for every location in the beam section where the maximum could be, a computer program is necessary. The computer program used is described in appendix H and the results are shown in the tables after each beam calculation.

TABLE X.3-1. SLENDERNESS RATIOS

		$K_3 = 1.0$											
Beam No.	3-3 AXIS				2-2 AXIS								
	λ_3	r_3	$K_3 \lambda_3$	r_2	Normal Loading			Accidental Loading			Travel Loading		
			r_3		λ_2	k_2	K_2/r	λ_2	k_2	K_2/r	λ_2	k_2	K_2/r
3 & 4	63	5.52	11.4	7.01	63	1.5 ⁽¹⁾	13.5	63	1.5 ⁽¹⁾	13.5	63	1.5 ⁽¹⁾	13.5
11	50	2.56	19.5	4.54	108	2.0	47.6	242	2.0	106.6	59	2.0 ⁽³⁾	26.0
12	50	2.56	19.5	4.54	108	2.0	47.6	108	2.0	47.6	59	2.0 ⁽³⁾	26.0
44 & 45	63	5.44	11.6	6.11	63	1.0	10.3	63	1.5 ⁽¹⁾	15.5	63	1.0	10.3
54 & 55	89	4.79	18.6	5.06	134	1.0	26.5	242	2.0	95.6	134	1.0	26.5
84 & 85	63	6.48	9.7	14.55	63	1.0	4.3	63	1.0	4.3	63	1.0	4.3
56 & 58	89	2.73	32.6	4.36	134	1.0	30.7	242	2.0	111.0	134	1.0	30.7
57 & 59	89	2.73	32.6	4.36	134	1.0	30.7	134	1.0	30.7	134	1.0	30.7
71	45	3.12	14.4	4.22	134	1.0	31.7	242	2.0	114.7	134	1.0	31.7
72	45	3.12	14.4	4.22	134	1.0	31.7	134	1.0	31.7	134	1.0	31.7
25 & 26	63	6.70	9.4	5.98	63	1.5 ⁽¹⁾	15.8	63	1.5 ⁽¹⁾	15.8	63	1.0 ⁽³⁾	10.5
552 & 553	63	6.71	9.4	5.65	63	1.5 ⁽¹⁾	16.7	63	1.5 ⁽¹⁾	16.7	63	1.5 ⁽¹⁾	16.7
75	45	2.59	17.4	7.86	134	1.0	17.0	242	2.0	61.6	134	1.0	17.0
76	45	2.59	17.4	7.86	134	1.0	17.0	134	1.0	17.0	134	1.0	17.0
88 & 89	63	6.55	9.6	5.42	63	1.0	11.6	63	1.0	11.6	63	1.0	11.6
34	49	2.56	19.1	4.54	108	2.0	47.6	242	2.0	106.6	49	1.0 ⁽³⁾	10.8
35	49	2.56	19.1	4.54	108	2.0	47.6	108	2.0	47.6	49	1.0 ⁽³⁾	10.8
90 & 91	70	7.86	8.9	2.59	70	1.7 ⁽²⁾	45.9	70	1.7 ⁽²⁾	45.9	70	1.7 ⁽²⁾	45.9
95 , 96 , 536 & 537	70	5.73	12.2	1.94	70	1.7 ⁽²⁾	61.3	70	1.7 ⁽²⁾	61.3	70	1.7 ⁽²⁾	61.3

- (1) k_2 is estimated as 1.5 to account for the lack of an actual support.
- (2) k_2 is estimated as the average of case (e) and (f) in the AISC recommended table p. 138.
- (3) These values are only valid if the latching mechanism between the cradle and the trailer is in compression, otherwise use λ_2 and k_2 as indicated for the normal condition.

X.4.1 Members 3 and 4Section Properties(4)

$$b = 2 \quad t = 0.25 \text{ (unstiffened)}$$

$$\begin{array}{llll} b_x = 12.5 \text{ in}, & t_x = 0.25 \text{ in}, & b_y = 15.5 \text{ in}, & t_y = 0.25 \\ A = 15.375 \text{ in}^2, & A_3 = 7.75 \text{ in}^2, & A_2 = 6.25 \text{ in}^2, & \\ J = 707.4 \text{ in}^4, & \bar{r}_2 = 7.046 \text{ in}, & \bar{r}_3 = 7.046 \text{ in}, & \\ I_2 = 643.7366 \text{ in}^4, & C_{\text{top}} = 9.481 \text{ in}, & C_{\text{bottom}} = 8.769 \text{ in}, & \\ I_3 = 452.2734 \text{ in}^4, & C_{\text{left}} = 6.5 \text{ in}, & C_{\text{right}} = 6.5 \text{ in}, & \\ L_2 = 63 \text{ in}, & K_2 = 1.0, & L_3 = 63 \text{ in}, & K_3 = 1.0 \end{array}$$

Forces at Joint 105 (Load Case 1)

$$\begin{array}{lll} R_1 = 51.09 \text{ (Comp) Lbs.} & R_2 = -294.7 \text{ Lbs.} & R_3 = -14.48 \text{ Lbs.} \\ M_T = 20.26 \text{ in. Lbs.} & M_2 = 607.1 \text{ in. Lbs.} & M_3 = 145.6 \text{ in. Lbs.} \end{array}$$

Forces at Joint 107 (Load Case 1)

$$\begin{array}{lll} R_1 = -51.09 \text{ Lbs.} & R_2 = 294.7 \text{ Lbs.} & R_3 = 14.48 \text{ Lbs.} \\ M_T = -20.26 \text{ in. Lbs.} & M_2 = -430.5 \text{ in. Lbs.} & M_3 = -3741 \text{ in. Lbs.} \end{array}$$

$$\frac{238}{\sqrt{F_y}} = 33.7 \quad \frac{95}{\sqrt{F_y}}$$

$$\frac{b_x}{t_x} = \frac{12.5}{0.25} = 50 > 33.7$$

$$\frac{b_y}{t_y} = \frac{15.5}{0.25} = 62 > 33.7$$

$$\frac{b}{t} = \frac{2}{0.25} = 8 < 13.4 \quad \text{O.K.} \quad \text{fully effective}$$

$$Q_s = 1.0$$

$$f = 0.6$$

$$F_y = 50$$

$$b_{ex} = \frac{253(0.25)}{\sqrt{30}} \left(1 - \frac{50.3}{50\sqrt{30}} \right) = 9.43" < 12.5 \quad \text{O.K.}$$

$$b_{ey} = \frac{253(0.25)}{\sqrt{30}} \left(1 - \frac{50.3}{62\sqrt{30}} \right) = 9.84" < 15.5 \quad \text{O.K.}$$

$$\begin{aligned} A_{eff} &= 15.375 - (12.5 - 9.43)(0.25)(2) - (15.5 - 9.84)(0.25)(2) \\ &= 11.01 \text{ in}^2 \end{aligned}$$

$$\begin{aligned} I_{22}(\text{eff}) &= 643.7366 - (3.07)(0.25)[(7.356)^2 + (8.394)^2] - \frac{(5.66)^3 \times 0.25 \times 2}{12} \\ &= 540.57 \text{ in}^4 \end{aligned}$$

$$\begin{aligned} I_{33}(\text{eff}) &= 452.2734 - (2)(5.66)(.25)[6.375]^2 - \frac{2(3.07)^3 \times 0.25}{12} \\ &= 336.05 \text{ in}^4 \end{aligned}$$

$$Q_a = \frac{11.01}{15.375} = 0.716$$

$$C_c' = \sqrt{\frac{2\pi^2(29 \times 10^3)}{(1.0)(.716)(50)}} = 126, \quad r_2 = 7.01", \quad r_3 = 5.52 \text{ in}$$

$$\frac{K_2 L_2}{r_2} = \frac{63}{7.01} = 8.99$$

$$\frac{K_3 L_3}{r_3} = \frac{63}{5.52} = 11.41 \text{ (governs)}$$

$$F_a = \frac{Q_s Q_a \left[1 - \frac{1}{2} \left(\frac{kL}{rC_c'} \right)^2 \right] F_y}{\frac{5}{3} + \frac{3}{8} \left(\frac{kL}{rC_c'} \right) - \frac{1}{8} \left(\frac{kL}{rC_c'} \right)^3} = 20.9 \text{ ksi} = 20,900 \text{ psi}$$

$$f_a = \frac{51.09}{11.01} = 4.64 \text{ psi}$$

$$\frac{f_a}{F_a} < 0.15$$

use equation (6.2) which is;

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} < 1.0$$

$$F_{bx} = F_{by} = 0.6(50) = 30 \text{ ksi} = 30,000 \text{ psi}$$

$$\left. \begin{aligned} f_{bx} &= \frac{430.5}{540.57} (9.481) = 7.55 \text{ psi} \\ f_{by} &= \frac{3741}{336.05} (6.5) = 72.36 \text{ psi} \end{aligned} \right\} \text{or} \left. \begin{aligned} f_{bx} &= \frac{607.1}{540.57} (9.481) = 10.65 \text{ psi} \\ f_{by} &= \frac{45.6}{336.05} (6.5) = 2.82 \text{ psi} \end{aligned} \right\}$$

$$\frac{4.64}{20900} + \frac{7.55}{30000} + \frac{72.36}{30000} = 0.003 \ll 1.0 \text{ section is safe}$$

$$f_{vx} = \frac{14.48}{7.75} = 1.87 \text{ psi} \qquad f_{vy} = \frac{294.7}{6.25} = 47.15 \text{ psi}$$

$$f_{Tx} = \frac{20.26 \times 7.046}{707.4} = 0.202 \text{ psi} \quad f_{Ty} = \frac{20.26 \times 7.046}{707.4} = 0.202 \text{ psi}$$

$$f_{vx} + f_{Tx} = 2.072 \text{ psi} \qquad f_{vy} + f_{Ty} = 47.352 \text{ psi}$$

All of these stresses are very small with respect to the allowable stress, F_v which is as shown below:

$$\frac{h}{t} = \frac{15.5}{0.25} = 62 < \frac{14,000}{\sqrt{50(50 + 16.5)}} = 247 \quad \text{O.K.}$$

$$\frac{a}{h} = \frac{26.5}{15.5} = 1.71$$

$$k = 5.34 + \frac{4.00}{(1.71)^2} = 6.71$$

$$C_v = \frac{190}{62} \times \frac{6.71}{50} = 1.123 > 0.8$$

$$F_v = \frac{50,000}{2.89} \times 1.123 = 19,420 \text{ psi} < 20,000 \text{ psi}$$

The tables in the succeeding pages are the results of the computerized calculations as described in appendix H, program AISCBM.

TABLE X.4.1-1. Normal and Shear Beam Stresses, Beam No. 3, Node No. 105

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SCR	BOT-LFT SDL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	3	105	-17.	-11.	9.	4.	0.001	0.0	-47.	-47.	-2.	-2.	0.002	0.002	410.6
2	3	105	-206.	443.	183.	-520.	0.011	0.014	-175.	453.	363.	-275.	0.013	0.015	55.9
3	3	105	-20.	-13.	10.	4.	0.001	0.0	-32.	-31.	-7.	-9.	0.002	0.002	599.3
4	3	105	-146.	335.	130.	-390.	0.003	0.010	-135.	333.	263.	-205.	0.013	0.013	77.7
5	3	105	-10.	-12.	4.	6.	0.000	0.0	-12.	-10.	-10.	-12.	0.001	0.001	1623.3
6	3	105	-23.	40.	17.	-51.	0.001	0.001	-26.	43.	29.	-39.	0.002	0.002	600.0
7	3	105	533.	-748.	-575.	712.	0.020	0.0	679.	879.	-2.	-2.	0.035	0.036	27.6
8	3	105	6.	15.	-3.	-14.	0.000	0.000	122.	125.	-9.	-12.	0.005	0.005	175.1
9	3	105	142.	-172.	-184.	132.	0.004	0.005	529.	527.	9.	12.	0.022	0.022	45.9
11	3	105	-17.	-11.	9.	4.	0.001	0.0	-47.	-46.	-2.	-2.	0.002	0.002	414.3
12	3	105	-265.	447.	183.	-520.	0.011	0.014	-174.	453.	363.	-274.	0.013	0.013	55.9
13	3	105	-20.	-13.	10.	4.	0.001	0.0	-32.	-31.	-7.	-9.	0.002	0.002	604.0
14	3	105	-145.	334.	130.	-399.	0.003	0.010	-134.	332.	262.	-204.	0.013	0.013	77.8
15	3	105	-4.	-12.	-0.	7.	0.000	0.0	-4.	-2.	-10.	-12.	0.001	0.001	1630.7
16	3	105	-14.	23.	9.	-27.	0.001	0.0	-13.	26.	13.	-27.	0.001	0.001	956.9

TABLE X.4.1-2. Normal and Shear Beam Stresses, Beam No. 3, Node No. 107

LOAD CASE	BEAM NC	NODE NC	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	3	107	-83.	61.	76.	-69.	0.003	0.0	47.	47.	2.	2.	0.002	0.003	360.4
2	3	107	-67.	228.	82.	-240.	0.006	0.007	175.	-463.	-363.	275.	0.018	0.018	55.9
3	3	107	-4993.	4986.	4984.	-4994.	0.166	0.0	32.	31.	7.	9.	0.002	0.166	6.0
4	3	107	-48.	186.	59.	-199.	0.005	0.005	135.	-333.	-263.	205.	0.013	0.013	77.7
5	3	107	-8.	22.	3.	-27.	0.001	0.0	12.	10.	10.	12.	0.001	0.001	1111.0
6	3	107	-2.	38.	1.	-45.	0.001	0.001	26.	-43.	-29.	39.	0.002	0.002	600.0
7	3	107	1838.	-2042.	-1875.	2006.	0.054	0.0	-879.	-879.	2.	2.	0.036	0.054	18.4
8	3	107	156.	-147.	-201.	111.	0.004	0.005	-122.	-125.	9.	12.	0.005	0.005	185.3
9	3	107	706.	-969.	-946.	725.	0.019	0.026	-529.	-527.	-9.	-12.	0.022	0.026	38.6
10	3	107	541.	4309.	819.	-3921.	0.115	0.121	1924.	-1216.	-2598.	541.	0.107	0.121	8.3
11	3	107	-83.	61.	75.	-68.	0.003	0.0	47.	46.	2.	2.	0.002	0.003	363.5
12	3	107	-66.	227.	82.	-239.	0.008	0.009	174.	-463.	-363.	274.	0.024	0.024	42.0
13	3	107	-53.	46.	44.	-55.	0.002	0.0	32.	31.	7.	9.	0.002	0.002	548.9
14	3	107	-47.	185.	58.	-198.	0.005	0.005	134.	-332.	-262.	204.	0.013	0.013	77.8
15	3	107	10.	10.	-13.	-13.	0.000	0.0	4.	2.	10.	12.	0.000	0.000	2168.8
16	3	107	8.	26.	-11.	-29.	0.001	0.0	13.	-26.	-13.	27.	0.001	0.001	956.9

TABLE X.4.1-3. Normal and Shear Beam Stresses, Beam No. 4, Node No. 108

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW		MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	EOF-RGT	EOF-LFT	SEL	RTOT1	RTOT2	22-TOP	22-DOT	33-RGT	33-LFT	RV		
			STL	STR	SER	SBL			V2T	V2S	V3R	V3L				
1	4	105	-83.	61.	76.	-69.		0.003	0.0	47.	47.	2.	2.	0.002	0.003	351.3
2	4	103	340.	-621.	-406.	533.		0.016	0.0	-305.	332.	346.	-270.	0.014	0.016	65.0
3	4	103	-54.	46.	45.	-55.		0.002	0.0	32.	31.	7.	9.	0.002	0.002	527.9
4	4	103	243.	-453.	-299.	403.		0.012	0.0	-224.	240.	277.	-187.	0.011	0.012	85.1
5	4	103	-8.	22.	3.	-27.		0.001	0.0	12.	10.	10.	12.	0.001	0.001	1033.0
6	4	103	33.	-55.	-49.	43.		0.001	0.0	-27.	37.	49.	-15.	0.002	0.002	532.7
7	4	105	1833.	-2042.	-1875.	2036.		0.055	0.0	-572.	-679.	2.	2.	0.035	0.055	13.3
8	4	103	156.	-147.	-201.	111.		0.004	0.005	-122.	-125.	9.	10.	0.002	0.005	153.3
9	4	103	706.	-962.	-943.	725.		0.019	0.006	-523.	-527.	-2.	-12.	0.002	0.003	35.6
11	4	103	-53.	61.	75.	-63.		0.003	0.0	47.	46.	2.	2.	0.002	0.003	357.3
12	4	103	311.	-622.	-403.	536.		0.013	0.0	-305.	331.	346.	-270.	0.014	0.015	62.9
13	4	103	-53.	46.	45.	-55.		0.002	0.0	32.	31.	7.	9.	0.002	0.002	527.7
14	4	103	243.	-453.	-299.	402.		0.012	0.0	-224.	239.	276.	-187.	0.011	0.012	85.2
15	4	103	10.	10.	-13.	-13.		0.000	0.0	4.	2.	16.	12.	0.001	0.001	1630.7
16	4	103	32.	-32.	-40.	25.		0.001	0.0	-17.	13.	32.	-3.	0.001	0.001	514.3

TABLE X.4.1-4. Normal and Shear Beam Stresses, Beam No. 4, Node No. 106

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RST STR	BOT-RST SRR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP VET	22-BOT VEB	33-RST VBR	33-LFT VBL			
1	4	106	-17.	-11.	9.	4.	0.001	0.0	-47.	-47.	-2.	-2.	0.002	0.002	410.6
2	4	106	230.	-721.	-352.	649.	0.013	0.0	305.	-332.	-363.	270.	0.014	0.013	54.4
3	4	106	-20.	-13.	10.	4.	0.001	0.0	-32.	-31.	-7.	-9.	0.002	0.002	509.8
4	4	106	131.	-544.	-242.	483.	0.014	0.0	224.	-240.	-277.	107.	0.011	0.011	72.0
5	4	106	-10.	-12.	4.	6.	0.000	0.0	-12.	-10.	-10.	-12.	0.001	0.001	1513.6
6	4	106	13.	-90.	-32.	76.	0.002	0.0	27.	-37.	-49.	15.	0.002	0.002	431.5
7	4	106	533.	-743.	-575.	712.	0.020	0.0	879.	379.	-2.	-2.	0.003	0.003	27.6
8	4	106	6.	15.	-3.	-11.	0.000	0.000	122.	125.	-9.	-12.	0.003	0.003	105.0
9	4	106	142.	-172.	-134.	132.	0.004	0.005	513.	527.	9.	12.	0.002	0.002	45.9
11	4	106	-17.	-11.	9.	4.	0.001	0.0	-47.	-43.	-2.	-2.	0.002	0.002	411.3
12	4	106	230.	-720.	-351.	649.	0.013	0.0	305.	-331.	-363.	270.	0.014	0.013	54.5
13	4	106	-20.	-13.	10.	4.	0.001	0.0	-32.	-31.	-7.	-9.	0.002	0.002	601.0
14	4	106	130.	-543.	-241.	482.	0.014	0.0	224.	-239.	-276.	107.	0.011	0.011	72.1
15	4	106	-4.	-12.	-0.	7.	0.000	0.0	-4.	-2.	-10.	-12.	0.001	0.001	1630.7
16	4	106	9.	-57.	-19.	48.	0.001	0.0	10.	-25.	-32.	3.	0.001	0.001	676.1

X.4.2 Member 11Section Properties (7)

$$\begin{array}{llll}
 b_x = 5.5 \text{ in}, & t_x = 0.5 \text{ in}, & b_y = 11 \text{ in}, & t_y = -.375 \text{ in}, \\
 A = 15.25 \text{ in}^2, & A_3 = 8.25 \text{ in}^2, & A_2 = 5.5 \text{ in}^2, & \\
 J = 215.2 \text{ in}^4, & \bar{r}_2 = 3.188 \text{ in}, & \bar{r}_3 = 4.25 \text{ in}, & \\
 I_2 = 314.771 \text{ in}^4, & C_{\text{top}} = 6 \text{ in}, & C_{\text{bottom}} = 6 \text{ in}, & \\
 I_3 = 99.87 \text{ in}^4, & C_{\text{left}} = 3.5 \text{ in}, & C_{\text{right}} = 3.5 \text{ in}, & \\
 L_2 = 108 \text{ in}, & K_2 = 2.0 & L_3 = 50 \text{ in}, & K_3 = 1.0
 \end{array}$$

Forces at Joint 112 (Load Case 1)

$$\begin{array}{lll}
 R_1 = 37.87(\text{comp}) \text{ Lbs.} & R_2 = -162.1 \text{ Lbs.} & R_3 = -51.09 \text{ Lbs.} \\
 M_T = -611.6 \text{ in. Lbs.} & M_2 = 1886 \text{ in. Lbs.} & M_3 = -8046 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 104 (Load Case 1)

$$\begin{array}{lll}
 R_1 = -37.87 \text{ Lbs.} & R_2 = 162.1 \text{ Lbs.} & R_3 = 51.09 \text{ Lbs.} \\
 M_T = 611.6 \text{ in. Lbs.} & M_2 = 668.2 \text{ in. Lbs.} & M_3 = -58.42 \text{ in. Lbs.}
 \end{array}$$

$$\frac{b_x}{t_x} = \frac{5.5}{0.5} = 11 < 35.7$$

$$\frac{b_y}{t_y} = \frac{11}{0.375} = 29.33 < 35.7 \quad \text{O.K.}$$

Total section is effective.

$$r_2 = 4.54" \quad r_3 = 2.56"$$

$$\frac{K_2 L_2}{r_2} = \frac{2 \times 108}{4.54} = 47.6$$

$$\frac{K_3 L_3}{r_3} = \frac{1.0 \times 50}{2.56} = 19.5$$

2-direction governs

$$C_c = \sqrt{\frac{2\pi^2(29 \times 10^3)}{50}} = 107$$

$$\frac{k_2^2}{r_2^2 C_c} = \frac{47.6}{107.0} = 0.445$$

$$F_a = \frac{[1 - \frac{1}{2}(.445)^2](50)}{\frac{5}{3} + \frac{3}{8}(.445) - \frac{1}{8}(.445)^3} = 24.7 \text{ ksi} = 24,700 \text{ psi}$$

$$f_a = \frac{37.87}{15.25} = 2.48 \text{ psi}$$

$$\frac{f_a}{F_a} < 0.15$$

$$f_{bx} = \frac{1886}{314.771} \times 6 = 35.9 \text{ psi}$$

$$f_{by} = \frac{8046 \times 3.5}{99.87} = 282 \text{ psi}$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = \frac{2.48}{24,700} + \frac{35.9}{30,000} + \frac{282}{30,000} = 0.01 < 1.0 \text{ O.K.}$$

$$f_{vx} = \frac{51.09}{8.25} = 6.19 \text{ psi}$$

$$f_{vy} = \frac{162.1}{5.5} = 29.5 \text{ psi}$$

$$f_{Tx} = \frac{611.6 \times 4.25}{215.2} = 12.08 \text{ psi}$$

$$f_{Ty} = \frac{611.6}{215.2} \times 3.188 = 9.06 \text{ psi}$$

$$f_{vx} + f_{Tx} = 18.27 \text{ psi}$$

$$f_{vy} + f_{Ty} = 38.56 \text{ psi}$$

these are very small stresses O.K.

$$\frac{h}{t} = \frac{11}{.375} = 29.33 < 247$$

O.K. no stiffeners required

$$\frac{a}{h} = \frac{18.75}{11} = 1.70$$

The results of the computerized calculations are given in the following pages.

Beam No. 12 has the same section properties as Beam No. 11.

TABLE X.4.2-1. Normal and Shear Beam Stresses, Beam No. 11, Node No. 112

LOAD CASE	BEAM NO.	NODE NO.	VALUE OF NORMAL STRESSES						RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW.	MAX RATIO STRESS OVER ALLOW.	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	BOT-RGT	BOT-LFT	SEL	SEL		22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	11	112	243.	-320.	-245.	315.			0.011 0.0	-20.	-39.	-13.	6.	0.002	0.011	93.5
2	11	112	793.	-1220.	-645.	1113.			0.031 0.0	332.	-371.	-531.	444.	0.021	0.031	31.5
3	11	112	113.	-231.	-139.	210.			0.003 0.0	-15.	-23.	-13.	-3.	0.001	0.003	123.7
4	11	112	515.	-913.	-574.	854.			0.024 0.0	275.	-260.	-403.	311.	0.015	0.024	42.0
5	11	112	67.	-143.	-95.	119.			0.003 0.0	-10.	-15.	-9.	-2.	0.001	0.003	199.2
6	11	112	100.	-219.	-135.	165.			0.065 0.0	34.	-64.	-64.	43.	0.002	0.003	105.3
7	11	112	-9973.	9733.	9973.	-9733.			0.233 0.0	1247.	773.	-327.	271.	0.030	0.233	3.3
8	11	112	-1320.	1320.	1320.	-1320.			0.035 0.0	93.	173.	53.	-51.	0.007	0.035	27.7
9	11	112	-5772.	5312.	5360.	-5224.		0.156	0.153 0.0	537.	622.	32.	-10.	0.035	0.153	6.4
11	11	112	233.	-315.	-213.	310.			0.011 0.0	-30.	-32.	-13.	3.	0.002	0.011	95.1
12	11	112	733.	-1212.	-673.	1160.			0.031 0.0	332.	-363.	-550.	473.	0.021	0.031	32.3
13	11	112	137.	-137.	-173.	136.			0.003 0.0	-13.	-23.	-13.	-3.	0.001	0.003	150.5
14	11	112	513.	-502.	-571.	551.			0.024 0.0	275.	-239.	-402.	310.	0.015	0.024	42.2
15	11	112	15.	-21.	15.	49.			0.002 0.001	-0.	-0.	-3.	-0.	0.003	0.002	609.5
16	11	112	15.	-105.	-67.	73.			0.003 0.0	15.	-32.	-39.	24.	0.001	0.003	315.5

TABLE X.4.2-2. Normal and Shear Beam Stresses, Beam No. 11, Node No. 104

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SSR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	11	104	8.	12.	-13.	-17.	0.001	0.0	20.	39.	18.	-6.	0.002	0.002	519.0
2	11	104	1290.	-833.	-1590.	833.	0.035	0.0	-382.	364.	551.	-444.	0.021	0.035	10.8
3	11	104	-1.	13.	-20.	-37.	0.001	0.0	15.	23.	13.	3.	0.001	0.001	769.1
4	11	104	954.	-623.	-1012.	560.	0.023	0.0	-276.	250.	403.	-311.	0.015	0.023	39.0
5	11	104	-11.	13.	-15.	-41.	0.001	0.0	10.	13.	9.	2.	0.001	0.001	673.9
6	11	104	127.	-77.	-161.	42.	0.005	0.0	-34.	43.	64.	-43.	0.002	0.005	217.7
7	11	104	95.	92.	-160.	-164.	0.003	0.0	-1247.	-730.	327.	-271.	0.030	0.030	20.0
8	11	104	-31.	-7.	2.	-21.	0.001	0.0	-93.	-173.	-73.	51.	0.007	0.007	141.9
9	11	104	12.	-11.	16.	39.	0.001	0.001	-587.	-622.	-43.	13.	0.025	0.025	60.2
11	11	104	8.	12.	-13.	-17.	0.001	0.0	20.	39.	18.	-6.	0.002	0.002	519.1
12	11	104	1290.	-833.	-1590.	833.	0.035	0.0	-382.	363.	550.	-443.	0.021	0.035	10.5
13	11	104	-1.	13.	-20.	-37.	0.001	0.0	15.	23.	13.	3.	0.001	0.001	769.0
14	11	104	952.	-625.	-1010.	567.	0.023	0.0	-275.	259.	402.	-310.	0.015	0.023	39.1
15	11	104	-13.	11.	-16.	-39.	0.002	0.0	0.	6.	8.	0.	0.000	0.002	570.4
16	11	104	66.	-33.	-90.	6.	0.003	0.0	-15.	32.	32.	-24.	0.001	0.003	336.4

TABLE X.4.2-3. Normal and Shear Beam Stresses, Beam No. 12, Node No. 113

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	12	113	315.	-249.	-300.	243.	0.011	0.0	-39.	-20.	18.	-6.	0.002	0.011	95.5
2	12	113	-2257.	2227.	3037.	-2777.	0.076	0.075	521.	-145.	-403.	405.	0.020	0.076	13.1
3	12	113	210.	-139.	-231.	113.	0.005	0.0	-23.	-15.	13.	3.	0.001	0.005	138.7
4	12	113	-2116.	1995.	2133.	-1973.	0.053	0.053	373.	-114.	-353.	297.	0.014	0.053	13.7
5	12	113	119.	-95.	-145.	67.	0.005	0.0	-15.	-10.	9.	2.	0.001	0.005	138.2
6	12	113	-203.	216.	201.	-239.	0.005	0.0	41.	-21.	-42.	41.	0.001	0.005	137.4
7	12	113	-9733.	9973.	9733.	-9973.	0.236	0.0	793.	1247.	307.	-271.	0.059	0.236	3.8
8	12	113	-1355.	1292.	1325.	-1320.	0.036	0.0	176.	93.	-56.	51.	0.007	0.036	27.7
9	12	113	-5521.	5009.	5252.	-5772.	0.156	0.153	602.	507.	-23.	13.	0.025	0.156	6.4
11	12	113	319.	-243.	-315.	239.	0.011	0.0	-39.	-20.	13.	-6.	0.002	0.011	95.1
12	12	113	-2252.	2104.	3034.	-2762.	0.076	0.076	521.	-145.	-402.	405.	0.020	0.076	13.1
13	12	113	205.	-137.	-230.	115.	0.005	0.0	-23.	-15.	13.	3.	0.001	0.005	138.2
14	12	113	-2114.	1993.	2131.	-1976.	0.053	0.053	373.	-114.	-352.	295.	0.014	0.053	13.7
15	12	113	21.	-15.	-49.	-13.	0.002	0.0	-6.	-0.	3.	0.	0.000	0.002	444.0
16	12	113	-151.	132.	126.	-164.	0.005	0.0	23.	-9.	-17.	23.	0.001	0.005	221.9

TABLE X.4.2-4. Normal and Shear Beam Stresses, Beam No. 12, Node No. 103

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SDR	BOT-LFT SCL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	12	103	-17.	-13.	12.	8.	0.001	0.0	39.	20.	-13.	6.	0.002	0.002	519.0
2	12	103	-676.	1313.	920.	-1274.	0.033	0.032	-521.	145.	403.	-405.	0.000	0.033	30.3
3	12	103	-37.	-20.	13.	-1.	0.001	0.0	25.	15.	-13.	-3.	0.001	0.001	784.1
4	12	103	966.	-649.	-947.	665.	0.024	0.024	-373.	114.	353.	-227.	0.014	0.024	41.3
5	12	103	-41.	-18.	13.	-11.	0.001	0.0	15.	10.	-9.	-2.	0.001	0.001	673.9
6	12	103	-125.	125.	103.	-143.	0.004	0.0	-41.	21.	42.	-41.	0.002	0.004	215.3
7	12	103	-104.	-103.	99.	95.	0.003	0.0	-743.	-1267.	-327.	271.	0.000	0.000	20.6
8	12	103	-21.	2.	-7.	-31.	0.001	0.0	-176.	-93.	66.	-51.	0.007	0.007	171.9
9	12	103	39.	16.	-11.	12.	0.001	0.001	-622.	-507.	23.	-13.	0.005	0.005	60.2
11	12	103	-17.	-13.	12.	8.	0.001	0.0	39.	20.	-13.	6.	0.002	0.002	519.1
12	12	103	-677.	1315.	913.	-1273.	0.033	0.032	-521.	145.	402.	-405.	0.000	0.033	30.4
13	12	103	-37.	-20.	13.	-1.	0.001	0.0	25.	15.	-13.	-3.	0.001	0.001	785.0
14	12	103	-647.	934.	664.	-917.	0.024	0.024	-373.	114.	352.	-226.	0.014	0.024	41.4
15	12	103	-39.	-16.	11.	-13.	0.002	0.0	6.	0.	-3.	-6.	0.000	0.002	500.4
16	12	103	-35.	66.	60.	-21.	0.003	0.0	-23.	9.	17.	-23.	0.001	0.003	374.1

X.4.3 Member 44

Section Properties (16)

$$\begin{array}{llll}
 b_x = 12.5 \text{ in}, & t_x = 0.25 \text{ in}, & b_y = 14 \text{ in}, & t_y = 0.25 \text{ in}, \\
 A = 13.6875 \text{ in}^2, & A_3 = 7 \text{ in}^2, & A_2 = 6.25 \text{ in}^2, & \\
 J = 611.3 \text{ in}^4, & r_2 = 6.73 \text{ in}, & r_3 = 6.73 \text{ in}, & \\
 I_2 = 453.73 \text{ in}^4, & C_{\text{top}} = 7.3476 \text{ in}, & C_{\text{bottom}} = 7.1524 \text{ in}, & \\
 I_3 = 384.45 \text{ in}^4, & C_{\text{left}} = 6.875 \text{ in}, & C_{\text{right}} = 6.875 \text{ in}, & \\
 L_2 = 63 \text{ in}, & K_2 = 1.5 & L_3 = 63 \text{ in}, & K_3 = 1.0
 \end{array}$$

Forces at Joint 128 (case 2)

$$\begin{array}{lll}
 R_1 = -222.5 \text{ (tension) Lbs.} & R_2 = 13400 \text{ Lbs.} & R_3 = 7650 \text{ Lbs.} \\
 M_T = 161700 \text{ in. Lbs.} & M_2 = -1044 \text{ in. Lbs.} & M_3 = -31600 \text{ ins.Lb}
 \end{array}$$

Forces at Joint 130 (Load Case 2)

$$\begin{array}{lll}
 R_1 = 222.5 \text{ Lbs.} & R_2 = -13400 \text{ Lbs.} & R_3 = -7650 \text{ Lbs.} \\
 M_T = -161700 \text{ in. Lbs.} & M_2 = -123600 \text{ in. Lbs.} & M_3 = -534400 \text{ lbs.L}
 \end{array}$$

Note that 33% increase in stress can be used in this case.

$$\frac{b_x}{t_x} = \frac{12.5}{0.25} = 50 > 33.7$$

$$\frac{b_y}{t_y} = \frac{14}{0.25} = 56 > 33.7$$

$$Q_s = 1.0 \quad f = 0.6(50) = 30 \text{ ksi}$$

$$b_{\text{ex}} = \frac{253(0.25)}{\sqrt{30}} \left(1 - \frac{50.3}{50\sqrt{30}} \right) = 9.43" < 12.5 \quad \text{O.K.} \quad b_{\text{ex}} = 9.43"$$

$$b_{\text{ey}} = \frac{253(0.25)}{\sqrt{30}} \left(1 - \frac{50.3}{56\sqrt{30}} \right) = 9.65 < 14 \quad \text{O.K.} \quad b_{\text{ey}} = 9.65"$$

$$A_{\text{eff}} = 13.6875 - (12.5 - 9.43)(0.25)(2) - (14 - 9.65)(.25)(2) = 9.9775 \text{ in}^2$$

$$I_{22(\text{effect})} = 453.73 - (3.07)(.25)[(7.3476 - .125)^2 + (7.1524 - .125)^2] \\ - \frac{4.35^3}{12} \times .25 \times 2 = 372.36 \text{ in}^4$$

$$I_{33(\text{effect})} = 384.45 - 4.35(.25)(2)(6.875 - .125)^2 - \frac{3.07^3}{12} \times .25 \times 2 \\ = 284.146 \text{ in}^4$$

$$Q_a = \frac{9.9775}{13.6875} = 0.729$$

Since the axial load is tension, then the section will be considered totally effective

$$F_t = F_{bx} = F_{by} = (1.33)(0.6)(50) = 40 \text{ ksi} = 40,000 \text{ psi}$$

$$f_t = \frac{222.5}{13.6875} = 16.26 \text{ psi}$$

$$f_{bx} = \frac{1044 \times 7.3476}{453.73} = 17 \text{ psi}$$

$$f_{bx} = \frac{123600 \times 7.3476}{453.73} = 2002 \text{ psi}$$

$$f_{by} = \frac{316000 \times 6.875}{384.45} = 5651 \text{ psi}$$

$$f_{by} = \frac{534400 \times 6.875}{384.45} = 9556 \text{ psi}$$

$$\frac{f_t}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = .142 < 1.0 \quad \text{O.K. at node 128}$$

$$.289 < 1.0 \quad \text{O.K. at node 130}$$

Check compression side using effective section properties and ignoring the axial tension (conservative approach, however, according to code requirement).

$$f_{bx} = \frac{123600 \times 7.1524}{372.36} = 2374 \text{ psi}$$

$$f_{by} = \frac{534400 \times 6.875}{284.146} = 12930 \text{ psi}$$

$$\frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = .383 < 1.0 \quad \text{O.K.}$$

$$f_{vx} = \frac{7650}{7} = 1093 \text{ psi}$$

$$f_{vy} = \frac{13400}{6.25} = 2144 \text{ psi}$$

$$f_{tx} = \frac{161,700 \times 6.73}{611.3} = 1.78 \text{ ksi}$$

$$f_{ty} = \frac{161,700 \times 6.73}{611.3} = 1.78 \text{ ksi}$$

$$f_{vx} + f_{tx} = 1.09 + 1.78 = 2.87 \text{ ksi}$$

$$f_{vy} + f_{ty} = 2.14 + 1.78 = 3.92 \text{ ksi}$$

$$\frac{h}{t} = \frac{14}{.25} = 56 < 260 \quad \text{O.K. no stiffeners required}$$

$$\frac{a}{h} = \frac{21.5}{14.0} = 1.536$$

$$k = 5.34 + \frac{4.00}{(1.536)^2} = 7.035$$

$$C_v = \frac{190}{\frac{14.0}{.25}} \sqrt{\frac{7.035}{50}} = 1.273 > 0.8 \quad \text{O.K.}$$

$$F_v = \frac{50}{2.89} (1.273) = 22.02 \text{ ksi} > 0.4 F_y \quad \text{Use } 20.0 \text{ ksi}$$

$$f_{vy} + f_{ty} = 3.92 < F_v \quad \text{O.K.}$$

The results of the computerized calculations for this beam is given in the following pages. Beam No. 45 has identical section properties as Beam No. 44.

TABLE X.4.3-1. Normal and Shear Beam Stresses, Beam No. 44, Node No. 128

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	DOT-RGT SER	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	44	128	-1008.	-3945.	870.	3122.	0.104	0.132	4213.	4213.	-1.	-1.	0.211	0.211	4.7
2	44	128	5651.	-7327.	-7349.	5647.	0.142	0.135	364.	3934.	2373.	-687.	0.143	0.135	5.4
3	44	128	-1716.	-3546.	1435.	2833.	0.095	0.119	2864.	2864.	-3.	-3.	0.143	0.143	7.0
4	44	128	3854.	-4973.	-5017.	3852.	0.077	0.126	26.	2443.	2590.	-233.	0.107	0.126	7.9
5	44	128	-1170.	-633.	935.	554.	0.032	0.019	351.	351.	-5.	-5.	0.019	0.040	25.2
6	44	128	376.	-244.	-435.	219.	0.009	0.011	-177.	305.	617.	135.	0.023	0.023	43.1
7	44	128	4377.	-2367.	-4933.	2911.	0.132	0.0	5.	5.	-1.	-1.	0.000	0.122	7.6
8	44	128	640.	-123.	-766.	117.	0.017	0.021	-1.	-1.	-4.	-4.	0.000	0.021	43.0
9	44	128	4059.	-2219.	-4057.	2221.	0.103	0.0	1.	1.	4.	4.	0.000	0.103	9.2
11	44	128	-1004.	-3941.	867.	3119.	0.104	0.132	4203.	4203.	-8.	-8.	0.210	0.210	4.8
12	44	128	5672.	-7316.	-7356.	5638.	0.142	0.135	364.	3913.	2863.	-683.	0.147	0.125	5.4
13	44	128	-1705.	-3532.	1427.	2827.	0.094	0.118	2859.	2859.	-3.	-3.	0.143	0.143	7.0
14	44	128	3377.	-4968.	-5003.	3844.	0.077	0.126	27.	2843.	2584.	-232.	0.107	0.126	7.9
15	44	128	-603.	-123.	593.	135.	0.017	0.021	94.	94.	-5.	-5.	0.035	0.021	43.3
16	44	128	159.	-6.	-167.	27.	0.004	0.005	-164.	100.	336.	72.	0.013	0.013	79.2

TABLE X.4.3-2. Normal and Shear Beam Stresses, Beam No. 44, Node No. 130

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	DOT-RGT	DOT-LFT		22-IOP V2I	22-DOY V2E	33-RGT V3R	33-LFT V3L			
1	44	130	6767.	-13945.	-9043.	10791.	0.350	-4213.	-4213.	1.	1.	0.211	0.465	2.1
2	44	130	7565.	-14877.	-10084.	11515.	0.259	-364.	-3624.	-2973.	667.	0.143	0.375	2.7
3	44	130	3756.	-10337.	-5123.	8046.	0.233	-2664.	-2664.	3.	3.	0.143	0.345	2.9
4	44	130	4325.	-11042.	-5042.	8586.	0.215	-26.	-2613.	-2590.	233.	0.107	0.277	3.6
5	44	130	-254.	-1523.	263.	1240.	0.041	-260.	-633.	-97.	106.	0.004	0.652	19.3
6	44	130	-213.	-1243.	225.	1011.	0.025	177.	-395.	-617.	-135.	0.023	0.032	31.6
7	44	130	4590.	-2977.	-4947.	2921.	0.132	-5.	-5.	1.	1.	0.000	0.132	7.6
8	44	130	667.	-116.	-773.	107.	0.017	1.	1.	4.	4.	0.060	0.021	47.5
9	44	130	4051.	-2232.	-4049.	2234.	0.103	-1.	-1.	-4.	-4.	0.060	0.103	9.3
11	44	130	6760.	-13931.	-9033.	10781.	0.359	-4197.	-4219.	-3.	19.	0.211	0.465	2.2
12	44	130	7562.	-14856.	-10013.	11459.	0.263	-364.	-3913.	-2968.	663.	0.147	0.373	2.7
13	44	130	3761.	-10321.	-5115.	8054.	0.233	-2651.	-2657.	-5.	11.	0.143	0.345	2.9
14	44	130	4315.	-11024.	-5038.	8572.	0.215	-27.	-2343.	-2564.	232.	0.107	0.277	3.6
15	44	130	-374.	-341.	323.	298.	0.011	-93.	-95.	3.	6.	0.005	0.013	77.3
16	44	130	-553.	-390.	295.	336.	0.005	164.	-160.	-336.	-72.	0.013	0.013	79.2

TABLE X.4.3-3. Normal and Shear Beam Stresses, Beam No. 45, Node No. 129

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SUR	BOT-LFT SDL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	45	129	-1003.	-3945.	870.	3122.	0.104	0.132	4213.	4213.	-1.	-1.	0.211	0.211	4.7
2	45	129	-8372.	-1484.	6664.	1261.	0.136	0.210	8492.	4932.	-2375.	656.	0.319	0.319	3.1
3	45	129	-1713.	-3546.	1435.	2333.	0.095	0.119	2214.	2234.	-3.	-3.	0.143	0.143	7.0
4	45	129	-7737.	-2777.	6174.	2331.	0.155	0.196	6013.	3175.	-2593.	227.	0.293	0.293	4.4
5	45	129	-1170.	-633.	936.	551.	0.032	0.040	331.	331.	-5.	-5.	0.019	0.019	23.2
6	45	129	-2338.	-797.	1924.	697.	0.043	0.061	794.	312.	-623.	-164.	0.039	0.061	16.5
7	45	129	4575.	-2935.	-4931.	2903.	0.131	0.0	5.	5.	-1.	-1.	0.080	0.131	7.6
8	45	129	640.	-123.	-766.	117.	0.017	0.021	-1.	-1.	-4.	-4.	0.000	0.021	43.0
9	45	129	4651.	-2222.	-4053.	2224.	0.103	0.0	1.	1.	4.	4.	0.000	0.103	9.2
11	45	129	-1064.	-3941.	837.	3119.	0.104	0.132	4219.	4197.	-12.	10.	0.211	0.211	4.7
12	45	129	-8352.	-1403.	6576.	1259.	0.165	0.210	8481.	4927.	-2370.	684.	0.319	0.319	3.1
13	45	129	-1713.	-3540.	1433.	2333.	0.094	0.119	2267.	2251.	-11.	5.	0.143	0.143	7.0
14	45	129	-7772.	-2771.	6162.	2327.	0.154	0.195	6006.	3150.	-2591.	225.	0.293	0.293	4.4
15	45	129	-603.	-123.	503.	135.	0.017	0.031	94.	94.	-5.	-5.	0.005	0.031	43.3
16	45	129	-1331.	-307.	1111.	237.	0.028	0.035	339.	185.	-345.	-81.	0.014	0.035	23.6

TABLE X.4.3-3(a). Normal and Shear Beam Stresses, Beam No. 45, Node No. 130

LOAD CASE	BEAM NO.	NODE NO.	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	BOT-LFT	BOT-RGT		22-10P	22-EXT	33-RGT	33-LFT			
			SIL	STR	SSR	SBL		V21	V2B	V3R	V3L			
1	45	130	6757.	-13945.	-9043.	10791.	0.360	-4213.	-4213.	1.	1.	0.211	0.465	2.1
2	45	130	7355.	-14377.	-10034.	11515.	0.239	-5492.	-4932.	2875.	-605.	0.319	0.373	2.7
3	45	130	3766.	-10337.	-5123.	8046.	0.248	-2034.	-2034.	3.	3.	0.143	0.345	2.9
4	45	130	4323.	-11042.	-5343.	8558.	0.215	-6013.	-3195.	2556.	-227.	0.225	0.277	3.6
5	45	130	-254.	-1523.	263.	1210.	0.041	-331.	-331.	5.	5.	0.019	0.052	19.3
6	45	130	-218.	-1243.	225.	1011.	0.025	-794.	-312.	623.	144.	0.030	0.032	31.6
7	45	130	4890.	-2977.	-4947.	2921.	0.132	-5.	-5.	1.	1.	0.600	0.132	7.6
8	45	130	647.	-116.	-773.	117.	0.017	1.	1.	4.	4.	0.600	0.021	47.5
9	45	130	4051.	-2232.	-4049.	2234.	0.103	-1.	-1.	-4.	-4.	0.600	0.103	9.3
11	45	130	6760.	-13331.	-9033.	10751.	0.359	-4219.	-4197.	12.	-10.	0.211	0.465	2.2
12	45	130	7552.	-14356.	-10043.	11479.	0.213	-8131.	-4927.	2670.	-694.	0.319	0.373	2.7
13	45	130	3761.	-10321.	-5115.	8034.	0.243	-2037.	-2031.	11.	-5.	0.143	0.345	2.9
14	45	130	4315.	-11024.	-5339.	8572.	0.215	-6006.	-3150.	2591.	-225.	0.225	0.277	3.6
15	45	130	-274.	-341.	323.	259.	0.011	-95.	-95.	6.	3.	0.605	0.013	77.3
16	45	130	-339.	-370.	295.	335.	0.003	-359.	-105.	345.	81.	0.014	0.014	72.1

X.4.4 Member 54Section Properties (18)

$$\begin{array}{llll}
 b_x = 11.125 \text{ in}, & t_x = 0.5 \text{ in}, & b_y = 12 \text{ in}, & t_y = 0.5 \text{ in}, \\
 A = 24.125 \text{ in}^2, & A_2 = 12 \text{ in}^2, & A_3 = 11.125 \text{ in}^2, & \\
 J = 875.3 \text{ in}^4, & \bar{r}_2 = 6.02 \text{ in}, & \bar{r}_3 = 6.02 \text{ in}, & \\
 I_2 = 617.8 \text{ in}^4, & C_{\text{top}} = 6.5 \text{ in}, & C_{\text{bottom}} = 6.5 \text{ in}, & \\
 I_3 = 554.2 \text{ in}^4, & C_{\text{left}} = 6 \text{ in}, & C_{\text{right}} = 6 \text{ in}, & \\
 L_2 = 242 \text{ in}, & K_2 = 2.0 & L_3 = 89 \text{ in}, & K_3 = 1.
 \end{array}$$

Forces at Joint 127 (case 2)

$$\begin{array}{lll}
 R_1 = 25960 \text{ (comp) Lbs.} & R_2 = -38600 \text{ Lbs.} & R_3 = 448.4 \text{ Lbs.} \\
 M_T = 261400 \text{ in. Lbs.} & M_2 = 103000 \text{ in. Lbs.} & M_3 = -124500 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 142 (Load Case 2)

$$\begin{array}{lll}
 R_1 = -25960 \text{ Lbs.} & R_2 = 38600 \text{ Lbs.} & R_3 = -448.4 \text{ Lbs.} \\
 M_T = -261400 \text{ in. Lbs.} & M_2 = -110800 \text{ in. Lbs.} & M_3 = -547000 \text{ in. Lbs.}
 \end{array}$$

$$\frac{b_x}{t_x} = \frac{11.125}{0.5} = 22.25 < 33.7$$

$$\frac{b_y}{t_y} = \frac{12}{0.5} = 24 < 33.7$$

full section is effective

$$Q_a = 1.0, Q_s = 1.0$$

$$C_c = \sqrt{\frac{2\pi^2(29 \times 10^3)}{(1.0)50}} = 107$$

$$r_3 = 4.79'' ,$$

$$r_2 = 5.06''$$

$$\frac{K_2 L_2}{r_2} = \frac{242(2.0)}{5.06} = 95.7 \text{ (governs)}$$

$$\frac{K_2 L_2}{r_2 C_c} = 0.8939$$

$$F_a = 1.33(15.66) = 20.8 \text{ ksi}$$

$$f_a = \frac{25.960}{24.125} = 1.076 \text{ ksi}$$

$$\frac{f_a}{F_a} < 0.15$$

$$F_{bx} = F_{by} = 1.33(0.6)(50) = 40 \text{ ksi}$$

stresses at node 142 governs

$$f_{bx} = \frac{110.8 \times 6.5}{617.8} = 1.17 \text{ ksi}$$

$$f_{by} = \frac{547 \times 6}{554.2} = 5.92 \text{ ksi}$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = \frac{1.076}{20.8} + \frac{1.17}{40} + \frac{5.92}{40} = 0.229 < 1.0 \quad \text{O.K.}$$

$$f_{vx} = \frac{.448}{12} = 0.04 \text{ ksi}$$

$$f_{vy} = \frac{38.6}{11.125} = 3.47 \text{ ksi}$$

$$f_{Tx} = \frac{261.4 \times 6.02}{875.3} = 1.80 \text{ ksi}$$

$$f_{Ty} = \frac{261.4 \times 6.02}{875.3} = 1.80 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 1.84 \text{ ksi}$$

$$f_{vy} + f_{Ty} = 5.27 \text{ ksi}$$

$$k = 5.34 + \frac{4.00}{\left(\frac{11}{12}\right)^2} = 10.10$$

$$C_v = \frac{190}{\frac{12}{.5}} \sqrt{\frac{10.1}{50}} = 3.56 > 0.8 \quad \text{O.K.}$$

$$F_v = \frac{50}{2.89} (3.56) > 0.4 F_y \quad \text{use } F_v = 0.4 F_y (1.33) = 26.6 \text{ ksi}$$

$$f_{vx} + f_{Tx} < F_v \quad \text{O.K.}$$

$$\frac{h}{t} = \frac{12}{0.5} = 24 < 247 \quad \text{O.K. no stiffeners required}$$

$$\frac{a}{h} = \frac{11.0}{12.0} = 0.917$$

The results of the computerized calculations are given in the following pages.

Beams No. 55 and 54 are identical.

TABLE X.4.4-1. Normal and Shear Stresses, Beam No. 54, Node No. 127

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT S1K	EOT-EOT SSR	EOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-EOT V2B	33-RGT VER	33-LFT V3L			
1	54	127	-123.	-1661.	-715.	823.	0.057	0.0	-2368.	-987.	745.	-633.	0.113	0.113	8.4
2	54	127	-789.	-3721.	-1354.	1359.	0.113	0.0	-5239.	-1673.	1835.	-1760.	0.193	0.193	5.0
3	54	127	-633.	-1753.	-623.	559.	0.051	0.0	-1872.	-683.	539.	713.	0.632	0.632	12.3
4	54	127	-1322.	-3431.	-1647.	1033.	0.112	0.0	-3632.	-1113.	1855.	-1153.	0.137	0.137	7.3
5	54	127	-257.	-417.	-93.	62.	0.014	0.0	-323.	-77.	182.	-87.	0.616	0.616	61.3
6	54	127	-571.	-857.	-131.	115.	0.031	0.0	-573.	-123.	234.	-154.	0.622	0.631	32.2
7	54	127	1654.	-823.	-1154.	1133.	0.039	0.035	1033.	342.	-467.	334.	0.613	0.613	23.1
8	54	127	464.	-283.	-376.	293.	0.012	0.011	179.	76.	-69.	57.	0.687	0.612	60.9
9	54	127	1516.	-822.	-1153.	1130.	0.040	0.033	930.	243.	-397.	334.	0.039	0.610	24.7
11	54	127	-123.	-1350.	-715.	823.	0.057	0.0	-2368.	-987.	745.	-633.	0.113	0.113	8.4
12	54	127	-789.	-3714.	-1354.	1355.	0.090	0.0	-5239.	-1671.	1835.	-1760.	0.193	0.193	5.1
13	54	127	-633.	-1631.	-637.	553.	0.051	0.0	-1850.	-667.	519.	-613.	0.631	0.631	12.3
14	54	127	-1320.	-3395.	-1647.	1031.	0.112	0.0	-3643.	-1142.	1223.	-1191.	0.135	0.135	7.3
15	54	127	-179.	-100.	14.	-65.	0.002	0.0	-132.	-22.	75.	-34.	0.607	0.603	113.0
16	54	127	-576.	-412.	-50.	-14.	0.015	0.0	-351.	-57.	140.	-161.	0.611	0.615	65.8

TABLE X.4.4-2. Normal and Shear Beam Stresses, Beam No. 54, Node No. 142

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ ALLOW	I. V. RATIO OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SOR	BOT-LFT SQL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-TOT V3R	33-LFT V3L			
1	54	142	-3790.	1767.	2951.	-2685.	0.123	0.0	2368.	967.	-745.	636.	0.113	0.123	7.2
2	54	142	-8223.	3739.	6971.	-5032.	0.231	0.0	5549.	1873.	-1075.	1740.	0.193	0.231	4.3
3	54	142	-3619.	800.	2035.	-1723.	0.102	0.0	1682.	663.	-550.	413.	0.072	0.102	9.6
4	54	142	-3406.	1533.	4113.	-3965.	0.150	0.0	3032.	1143.	-1255.	1193.	0.137	0.150	5.3
5	54	142	-766.	-73.	411.	-282.	0.036	0.0	323.	77.	-102.	27.	0.016	0.036	23.4
6	54	142	-1394.	-215.	622.	-557.	0.074	0.0	573.	125.	-204.	134.	0.062	0.074	22.9
7	54	142	3052.	-2255.	-2742.	2536.	0.081	0.677	-1093.	-342.	407.	-334.	0.043	0.081	12.3
8	54	142	723.	-479.	-341.	537.	0.019	0.013	-179.	-73.	49.	-34.	0.007	0.019	51.5
9	54	142	2064.	-2052.	-2503.	2110.	0.077	0.072	-950.	-213.	387.	-334.	0.039	0.077	13.0
11	54	142	-3790.	1767.	2952.	-2687.	0.123	0.0	2368.	967.	-745.	636.	0.113	0.123	7.2
12	54	142	-8216.	3733.	6965.	-5037.	0.233	0.0	5552.	1871.	-1073.	1735.	0.193	0.233	4.3
13	54	142	-3615.	799.	2042.	-1722.	0.102	0.0	1680.	667.	-549.	413.	0.051	0.102	9.6
14	54	142	-3476.	1537.	4112.	-3981.	0.159	0.0	3027.	1141.	-1254.	1192.	0.133	0.159	5.3
15	54	142	-765.	-70.	220.	-135.	0.015	0.0	132.	22.	-73.	33.	0.007	0.015	65.2
16	54	142	-795.	-73.	340.	-353.	0.025	0.0	140.	-164.	-140.	164.	0.005	0.025	40.3

TABLE X.4.4-3. Normal and Shear Beam Stresses, Beam No. 55, Node No. 143

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	EOI-RGT	EOI-LFT	SEL	RTOT1	RTOT2	22-TOP	22-BOT	33-RGT			
			STL	SIR	SCR	SEI			VET	VER	VSL	VSL	RV		
1	55	143	-3790.	1767.	2951.	-2636.	0.128	0.0	2365.	937.	-745.	656.	0.118	0.123	7.8
2	55	143	850.	-600.	-339.	830.	0.022	0.016	-513.	336.	-533.	-530.	0.012	0.022	44.8
3	55	143	-3019.	800.	2025.	-1723.	0.102	0.0	1532.	648.	-550.	413.	0.032	0.102	9.8
4	55	143	600.	-83.	-78.	619.	0.015	0.009	-354.	212.	157.	-359.	0.014	0.015	65.4
5	55	143	-766.	-73.	411.	-232.	0.025	0.0	336.	77.	-132.	87.	0.016	0.025	33.4
6	55	143	113.	101.	62.	74.	0.003	0.001	-42.	-4.	-16.	-51.	0.002	0.003	333.4
7	55	143	3052.	-2356.	-2702.	2565.	0.031	0.077	-1033.	-312.	467.	-339.	0.013	0.031	12.3
8	55	143	703.	-479.	-641.	537.	0.019	0.013	-179.	-76.	43.	-54.	0.007	0.019	51.5
9	55	143	2534.	-2022.	-2826.	2310.	0.077	0.072	-809.	-249.	397.	-334.	0.039	0.077	13.0
11	55	143	-3790.	1769.	2452.	-2307.	0.103	0.0	2313.	617.	-745.	633.	0.113	0.103	7.8
12	55	143	847.	-397.	-357.	237.	0.022	0.016	-2273.	4891.	4104.	-4025.	0.131	0.131	6.2
13	55	143	-3015.	799.	2032.	-1792.	0.102	0.0	1633.	637.	-519.	413.	0.031	0.102	9.8
14	55	143	512.	-86.	-77.	603.	0.015	0.009	-353.	212.	156.	-359.	0.014	0.015	65.7
15	55	143	-739.	20.	220.	-125.	0.015	0.0	132.	22.	-73.	53.	0.007	0.015	65.2
16	55	143	31.	95.	60.	-5.	0.002	0.001	-37.	-14.	-10.	-55.	0.001	0.002	421.2

TABLE X.4.4-4. Normal and Shear Beam Stresses, Beam No. 55, Node No. 126

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SER	BOT-LFT SOL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	55	126	-123.	-1661.	-715.	823.	0.057	0.0	-2348.	-937.	745.	-633.	0.113	0.113	8.4
2	55	126	829.	-24.	-339.	514.	0.021	0.015	513.	-303.	-373.	508.	0.019	0.021	43.1
3	55	126	-433.	-1633.	-403.	539.	0.051	0.0	-1632.	-613.	550.	-413.	0.002	0.002	12.3
4	55	126	649.	252.	-113.	270.	0.016	0.009	354.	-212.	-197.	339.	0.014	0.013	62.4
5	55	126	-257.	-417.	-93.	62.	0.014	0.0	-383.	-77.	152.	-67.	0.013	0.013	31.3
6	55	126	141.	276.	31.	-51.	0.003	0.003	42.	4.	15.	54.	0.002	0.003	176.6
7	55	126	1664.	-818.	-1154.	1133.	0.039	0.035	1033.	342.	-407.	337.	0.043	0.043	23.1
8	55	126	464.	-285.	-376.	203.	0.012	0.011	179.	76.	-62.	54.	0.007	0.012	89.9
9	55	126	1516.	-322.	-1153.	1133.	0.040	0.036	900.	249.	-397.	334.	0.039	0.040	24.7
11	55	126	823.	-715.	-1661.	-123.	0.057	0.0	-2348.	-937.	745.	-633.	0.113	0.113	8.4
12	55	126	827.	-23.	-337.	513.	0.021	0.015	512.	-325.	-333.	499.	0.019	0.021	43.3
13	55	126	-433.	-1633.	-403.	539.	0.051	0.0	-1632.	-617.	549.	-413.	0.001	0.001	12.3
14	55	126	633.	232.	-117.	269.	0.016	0.009	353.	-212.	-193.	339.	0.014	0.013	62.5
15	55	126	-179.	-169.	14.	-65.	0.003	0.0	-132.	-22.	75.	-34.	0.007	0.003	112.0
16	55	126	25.	195.	67.	-104.	0.003	0.004	37.	14.	10.	33.	0.001	0.005	204.2

X.4.5 Member 84Section Properties (26)

$$\begin{array}{llll}
 b_x = 15 \text{ in}, & t_x = 0.25 \text{ in}, & b_y = 31.5 \text{ in}, & t_y = 0.25 \text{ in}, \\
 A = 23.5 \text{ in}^2, & A_3 = 15.75 \text{ in}^2, & A_2 = 7.5 \text{ in}^2, & \\
 J = 2494 \text{ in}^4, & \bar{r}_2 = 10.3 \text{ in}, & \bar{r}_3 = 10.3 \text{ in}, & \\
 I_2 = 3256 \text{ in}^4, & C_{\text{top}} = 16 \text{ in}, & C_{\text{bottom}} = 16 \text{ in}, & \\
 I_3 = 1071 \text{ in}^4, & C_{\text{left}} = 7.25 \text{ in}, & C_{\text{right}} = 7.25 \text{ in}, & \\
 L_2 = 63 \text{ in}, & K_2 = 1.0 & L_3 = 63 \text{ in}, & K_3 = 1.0
 \end{array}$$

Forces at Joint 167 (case 1)

$$\begin{array}{lll}
 R_1 = 5211 \text{ (comp) Lbs.} & R_2 = 102.3 \text{ Lbs.} & R_3 = 18.03 \text{ Lbs.} \\
 M_T = 81.93 \text{ in. Lbs.} & M_2 = 20080 \text{ in. Lbs.} & M_3 = 207800 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 169

$$\begin{array}{lll}
 R_1 = -5211 \text{ Lbs.} & R_2 = -102.3 \text{ Lbs.} & R_3 = 18.03 \text{ Lbs.} \\
 M_T = -81.93 \text{ in. Lbs.} & M_2 = -19820 \text{ in. Lbs.} & M_3 = 209300 \text{ in. Lbs.}
 \end{array}$$

$$\frac{b_x}{t_x} = \frac{15}{.25} = 60 > 33.7 \qquad \frac{b_y}{t_y} = \frac{31.5}{0.25} = 126 > 33.7$$

$$Q_s = 1.0 \qquad f = 0.6 \qquad F_y = 30 \text{ ksi}$$

$$b_{ex} = \frac{253(0.25)}{\sqrt{30}} \left(1 - \frac{50.3}{60\sqrt{30}} \right) = 9.78 < 15 \qquad b_x - b_{ex} = 5.22"$$

$$b_{ey} = \frac{253(0.25)}{\sqrt{30}} \left(1 - \frac{50.3}{126\sqrt{30}} \right) = 10.71 < 31.5 \qquad b_y - b_{ey} = 20.79"$$

$$A_{\text{eff}} = 23.5 - (5.22)(.25)(2) - (20.79)(.25)(2) = 10.5 \text{ in}^2$$

$$I_{2 \text{ effec.}} = 3256 - (5.22)(.25)(2)(16)^2 - \frac{20.79^3}{12} \times .25 \times 2 = 2213 \text{ in}^4$$

$$I_3 \text{ effent} = 1071 - (20.79)(.25)(2)(7.75)^2 - \frac{5.22^3}{12} \times .25 \times 2 = 440.7 \text{ in}^4$$

$$Q_a = \frac{10.5}{23.5} = 0.447$$

$$C_c' = \sqrt{\frac{2\pi^2(29 \times 10^3)}{(1.0)(.447)(50)}} = 113$$

$$r_2 = 14.5 \text{ in.} \quad r_3 = 6.48 \text{ in.}$$

$$\frac{k_2^2}{r_2} = \frac{63}{14.5} = 4.34$$

$$\frac{k_3^2}{r_3} = \frac{63}{6.48} = 9.72 \text{ governs}$$

$$F_a = 13.08 \text{ ksi}$$

$$f_a = \frac{5.211}{10.5} = 0.496 \text{ ksi}$$

$$\frac{f_a}{F_a} = 0.04 < 0.15$$

$$F_{bx} = F_{by} = 30 \text{ ksi}$$

$$f_{bx} = \frac{19.82 \times 16}{2213} = 0.14 \text{ ksi}$$

$$f_{by} = \frac{209.3 \times 7.75}{440.7} = 3.68 \text{ ksi}$$

$$\frac{f_a}{F_a} = \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.17 < 1.0 \quad \text{O.K.}$$

$$f_{vx} = \frac{18.03}{15.75} = 1.14 \text{ psi}$$

$$f_{vy} = \frac{102.3}{7.5} = 13.64 \text{ psi}$$

$$f_{Tx} = \frac{81.93 \times 10.3}{2494} = 0.34 \text{ psi}$$

$$f_{Ty} = \frac{81.93 \times 10.3}{2494} = 0.34 \text{ psi}$$

$$f_{vx} + f_{Tx} = 1.48 \text{ psi}$$

$$f_{vy} + f_{Ty} = 13.98 \text{ psi}$$

very low stress, O.K.

$$\frac{h}{t} = \frac{31.5}{.25} = 126 < 260$$

$$\text{O.K. } \frac{a}{h} = \frac{17.5}{31.5} = 0.55$$

The results of the computerized calculations are given in the following pages.

Beams No. 84 and 85 are identical.

TABLE X.4.5-1. Normal and Shear Beam Stresses, Beam No. 84, Node No. 167

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SDR	BOT-LFT SCL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	84	167	3129.	-3362.	-3573.	3418.	0.133	0.0	13.	14.	-1.	-1.	0.001	0.133	7.2
2	84	167	5464.	-3950.	-5773.	3503.	0.155	0.0	533.	-1178.	-509.	1202.	0.053	0.155	6.4
3	84	167	3410.	-2751.	-3743.	2415.	0.132	0.0	8.	11.	-3.	-6.	0.001	0.132	7.6
4	84	167	4937.	-2317.	-5274.	1909.	0.137	0.0	570.	-263.	-439.	1023.	0.045	0.137	7.3
5	84	167	637.	169.	-1411.	-343.	0.033	0.0	-2.	2.	-5.	-9.	0.000	0.033	15.8
6	84	167	1729.	-123.	-2452.	-525.	0.073	0.0	113.	-169.	-69.	213.	0.009	0.073	13.7
7	84	167	5397.	-4833.	-6203.	4412.	0.174	0.0	13.	14.	-1.	-1.	0.001	0.174	5.7
8	84	167	815.	1276.	-794.	-1335.	0.034	0.052	-4.	-0.	-5.	-8.	0.000	0.032	19.3
9	84	167	-7.	-2270.	-103.	2130.	0.032	0.0	4.	0.	5.	0.	0.000	0.032	16.0
11	84	167	3090.	-3313.	-3521.	3333.	0.133	0.0	13.	14.	-1.	-1.	0.001	0.133	7.3
12	84	167	5420.	-3903.	-5151.	3472.	0.153	0.0	532.	-1176.	-509.	1197.	0.052	0.153	6.5
13	84	167	3360.	-2702.	-3690.	2373.	0.130	0.0	8.	11.	-3.	-6.	0.001	0.130	7.7
14	84	167	4893.	-2275.	-5210.	1914.	0.133	0.0	533.	-267.	-429.	1024.	0.045	0.133	7.4
15	84	167	2341.	-1251.	-3507.	635.	0.131	0.0	-30.	-26.	-5.	-9.	0.001	0.131	7.6
15	84	167	3165.	-1131.	-3719.	513.	0.103	0.0	75.	-23.	-44.	119.	0.005	0.103	9.7

TABLE X.4.5-2. Normal and Shear Beam Stresses, Beam No. 84, Node No. 169

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RST STR	BOT-RST SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-TST V3T	33-LFT V3L			
1	84	169	3157.	-3235.	-3300.	3442.	0.139	0.0	-13.	-14.	1.	1.	0.001	0.139	7.2
2	84	169	4361.	-3709.	-4740.	3135.	0.176	0.0	-533.	1173.	509.	-1202.	0.053	0.176	7.9
3	84	169	3434.	-2760.	-3770.	2954.	0.133	0.0	-8.	-11.	3.	6.	0.001	0.173	7.5
4	84	169	4191.	-2351.	-4523.	2814.	0.119	0.0	-573.	233.	430.	-1076.	0.015	0.119	8.4
5	84	169	643.	130.	-1621.	-953.	0.064	0.0	2.	-2.	5.	9.	0.000	0.064	15.7
6	84	169	1960.	-200.	-2073.	-553.	0.057	0.0	-113.	109.	6.	-210.	0.000	0.059	13.3
7	84	169	5925.	-4831.	-6315.	4141.	0.175	0.0	-13.	-14.	1.	1.	0.001	0.175	5.7
8	84	169	820.	1005.	-801.	-1501.	0.034	0.052	4.	0.	5.	2.	0.000	0.052	19.1
9	84	169	-13.	-2235.	-97.	2175.	0.033	0.0	-4.	-0.	-5.	-3.	0.000	0.033	19.9
11	84	169	3113.	-3337.	-3513.	3455.	0.137	0.0	-13.	-14.	1.	1.	0.001	0.137	7.3
12	84	169	4034.	-3182.	-4405.	3451.	0.131	0.0	-532.	1163.	509.	-1199.	0.052	0.131	8.0
13	84	169	3347.	-2713.	-3743.	2733.	0.131	0.0	-8.	-11.	3.	6.	0.001	0.131	7.6
14	84	169	4142.	-2503.	-4173.	2175.	0.117	0.0	-523.	237.	422.	-1024.	0.015	0.117	8.5
15	84	169	2982.	-1010.	-3537.	623.	0.132	0.0	30.	20.	5.	9.	0.002	0.132	7.6
16	84	169	3031.	-1131.	-3543.	507.	0.101	0.0	-75.	23.	44.	-119.	0.005	0.101	9.9

TABLE X.4.5-3. Normal and Shear Beam Stresses, Beam No. 85, Node No. 168

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SDR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	85	168	3157.	-3835.	-3600.	3442.	0.139	0.0	-13.	-14.	1.	1.	0.001	0.139	7.2
2	85	168	2013.	-3844.	-2457.	3401.	0.103	0.0	503.	-1201.	-507.	1205.	0.033	0.103	9.7
3	85	168	3434.	-2760.	-3770.	2424.	0.133	0.0	-3.	-11.	3.	6.	0.001	0.133	7.5
4	85	168	2704.	-2923.	-3041.	2368.	0.002	0.0	572.	-890.	-423.	1039.	0.045	0.002	12.3
5	85	168	643.	130.	-1421.	-953.	0.004	0.0	2.	-2.	5.	9.	0.000	0.004	15.7
6	85	168	1215.	-359.	-1933.	-364.	0.000	0.0	120.	-173.	-60.	233.	0.010	0.000	16.7
7	85	168	5705.	-4331.	-6315.	4441.	0.175	0.0	-13.	-14.	1.	1.	0.001	0.175	5.7
8	85	168	820.	115.	-801.	-1631.	0.034	0.052	4.	0.	5.	8.	0.000	0.034	19.1
9	85	168	-13.	-2235.	-97.	2175.	0.003	0.0	-4.	-8.	-5.	-8.	0.000	0.003	16.9
11	85	168	3113.	-3537.	-3548.	3405.	0.137	0.0	-13.	-14.	1.	1.	0.001	0.137	7.3
12	85	168	1977.	-3794.	-2497.	3363.	0.102	0.0	505.	-1204.	-507.	1202.	0.033	0.102	9.8
13	85	168	3337.	-2713.	-3716.	2523.	0.131	0.0	-3.	-11.	3.	6.	0.001	0.131	7.6
14	85	168	2653.	-2933.	-2937.	2305.	0.000	0.0	570.	-889.	-422.	1036.	0.045	0.000	12.5
15	85	168	2952.	-1240.	-3567.	605.	0.132	0.0	2.	-2.	5.	9.	0.000	0.132	7.3
16	85	168	2837.	-1243.	-3431.	604.	0.097	0.0	79.	-92.	-34.	136.	0.003	0.097	10.5

TABLE X.4.5-4. Normal and Shear Beam Stresses, Beam No. 85, Node No. 166

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESSES OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SDR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT VER	33-LFT V3L			
1	85	166	3129.	-3362.	-3573.	3413.	0.133	0.0	13.	14.	-1.	-1.	0.001	0.133	7.2
2	85	166	1253.	-4231.	-1397.	3707.	0.113	0.0	-506.	1206.	507.	-1205.	0.053	0.113	8.3
3	85	166	3410.	-2751.	-3743.	2415.	0.132	0.0	8.	11.	-3.	-6.	0.001	0.132	7.6
4	85	166	1937.	-3100.	-3244.	2133.	0.083	0.0	-572.	890.	423.	-1030.	0.045	0.083	11.7
5	85	166	637.	139.	-1411.	-943.	0.003	0.0	39.	31.	-5.	-9.	0.002	0.003	15.3
6	85	166	1624.	-453.	-1747.	-270.	0.055	0.0	-120.	173.	60.	-233.	0.010	0.055	10.1
7	85	166	5297.	-4003.	-4003.	4413.	0.174	0.0	13.	14.	-1.	-1.	0.001	0.174	5.7
8	85	166	815.	1276.	-795.	-1133.	0.039	0.052	-4.	-0.	-5.	-8.	0.000	0.039	12.3
9	85	166	-6.	-2239.	-102.	2131.	0.032	0.0	4.	0.	5.	8.	0.000	0.032	13.0
11	85	166	3090.	-3813.	-3321.	3713.	0.133	0.0	13.	14.	-1.	-1.	0.001	0.133	7.3
12	85	166	766.	-3725.	-1197.	3215.	0.100	0.0	-505.	1204.	507.	-1202.	0.053	0.100	10.0
13	85	166	3360.	-2702.	-3400.	2373.	0.130	0.0	8.	11.	-3.	-6.	0.001	0.130	7.7
14	85	166	1831.	-3149.	-2122.	3313.	0.034	0.0	-570.	839.	423.	-1030.	0.045	0.034	11.9
15	85	166	2941.	-1251.	-3557.	633.	0.131	0.0	23.	30.	-5.	-9.	0.002	0.131	7.6
15	85	166	2770.	-1338.	-3534.	734.	0.094	0.0	-79.	92.	34.	-136.	0.035	0.094	10.6

X.4.6 Member 56Section Properties (19)Unstiffened $b = 1''$ $t = 3/8''$

$$\begin{array}{llll}
 b_x = 5.5 \text{ in}, & t_x = 0.5 \text{ in}, & b_y = 11 \text{ in}, & t_y = 3/8 \text{ in}, \\
 A = 20.125 \text{ in}^2, & A_3 = 12.375 \text{ in}^2, & A_2 = 5.75 \text{ in}^2, & \\
 J = 291.1 \text{ in}^4, & \bar{r}_2 = 4.05 \text{ in}, & \bar{r}_3 = 5.4 \text{ in}, & \\
 I_2 = 383.43 \text{ in}^4, & C_{\text{top}} = 6.5 \text{ in}, & C_{\text{bottom}} = 6.5 \text{ in}, & \\
 I_3 = 150 \text{ in}^4, & C_{\text{left}} = 4.393 \text{ in}, & C_{\text{right}} = 2.982 \text{ in}, & \\
 L_2 = 242 \text{ in}, & K_2 = 2.0 & L_3 = 89 \text{ in}, & k_3 = 0.0
 \end{array}$$

Forces at Joint 144 (Load case 2)

$$\begin{array}{lll}
 R_1 = -17150 \text{ (tension) Lbs.} & R_2 = 7907 \text{ Lbs.} & R_3 = 202.1 \text{ Lbs.} \\
 M_T = 86930 \text{ in. Lbs.} & M_2 = -30710 \text{ in. Lbs.} & M_3 = 199900 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 125 (Load Case 2)

$$\begin{array}{lll}
 R_1 = 17150 \text{ Lbs.} & R_2 = -7907 \text{ Lbs.} & R_3 = -202.1 \text{ Lbs.} \\
 M_T = -86930 \text{ in. Lbs.} & M_2 = 27190 \text{ in. Lbs.} & M_3 = -62330 \text{ in. Lbs.}
 \end{array}$$

$$253/\sqrt{F_y} = 35.8$$

$$\frac{b_x}{t_x} = \frac{5.5}{0.5} = 11 < 35.8$$

$$\frac{b_y}{t_y} = \frac{11}{.375} = 29.3 < 35.8$$

whole section is effective

$$Q_a = 1.0, \quad Q_s = 1.0$$

$$F_t = 1.33(0.6)(50) = 40 \text{ ksi}$$

$$F_{bx} = F_{by} = 1.33(0.6)(50) = 40 \text{ ksi}$$

$$f_{bx} = \frac{30.71 \times 6.5}{383.43} = 0.52 \text{ ksi}$$

$$f_{by} = \frac{199.9 \times 4.393}{150.16} = 5.85 \text{ ksi}$$

$$f_t = \frac{17.150}{20.125} = 0.85 \text{ ksi}$$

$$\frac{f_t}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.18 < 1.0 \quad \text{O.K.}$$

Stress very small, no need for compression check.

$$f_{vx} = \frac{.202}{12.375} = 0.016 \text{ ksi}$$

$$f_{vy} = \frac{7.907}{5.75} = 1.38 \text{ ksi}$$

$$f_{Tx} = \frac{86.93 \times 5.4}{291.1} = 1.61 \text{ ksi}$$

$$f_{Ty} = \frac{86.93 \times 4.05}{291.1} = 1.21 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 1.626$$

$$f_{vy} + f_{Ty} = 2.59 \text{ ksi}$$

Stresses so small, no need to evaluate allowable stress accurately

$$F_v = 0.4(50)(1.33) = 26.6 \text{ ksi}$$

$$\left. \begin{aligned} \frac{d}{t} &= 34.7 < 247 \\ \frac{h}{t} &= \frac{11}{0.375} = 29.33 < 260 \end{aligned} \right\} \quad \text{O.K.}$$

$$\frac{a}{h} = \frac{26.5}{11} = 2.41$$

The results of the computerized calculations are given in the succeeding pages.
Beams No. 56 and 57 are identical.

TABLE X.4.6-1. Normal and Shear Beam Stresses, Beam No. 56, Node No. 144

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	56	144	-2576.	3042.	2491.	-3128.	0.101	0.121	685.	1614.	643.	-596.	0.081	0.121	8.3
2	56	144	-4470.	5339.	4298.	-5511.	0.134	0.159	166.	2585.	1629.	-1556.	0.097	0.152	6.3
3	56	144	-1443.	2364.	1755.	-2052.	0.079	0.086	441.	1089.	462.	-402.	0.054	0.086	11.7
4	56	144	-2308.	4106.	2946.	-3467.	0.103	0.110	89.	1763.	1138.	-1094.	0.066	0.110	9.1
5	56	144	25.	460.	225.	-210.	0.015	0.013	-58.	109.	128.	-95.	0.006	0.015	65.2
6	56	144	-72.	736.	352.	-311.	0.018	0.015	-131.	171.	214.	-138.	0.008	0.018	54.2
7	56	144	3249.	-2728.	-2492.	3484.	0.073	0.0	-30.	-528.	-348.	316.	0.021	0.073	13.6
8	56	144	777.	-750.	-681.	845.	0.020	0.0	-55.	-124.	-45.	47.	0.005	0.020	49.2
9	56	144	2901.	-2443.	-2216.	3128.	0.066	0.0	133.	-359.	-342.	314.	0.014	0.066	15.2
11	56	144	-2577.	3041.	2480.	-3128.	0.101	0.121	685.	1614.	643.	-596.	0.081	0.121	8.3
12	56	144	-4465.	5333.	4294.	-5505.	0.134	0.159	165.	2581.	1627.	-1594.	0.097	0.159	6.3
13	56	144	-1442.	2361.	1753.	-2050.	0.079	0.086	440.	1088.	451.	-402.	0.054	0.086	11.7
14	56	144	-2305.	4099.	2941.	-3462.	0.103	0.110	89.	1760.	1137.	-1092.	0.066	0.110	9.1
15	56	144	-81.	227.	127.	-181.	0.008	0.003	-49.	26.	53.	-41.	0.003	0.008	128.4
16	56	144	-38.	419.	214.	-242.	0.010	0.009	-90.	74.	117.	-101.	0.004	0.010	95.3

TABLE X.4.6-2. Normal and Shear Beam Stresses, Beam No. 56, Node No. 125

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES						RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2		22-TOP 1/2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	56	125	697.	675.	296.	319.	0.023	0.007		-685.	-1614.	-643.	596.	0.081	0.081	12.4
2	56	125	-508.	2550.	1623.	-1439.	0.064	0.057		-166.	-2535.	-1629.	1596.	0.097	0.097	10.3
3	56	125	686.	736.	345.	295.	0.025	0.008		-441.	-1089.	-462.	402.	0.054	0.054	18.4
4	56	125	319.	2186.	1190.	-677.	0.055	0.040		-89.	-1763.	-1138.	1094.	0.056	0.056	15.1
5	56	125	41.	349.	234.	-75.	0.012	0.003		58.	-109.	-128.	95.	0.006	0.012	86.0
6	56	125	84.	649.	360.	-206.	0.015	0.012		131.	-171.	-214.	183.	0.008	0.016	61.4
7	56	125	2491.	-2116.	-1997.	2610.	0.057	0.0		30.	528.	343.	-316.	0.021	0.057	17.5
8	56	125	512.	-576.	-500.	537.	0.016	0.0		55.	124.	45.	-47.	0.015	0.016	63.8
9	56	125	2620.	-2168.	-2041.	2747.	0.053	0.0		-133.	359.	342.	-314.	0.014	0.058	17.1
11	56	125	696.	675.	296.	317.	0.023	0.007		-685.	-1614.	-643.	596.	0.081	0.081	12.4
12	56	125	-511.	2549.	1628.	-1432.	0.064	0.057		-165.	-2531.	-1627.	1594.	0.097	0.097	10.3
13	56	125	683.	736.	345.	293.	0.025	0.003		-440.	-1033.	-461.	402.	0.054	0.054	18.4
14	56	125	316.	2183.	1183.	-673.	0.055	0.040		-89.	-1760.	-1137.	1092.	0.056	0.056	15.1
15	56	125	-146.	219.	181.	-134.	0.007	0.003		49.	-26.	-53.	41.	0.003	0.008	127.0
16	56	125	176.	225.	78.	29.	0.006	0.003		90.	-74.	-117.	101.	0.004	0.006	177.1

TABLE X.4.6-3. Normal and Shear Beam Stresses, Beam No. 57, Node No. 145

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SEL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	57	145	-3128.	2491.	3042.	-2576.	0.101	0.121	1614.	685.	-643.	596.	0.081	0.121	8.3
2	57	145	-457.	466.	535.	-337.	0.013	0.015	690.	1254.	341.	-411.	0.047	0.147	21.2
3	57	145	-2052.	1755.	2364.	-1443.	0.079	0.036	1089.	441.	-662.	402.	0.054	0.086	11.7
4	57	145	-416.	412.	471.	-357.	0.012	0.013	452.	833.	216.	-292.	0.031	0.031	31.9
5	57	145	-210.	225.	460.	25.	0.015	0.013	109.	-55.	-128.	95.	0.005	0.015	65.2
6	57	145	-59.	17.	22.	-54.	0.002	0.0	-2.	23.	2.	-32.	0.001	0.002	527.3
7	57	145	3484.	-2492.	-2728.	3249.	0.073	0.0	-528.	-30.	348.	-316.	0.021	0.073	13.6
8	57	145	845.	-631.	-750.	777.	0.020	0.0	-124.	-55.	45.	-47.	0.005	0.020	49.2
9	57	145	3128.	-2216.	-2443.	2901.	0.066	0.0	-359.	133.	342.	-314.	0.014	0.066	15.2
11	57	145	-3128.	2490.	3041.	-2577.	0.101	0.121	1614.	685.	-643.	596.	0.021	0.121	8.3
12	57	145	-459.	467.	536.	-390.	0.013	0.015	690.	1253.	340.	-411.	0.047	0.047	21.2
13	57	145	-2050.	1753.	2361.	-1442.	0.079	0.033	1088.	440.	-602.	461.	0.054	0.086	11.7
14	57	145	-417.	412.	471.	-359.	0.012	0.013	452.	832.	221.	-286.	0.031	0.031	32.0
15	57	145	-181.	127.	227.	-81.	0.008	0.003	26.	-49.	-53.	41.	0.003	0.008	128.4
16	57	145	-100.	29.	27.	-102.	0.003	0.0	-22.	-6.	1.	-20.	0.001	0.003	290.8

TABLE X.4.6-4. Normal and Shear Beam Stresses, Beam No. 57, Node No. 124

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL		22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	57	124	319.	296.	675.	697.	0.023	-1614.	-685.	643.	-596.	0.081	3.081	12.4
2	57	124	2516.	-1335.	-1524.	2327.	0.063	-690.	-1254.	-541.	411.	0.047	0.063	15.9
3	57	124	295.	345.	735.	685.	0.025	-1089.	-441.	462.	-402.	0.054	0.054	18.4
4	57	124	1600.	-726.	-942.	1384.	0.040	-452.	-833.	123.	631.	0.031	0.040	24.9
5	57	124	-75.	234.	349.	41.	0.012	-109.	58.	123.	-95.	0.006	0.012	86.0
6	57	124	27.	52.	-54.	-79.	0.002	2.	-23.	-2.	32.	0.001	0.002	418.0
7	57	124	2610.	-1997.	-2116.	2491.	0.057	528.	30.	-348.	316.	0.021	0.057	17.5
8	57	124	587.	-500.	-576.	512.	0.016	124.	55.	-45.	47.	0.005	0.016	63.8
9	57	124	2747.	-2041.	-2163.	2620.	0.053	359.	-133.	-342.	314.	0.014	0.038	17.1
11	57	124	317.	296.	675.	695.	0.023	-1614.	-655.	643.	-596.	0.081	0.081	12.4
12	57	124	2510.	-1332.	-1520.	2321.	0.063	-690.	-1253.	-340.	411.	0.047	0.063	15.9
13	57	124	293.	345.	735.	683.	0.025	-1088.	-440.	462.	-402.	0.054	0.054	18.4
14	57	124	1597.	-724.	-940.	1331.	0.040	-452.	-832.	-216.	291.	0.031	0.040	25.0
15	57	124	-184.	181.	219.	-146.	0.007	-26.	49.	53.	-41.	0.003	0.008	127.0
15	57	124	-106.	90.	20.	-176.	0.005	22.	6.	-1.	20.	0.001	0.005	188.6

X.4.7 Member 58Section Properties (19)unstiffened $b = 1" \quad t = 3/8"$

$$\begin{aligned}
 b_x &= 5.5 \text{ in}, & t_x &= 0.5 \text{ in}, & b_y &= 11 \text{ in}, & t_y &= 3/8 \text{ in}, \\
 A &= 20.125 \text{ in}^2, & A_3 &= 12.375 \text{ in}^2, & A_2 &= 5.75 \text{ in}^2, \\
 J &= 291.1 \text{ in}^4, & \bar{r}_2 &= 4.05 \text{ in}, & \bar{r}_3 &= 5.4 \text{ in}, \\
 I_2 &= 383.43 \text{ in}^4, & C_{\text{top}} &= 6.5 \text{ in}, & C_{\text{bottom}} &= 6.5 \text{ in}, \\
 I_3 &= 150.16 \text{ in}^4, & C_{\text{left}} &= 4.393 \text{ in}, & C_{\text{right}} &= 2.982 \text{ in}, \\
 L_2 &= 242 \text{ in}, & K_2 &= 2.0, & L_3 &= 89 \text{ in}, & K_3 &= 1.0
 \end{aligned}$$

Forces at Joint 148 (Case 2)

$$\begin{aligned}
 R_1 &= -36210 \text{ (tension) Lbs.} & R_2 &= -21960 \text{ Lbs.} & R_3 &= 430.6 \text{ Lbs.} \\
 M_T &= 49510 \text{ in. Lbs.} & M_2 &= 15390 \text{ in. Lbs.} & M_3 &= -282500 \text{ in. Lbs.}
 \end{aligned}$$

Forces at Joint 144

$$\begin{aligned}
 R_1 &= 36210 \text{ Lbs.} & R_2 &= 21960 \text{ Lbs.} & R_3 &= -430.6 \text{ Lbs.} \\
 M_T &= -49510 \text{ in. Lbs.} & M_2 &= -46110 \text{ in. Lbs.} & M_3 &= -1,284,000 \text{ in. Lbs.}
 \end{aligned}$$

$$b/t \text{ (unstiffened)} = \frac{1}{3/8} = 2.7 < \frac{95}{\sqrt{F_y}} = 13.4$$

whole section effective (see member 56)

$$F_t = F_{bx} = F_{by} = 40 \text{ ksi}$$

$$f_{bx} = \frac{46.11 \times 6.5}{383.43} = 0.78 \text{ ksi}$$

$$f_{by} = \frac{1284 \times 4.393}{150.16} = 37.56 \text{ ksi}$$

$$F_t = \frac{36.21}{20.125} = 1.8 \text{ ksi}$$

$$\frac{f_t}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 1.00 \quad \text{O.K.}$$

compression side only is also safe O.K.

$$f_{vx} = \frac{.4306}{12.375} = 0.035 \text{ ksi}$$

$$f_{vy} = \frac{21.96}{5.75} = 3.82 \text{ ksi}$$

$$f_{Tx} = \frac{49.51 \times 5.4}{291.1} = 0.92 \text{ ksi}$$

$$f_{Ty} = \frac{49.51 \times 4.05}{291.1} = 0.69 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 0.955$$

$$f_{vy} + f_{Ty} = 4.51 \text{ ksi}$$

$$F_v = 0.4(50)(1.33) = 26.6 \text{ ksi}$$

shear stress is O.K.

$$\frac{h}{t} = 29.3 < 247 \text{ O.K. No stiffeners required}$$

$$\frac{a}{h} = \frac{26.5}{11} = 2.41$$

The results of the computerized calculations described in appendix H are given in the succeeding pages. Beams No. 58 and 59 are identical.

TABLE X.4.7-1. Normal and Shear Beam Stresses, Beam No. 58, Node No. 148

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SDR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	58	148	1063.	1575.	1057.	545.	0.052	0.019	-1215.	-1841.	-342.	482.	0.092	0.092	10.9
2	58	148	9796.	-4066.	-3544.	10317.	0.259	0.147	-4503.	-3130.	953.	-834.	0.169	0.259	3.9
3	58	148	1375.	1790.	958.	543.	0.060	0.022	-887.	-1349.	-212.	404.	0.067	0.067	14.8
4	58	148	7394.	-1600.	-1665.	7330.	0.135	0.092	-3138.	-2277.	644.	-504.	0.118	0.185	5.4
5	58	148	2228.	-230.	-877.	1531.	0.074	0.044	-386.	-350.	90.	16.	0.019	0.074	13.5
6	58	148	3187.	-734.	-1164.	2753.	0.090	0.045	-706.	-469.	199.	-117.	0.027	0.080	12.5
7	58	148	1451.	-2229.	-1737.	1944.	0.061	0.0	1014.	965.	-83.	-13.	0.041	0.061	16.4
8	58	148	384.	-391.	-582.	184.	0.016	0.0	110.	362.	172.	-165.	0.014	0.016	62.3
9	58	148	-3185.	1153.	1503.	-2831.	0.035	0.0	1171.	1462.	150.	-237.	0.058	0.086	11.6
11	58	148	1046.	1585.	1068.	528.	0.053	0.019	-1215.	-1837.	-339.	490.	0.092	0.092	10.9
12	58	148	9768.	-4050.	-3530.	10283.	0.253	0.147	-4503.	-3125.	954.	-884.	0.169	0.253	3.9
13	58	148	1323.	1764.	1001.	560.	0.059	0.021	-885.	-1355.	-210.	402.	0.067	0.067	14.9
14	58	148	7367.	-1533.	-1652.	7303.	0.135	0.092	-3133.	-2272.	644.	-505.	0.118	0.185	5.4
15	58	148	1517.	-953.	-1370.	1100.	0.054	0.0	202.	234.	-6.	-43.	0.012	0.054	18.6
16	58	148	2151.	-656.	-979.	1828.	0.054	0.032	-409.	-326.	308.	198.	0.015	0.054	18.6

TABLE X.4.7-2. Normal and Shear Beam Stresses, Beam No. 58, Node No. 144

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR	
			TOP-LFT	TOP-RGT	BOT-RGT	BOT-LFT	SBL	SBR	22-TOP	22-BOT	33-RGT	33-LFT				
			STL	STR				RTOT1	RTOT2	V2T	V2B	V3R	V3L			
1	58	144	-18395.	12391.	14621.	-16645.		0.437	0.650	1215.	1841.	342.	-492.	0.092	0.650	1.5
2	58	144	-36510.	26493.	23056.	-34947.		0.703	0.960	4508.	3130.	-953.	834.	0.169	0.960	1.0
3	58	144	-13467.	9453.	11495.	-11425.		0.383	0.489	887.	1319.	212.	-404.	0.067	0.489	2.0
4	58	144	-26114.	19391.	21417.	-24068.		0.537	0.705	3138.	2277.	-644.	504.	0.118	0.705	1.4
5	58	144	-2863.	1895.	2833.	-1924.		0.094	0.110	336.	330.	-90.	-16.	0.019	0.110	9.1
6	58	144	-4480.	3430.	4240.	-3670.		0.105	0.128	705.	469.	-159.	117.	0.027	0.128	7.8
7	58	144	14067.	-9535.	-10541.	13061.		0.283	0.0	-1014.	-565.	83.	18.	0.041	0.283	3.5
8	58	144	3165.	-2360.	-2454.	3071.		0.066	0.0	-110.	-362.	-172.	165.	0.014	0.066	15.2
9	58	144	13186.	-8973.	-9794.	12365.		0.263	0.0	-1171.	-1462.	-150.	237.	0.058	0.263	3.8
11	58	144	-18382.	12879.	14618.	-16643.		0.437	0.650	1215.	1837.	339.	-490.	0.092	0.650	1.5
12	58	144	-36484.	26470.	28034.	-34920.		0.703	0.959	4503.	3125.	-954.	834.	0.169	0.959	1.0
13	58	144	-13450.	9440.	11479.	-11411.		0.383	0.488	886.	1365.	210.	-402.	0.067	0.488	2.0
14	58	144	-26078.	19363.	21397.	-24055.		0.536	0.704	3133.	2272.	-644.	505.	0.118	0.704	1.4
15	58	144	-1506.	410.	814.	-1102.		0.093	0.0	-202.	-234.	6.	43.	0.012	0.058	17.2
16	58	144	-2635.	1957.	2391.	-2201.		0.060	0.074	409.	326.	-308.	-193.	0.015	0.074	13.5

TABLE X.4.7-3. Normal and Shear Beam Stresses, Beam No. 59, Node No. 149

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SPR	BOT-LFT SBL		22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	59	149	545.	1057.	1575.	1063.	0.052 0.019	-1841.	-1215.	342.	-492.	0.092	0.092	10.9
2	59	149	-9362.	5766.	7305.	-7823.	0.183 0.245	-1422.	2112.	1575.	-1203.	0.079	0.245	4.1
3	59	149	543.	958.	1790.	1375.	0.030 0.022	-1349.	-837.	212.	-404.	0.067	0.067	14.8
4	59	149	-6469.	3742.	5332.	-4879.	0.134 0.172	-324.	1418.	1035.	-1278.	0.053	0.172	5.8
5	59	149	1581.	-876.	-230.	2228.	0.074 0.044	-330.	-385.	-90.	-16.	0.019	0.074	13.5
6	59	149	93.	-535.	184.	812.	0.020 0.015	-120.	53.	66.	-164.	0.006	0.020	49.2
7	59	149	1944.	-1737.	-2229.	1451.	0.061 0.0	965.	1014.	83.	18.	0.041	0.061	16.4
8	59	149	194.	-582.	-392.	354.	0.016 0.0	362.	110.	-172.	165.	0.014	0.016	62.2
9	59	149	-2770.	1569.	1092.	-3246.	0.033 0.0	1462.	1171.	-150.	237.	0.053	0.088	11.4
11	59	149	528.	1068.	1535.	1046.	0.053 0.019	-1837.	-1215.	339.	-490.	0.092	0.092	10.9
12	59	149	-9367.	5771.	7307.	-7830.	0.183 0.245	-419.	2103.	1572.	-1789.	0.079	0.245	4.1
13	59	149	526.	968.	1798.	1357.	0.030 0.023	-1345.	-836.	210.	-402.	0.067	0.067	14.9
14	59	149	-6474.	3747.	5333.	-4887.	0.134 0.172	-322.	1403.	1032.	-1274.	0.053	0.172	5.8
15	59	149	1102.	-814.	-410.	1504.	0.050 0.033	-234.	-202.	6.	-43.	0.012	0.050	19.9
16	59	149	361.	-631.	-140.	851.	0.021 0.016	-134.	8.	64.	-125.	0.005	0.021	46.8

TABLE X.4.7-4. Normal and Shear Beam Stresses, Beam No. 59, Node No. 145

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	59	145	-16645.	14621.	12881.	-18385.	0.487	0.650	1841.	1215.	-342.	492.	0.092	0.650	1.5
2	59	145	2473.	592.	-1276.	606.	0.062	0.042	422.	-2112.	-1575.	1803.	0.079	0.079	12.6
3	59	145	-11425.	11495.	9453.	-13467.	0.383	0.489	1349.	897.	-212.	404.	0.067	0.489	2.0
4	59	145	1857.	1141.	-904.	-183.	0.047	0.033	324.	-1410.	-1035.	1278.	0.053	0.053	18.9
5	59	145	-1924.	2833.	1895.	-2862.	0.094	0.110	330.	386.	90.	16.	0.019	0.110	9.1
6	59	145	425.	475.	-278.	-328.	0.012	0.010	120.	-53.	-66.	164.	0.005	0.012	83.9
7	59	145	13061.	-10541.	-9535.	14067.	0.263	0.0	-95.	-1014.	-83.	-18.	0.041	0.283	3.5
8	59	145	3071.	-2454.	-2360.	3165.	0.066	0.0	-362.	-110.	172.	-165.	0.014	0.066	15.2
9	59	145	12365.	-9794.	-8973.	13185.	0.263	0.0	-1462.	-1171.	150.	-237.	0.058	0.263	3.8
11	59	145	-16643.	14618.	12379.	-18382.	0.487	0.650	1837.	1215.	-339.	490.	0.092	0.650	1.5
12	59	145	2461.	596.	-1268.	597.	0.062	0.042	419.	-2103.	-1572.	1799.	0.079	0.079	12.6
13	59	145	-11411.	11479.	9440.	-13450.	0.333	0.483	1345.	836.	-210.	402.	0.067	0.483	2.0
14	59	145	1849.	1143.	-899.	-193.	0.046	0.033	322.	-1408.	-1032.	1274.	0.053	0.053	18.9
15	59	145	-1100.	1370.	953.	-1517.	0.046	0.055	233.	202.	6.	43.	0.012	0.056	17.9
16	59	145	60.	331.	-81.	-352.	0.008	0.009	134.	-8.	-64.	125.	0.005	0.009	103.6

X.4.8 Member 71Section Properties (23)

$$\begin{array}{llll}
 b_x = 5.5 \text{ in,} & t_x = 0.5 \text{ in,} & b_y = 11 \text{ in,} & t_y = 3/8" \text{ in,} \\
 A = 26.63 \text{ in}^2, & A_3 = 17.88 \text{ in}^2, & A_2 = 5.813 \text{ in}^2, & \\
 J = 422.3 \text{ in}^4, & \bar{r}_2 = 5.54 \text{ in,} & \bar{r}_3 = 7.39 \text{ in,} & \\
 I_2 = 474.9 \text{ in}^4, & C_{\text{top}} = 6.5 \text{ in,} & C_{\text{bottom}} = 6.5 \text{ in,} & \\
 I_3 = 259.5 \text{ in}^4, & C_{\text{left}} = 3.94 \text{ in,} & C_{\text{right}} = 3.94 \text{ in,} & \\
 L_2 = 134. \text{ in,} & K_2 = 1.0 & L_3 = 45.0 \text{ in,} & K_3 = 1.0
 \end{array}$$

Forces at Joint 158 (case 1)

$$\begin{array}{lll}
 R_1 = 22240 \text{ (tension) Lbs.} & R_2 = 13560 \text{ Lbs.} & R_3 = -1258 \text{ Lbs.} \\
 M_T = 39830 \text{ in. Lbs.} & M_2 = -6801 \text{ in..Lbs..} & M_3 = -10540 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 148 (Load Case 1)

$$\begin{array}{lll}
 R_1 = 22240 \text{ Lbs.} & R_2 = -13560 \text{ Lbs.} & R_3 = -1258 \text{ Lbs.} \\
 M_T = -39830 \text{ in. Lbs.} & M_2 = -19940 \text{ in..Lbs.} & M_3 = -10540 \text{ in. Lbs.}
 \end{array}$$

whole section effective (see member 56)

$$F_t = F_{bx} = F_{by} = 0.6(50) = 30 \text{ ksi}$$

$$f_{bx} = \frac{6.801 \times 6.5}{474.9} = 0.09 \text{ ksi}$$

$$f_{by} = \frac{298.7 \times 3.94}{259.5} = 4.54 \text{ ksi}$$

$$f_t = \frac{22.240}{26.63} = 0.84 \text{ ksi}$$

$$\frac{f_t}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.182 < 1.0 \quad \text{O.K.}$$

No need to check compression side, stress is too low.

$$f_{vx} = \frac{1.258}{17.88} = 0.07 \text{ ksi}$$

$$f_{vy} = \frac{13.56}{5.813} = 2.33 \text{ ksi}$$

$$f_{Tx} = \frac{39.83 \times 5.54}{422.3} = 0.52 \text{ ksi}$$

$$f_{Ty} = \frac{39.83 \times 7.39}{422.3} = 0.70 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 0.59 \text{ ksi}$$

$$f_{vy} + f_{Ty} = 3.03 \text{ ksi}$$

$$F_v \approx 0.4(50) = 20 \text{ ksi}$$

shear stress is safe.

$$\frac{d}{t} = 34.7 < 247$$

$$\frac{h}{t} = 29.3 < 260 \quad \text{O.K.}$$

$$\frac{a}{h} = \frac{15.25}{11} = 1.386$$

The results of the computerized calculations described in appendix H are given in the succeeding pages. Beams No. 71 and 72 are identical.

TABLE X.4.8-1. Normal and Shear Beam Stresses, Beam No. 71, Node No. 158

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	BOT-RGT	BOT-LFT	SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L		
1	71	158	-3526.	5532.	5346.	-3713.	0.184	0.152	1415.	2460.	767.	-627.	0.123	0.184	5.4
2	71	158	1677.	2026.	861.	512.	0.051	0.019	-1788.	2356.	2814.	-2727.	0.106	0.106	9.5
3	71	158	-1994.	3708.	3389.	-1813.	0.130	0.096	954.	1454.	310.	-357.	0.073	0.130	7.7
4	71	158	1383.	2097.	1498.	784.	0.053	0.016	-1245.	1596.	1855.	-1935.	0.073	0.073	13.7
5	71	158	3583.	-3483.	-3064.	4002.	0.133	0.127	-884.	-1584.	-591.	342.	0.079	0.133	7.5
6	71	158	3637.	-3157.	-2845.	3948.	0.099	0.090	-986.	-1358.	-335.	112.	0.051	0.099	10.1
7	71	158	-4095.	2932.	3458.	-3569.	0.110	0.0	2315.	1808.	-400.	276.	0.093	0.110	9.1
8	71	158	2567.	-3826.	-2965.	3429.	0.102	0.0	-1069.	-1562.	-490.	168.	0.062	0.102	9.8
9	71	158	-4000.	4133.	3525.	-4609.	0.124	0.0	1255.	1171.	53.	167.	0.050	0.124	8.1
11	71	158	-3516.	5522.	5335.	-3703.	0.184	0.151	1402.	2455.	773.	-631.	0.123	0.184	5.4
12	71	158	1679.	2019.	856.	515.	0.051	0.019	-1795.	2361.	2816.	-2728.	0.106	0.106	9.4
13	71	158	-1990.	3702.	3832.	-1811.	0.129	0.096	945.	1452.	315.	-361.	0.073	0.129	7.7
14	71	158	1380.	2094.	1495.	781.	0.052	0.016	-1250.	1594.	1857.	-1937.	0.073	0.073	13.7
15	71	158	2063.	-2601.	-1924.	2740.	0.091	0.090	-315.	-1237.	-769.	460.	0.062	0.091	10.9
16	71	158	2326.	-2554.	-1973.	2907.	0.073	0.069	-461.	-1161.	-623.	311.	0.044	0.073	13.7

TABLE X. 4.8-2. Normal and Shear Beam Stresses, Beam No. 71, Node No. 148

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL		22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	71	148	405.	725.	1271.	951.	0.042	-1415.	-2460.	-767.	627.	0.123	0.123	8.1
2	71	148	2092.	1137.	424.	1379.	0.052	1788.	-2366.	-2814.	2727.	0.106	0.106	9.5
3	71	148	793.	1069.	1007.	737.	0.036	-954.	-1454.	-310.	357.	0.073	0.073	13.8
4	71	148	1981.	1903.	887.	964.	0.050	1245.	-1596.	-1355.	1035.	0.073	0.073	13.7
5	71	148	1493.	-6.	-883.	617.	0.050	884.	1534.	591.	-342.	0.079	0.079	12.6
6	71	148	1742.	235.	-863.	644.	0.044	986.	1353.	335.	-112.	0.051	0.051	19.6
7	71	148	799.	-1473.	-1559.	683.	0.044	-2315.	-1806.	400.	-276.	0.093	0.093	10.8
8	71	148	486.	26.	-785.	-325.	0.021	1069.	1562.	490.	-163.	0.062	0.062	16.0
9	71	148	-1881.	781.	1315.	-1347.	0.051	-1255.	-1171.	-53.	-167.	0.050	0.051	19.6
11	71	148	395.	732.	1280.	944.	0.043	-1402.	-2455.	-770.	633.	0.123	0.123	8.1
12	71	148	2080.	1142.	434.	1372.	0.052	1795.	-2361.	-2816.	2728.	0.106	0.106	9.4
13	71	148	786.	1074.	1016.	723.	0.035	-945.	-1452.	-315.	361.	0.073	0.073	13.8
14	71	148	1968.	1906.	895.	957.	0.049	1250.	-1594.	-1357.	1937.	0.073	0.073	13.7
15	71	148	1146.	-18.	-950.	215.	0.033	315.	1237.	769.	-660.	0.062	0.062	16.2
16	71	148	1339.	118.	-926.	295.	0.034	461.	1161.	623.	-311.	0.044	0.044	22.9

TABLE X.4.8-3. Normal and Shear Beam Stresses, Beam No. 72, Node No. 155

LOAD CASE	DEAM NO	NODE NO	VALUE OF NORMAL STRESSES					RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	BOT-RGT	BOT-LFT	SBL		22-TOP	22-BOT	33-RGT	33-LFT			
			STL	STR	SER	SBL		RTOT1	V2T	V2B	V3R	V3L	RV		
1	72	155	-3713.	5346.	5532.	-3526.		0.184	2460.	1415.	-767.	627.	0.123	0.184	5.4
2	72	155	-7986.	9836.	9091.	-8781.		0.248	2548.	4603.	1273.	-1469.	0.173	0.248	4.0
3	72	155	-1813.	3389.	3708.	-1994.		0.130	1454.	954.	-310.	357.	0.073	0.130	7.7
4	72	155	-4486.	6362.	5397.	-5451.		0.159	1318.	3111.	1200.	-1191.	0.117	0.159	6.3
5	72	155	4002.	-3064.	-3483.	3583.		0.133	-1582.	-836.	539.	-340.	0.079	0.133	7.5
6	72	155	3242.	-2547.	-3222.	2567.		0.031	-1586.	-420.	909.	-646.	0.060	0.082	12.2
7	72	155	-3569.	3458.	2932.	-4095.		0.110	1808.	2315.	400.	-276.	0.093	0.110	9.1
8	72	155	3428.	-2965.	-3826.	2567.		0.102	-1562.	-1069.	490.	-168.	0.062	0.102	9.8
9	72	155	-4609.	3525.	4133.	-6000.		0.124	1171.	1255.	-53.	-167.	0.050	0.124	8.1
11	72	155	-3703.	5335.	5522.	-3516.		0.184	2455.	1402.	-773.	631.	0.123	0.184	5.4
12	72	155	-7970.	9866.	9073.	-8762.		0.247	2542.	4536.	1255.	-1462.	0.172	0.247	4.0
13	72	155	-1811.	3882.	3702.	-1990.		0.129	1452.	945.	-315.	361.	0.073	0.129	7.7
14	72	155	-4479.	6351.	5339.	-5141.		0.159	1316.	3038.	1183.	-1189.	0.116	0.159	6.3
15	72	155	2740.	-1924.	-2601.	2063.		0.091	-1237.	-315.	769.	-460.	0.062	0.091	10.9
16	72	155	2554.	-1847.	-2613.	1783.		0.064	-1304.	-165.	913.	-607.	0.049	0.066	15.2

TABLE X.4.8-4. Normal and Shear Beam Stresses, Beam No. 72, Node No. 149

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	72	149	951.	1271.	725.	405.	0.042	0.014	-2460.	-1415.	767.	-627.	0.123	0.123	8.1
2	72	149	456.	2197.	332.	-1359.	0.055	0.044	-2540.	-4503.	-1273.	1469.	0.173	0.173	5.8
3	72	149	737.	1007.	1069.	793.	0.035	0.005	-1454.	-954.	310.	-357.	0.073	0.073	13.8
4	72	149	405.	1261.	342.	-515.	0.032	0.022	-1318.	-3111.	-1200.	1191.	0.117	0.117	8.6
5	72	149	617.	-883.	-6.	1493.	0.050	0.040	1582.	835.	-559.	340.	0.079	0.079	12.6
6	72	149	334.	-932.	-239.	1026.	0.026	0.025	1586.	420.	-909.	646.	0.060	0.060	16.8
7	72	149	683.	-1539.	-1473.	799.	0.044	0.0	-1808.	-2315.	-400.	276.	0.093	0.093	10.8
8	72	149	-325.	-785.	26.	483.	0.021	0.0	1562.	1059.	-490.	168.	0.062	0.062	16.0
9	72	149	-1347.	1315.	781.	-1381.	0.051	0.0	-1171.	-1255.	53.	167.	0.050	0.051	19.6
11	72	149	944.	1280.	732.	395.	0.043	0.015	-2455.	-1402.	770.	-633.	0.123	0.123	8.1
12	72	149	447.	2206.	391.	-1363.	0.055	0.044	-2542.	-4586.	-1235.	1462.	0.172	0.172	5.8
13	72	149	728.	1016.	1074.	765.	0.036	0.005	-1452.	-945.	315.	-361.	0.073	0.073	13.8
14	72	149	395.	1270.	349.	-525.	0.032	0.022	-1316.	-3098.	-1192.	1184.	0.116	0.116	8.6
15	72	149	215.	-950.	-13.	1143.	0.033	0.035	1237.	315.	-769.	460.	0.062	0.062	16.2
16	72	149	130.	-958.	-140.	943.	0.024	0.024	1304.	165.	-913.	607.	0.049	0.049	20.4

X.4.9 Member 25Section Properties (11) unstiffened $b = 6"$, $t = 0.25"$

$$\begin{array}{llll}
 b_x = 15 \text{ in}, & t_x = 0.25 \text{ in}, & b_y = 12 \text{ in}, & t_y = 0.25 \text{ in}, \\
 A = 16.875 \text{ in}^2, & A_3 = 6 \text{ in}^2, & A_2 = 7.5 \text{ in}^2, & \\
 J = 634.5 \text{ in}^4, & \bar{r}_2 = 6.79 \text{ in}, & \bar{r}_3 = 6.79 \text{ in}, & \\
 I_2 = 590.5 \text{ in}^4, & C_{\text{top}} = 10.653 \text{ in}, & C_{\text{bottom}} = 8.097 \text{ in}, & \\
 I_3 = 685.74 \text{ in}^4, & C_{\text{left}} = 7.75 \text{ in}, & C_{\text{right}} = 7.75 \text{ in}, & \\
 L_2 = 63 \text{ in}, & K_2 = 1.5 & L_3 = 63 \text{ in}, & K_3 = 1.0
 \end{array}$$

Forces at Joint 119 (case 2)

$$\begin{array}{lll}
 R_1 = -867.2 \text{ (tension) Lbs.} & R_2 = -10450 \text{ Lbs.} & R_3 = 609.3 \text{ Lbs.} \\
 M_T = 104800 \text{ in. Lbs.} & M_2 = -24210 \text{ in. Lbs.} & M_3 = 34490 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 121 (Load Case 2)

$$\begin{array}{lll}
 R_1 = 867.2 \text{ Lbs.} & R_2 = 10450 \text{ Lbs.} & R_3 = -609.3 \text{ Lbs.} \\
 M_T = -104800 \text{ in. Lbs.} & M_2 = 17230 \text{ in. Lbs.} & M_3 = -154300 \text{ in. Lbs.}
 \end{array}$$

$$\text{unstiffened element } b/t = \frac{6}{0.25} = 24 > \frac{95}{\sqrt{F_y}} = 13.4$$

$$\frac{176}{\sqrt{F_y}} = 24.89$$

$$\frac{95}{\sqrt{F_y}} < b/t < \frac{176}{\sqrt{F_y}} \quad \text{use eqn. 3.3 to compute } Q_s$$

$$Q_s = 1.415 - .00437(24)\sqrt{50} = 0.674$$

$$f = Q_s(0.6)F_y = 0.674(0.6)(50) = 20.2 \text{ ksi}$$

$$\frac{b_x}{t_x} = \frac{15}{0.25} = 60 > 33.7$$

$$\frac{b_y}{t_y} = \frac{12}{.25} = 48 > 33.7$$

$$b_{ex} = \frac{253(.25)}{\sqrt{20.2}} \left(1 - \frac{50.3}{60\sqrt{20.2}} \right) = 11.4 < 15 \quad \text{use } b_{ex} = 11.4$$

$$b_x - b_{ex} = 3.6$$

$$b_{ey} = \frac{253(.25)}{20.2} \left(1 - \frac{50.3}{48 \cdot 20.2} \right) = 10.8 < 12 \quad \text{use } b_{ey} = 10.8''$$

$$b_y - b_{ey} = 1.2$$

$$A_{eff} = 16.875 - 3.6(0.25)(2) - 1.2(.25)(2) = 14.475$$

$$I_{2 \text{ effect.}} = 590.5 - 3.6(.25)[4.528^2 + 7.722^2] - \frac{(1.2)^3 \times .25 \times 2}{12} = 518.3 \text{ in}^4$$

$$I_{3 \text{ effect.}} = 685.74 - 1.2(.25)(2)(7.625)^2 - \frac{(3.6)^3 \times .25 \times 2}{12} = 648.9 \text{ in}^4$$

$$Q_a = \frac{14.475}{16.875} = .858$$

Tension Force, then check tension stresses for whole section.

$$F_t = F_{bx} = F_{by} = 1.33(0.6)(50) = 40 \text{ ksi}$$

$$f_t = \frac{0.867}{16.875} = 0.05 \text{ ksi}$$

$$f_{bx} = \frac{17.23 \times 10.653}{590.5} = 0.31 \text{ ksi}$$

$$f_{by} = \frac{154.3 \times 7.75}{685.74} = 1.74 \text{ ksi}$$

$$\frac{f_t}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.10 < 1.0 \quad \text{O.K.}$$

Compression stresses (ignore tension stress) use effective section properties.

$$F_{bx} = F_{by} = 40 \text{ ksi}$$

$$f_{bx} = \frac{17.23 \times 10.653}{518.3} = 0.36 \text{ ksi}$$

$$f_{by} = \frac{154.3 \times 7.75}{648.9} = 1.85 \text{ ksi}$$

$$\frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.055 < 1.0 \quad \text{O.K.}$$

$$f_{vx} = \frac{.6093}{6} = 0.01 \text{ ksi}$$

$$f_{vy} = \frac{10.45}{7.5} = 1.39 \text{ ksi}$$

$$f_{Tx} = \frac{104.8 \times 6.79}{634.5} = 1.12 \text{ ksi}$$

$$f_{Ty} = \frac{104.8 \times 6.79}{634.5} = 1.12 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 1.22 < 26.6 \text{ O.K.}$$

$$f_{vy} + f_{Ty} = 2.51 < 26.6 \text{ ksi O.K.}$$

$$\frac{d}{t} = 75 < 247 \quad \text{and} \quad \frac{h}{t} = \frac{12.0}{.25} = 48 < 260 \text{ O.K.}$$

$$\frac{a}{h} = \frac{19.0}{12.0} = 1.583$$

The results of the computerized calculations described in appendix H are given in the succeeding pages. Beams No. 25 and 26 are identical.

TABLE X.4.9-1. Normal and Shear Beam Stresses, Beam No. 25, Node No. 119

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW		MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L				
1	25	119	263.	68.	-152.	61.	0.009	0.007	-242.	-241.	-2.	-3.	0.012	0.012	0.012	82.8
2	25	119	98.	878.	109.	-739.	0.022	0.020	-2863.	-620.	1203.	-1040.	0.108	0.108	0.108	9.3
3	25	119	252.	156.	-119.	-17.	0.008	0.006	-167.	-167.	-10.	-10.	0.008	0.008	0.008	119.0
4	25	119	193.	791.	30.	-631.	0.020	0.017	-2008.	-387.	874.	-746.	0.075	0.075	0.075	13.2
5	25	119	71.	95.	-16.	-41.	0.003	0.002	13.	13.	-14.	-14.	0.001	0.001	0.003	315.9
6	25	119	70.	187.	-12.	-136.	0.005	0.004	-222.	6.	115.	-113.	0.008	0.008	0.008	119.9
7	25	119	310.	-430.	-317.	408.	0.011	0.012	3203.	3203.	-2.	-3.	0.128	0.128	0.128	7.8
8	25	119	-67.	-32.	33.	-2.	0.002	0.0	-428.	-429.	-14.	-14.	0.017	0.017	0.017	53.3
9	25	119	51.	-274.	-123.	202.	0.007	0.0	293.	294.	14.	14.	0.012	0.012	0.012	85.2
11	25	119	263.	68.	-152.	61.	0.009	0.007	-248.	-236.	4.	-9.	0.012	0.012	0.012	80.5
12	25	119	98.	877.	109.	-738.	0.022	0.020	-2859.	-621.	1201.	-1038.	0.107	0.107	0.107	9.3
13	25	119	252.	155.	-118.	-17.	0.008	0.006	-167.	-167.	-10.	-10.	0.008	0.008	0.008	119.2
14	25	119	193.	789.	29.	-630.	0.020	0.017	-2004.	-387.	873.	-745.	0.075	0.075	0.075	13.3
15	25	119	27.	43.	-1.	-19.	0.001	0.001	19.	54.	3.	-32.	0.003	0.003	0.003	373.3
16	25	119	36.	105.	-4.	-77.	0.003	0.002	-97.	29.	58.	-68.	0.004	0.004	0.004	274.4

TABLE X.4.9-2. Normal and Shear Beam Stresses, Beam No. 25, Node No. 121

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	25	121	79.	259.	50.	-148.	0.009	0.007	242.	241.	2.	3.	0.012	0.012	82.8
2	25	121	-1437.	2106.	1559.	-2061.	0.053	0.053	2853.	620.	-1203.	1040.	0.108	0.108	9.3
3	25	121	139.	302.	17.	-168.	0.010	0.008	167.	167.	10.	10.	0.008	0.010	99.4
4	25	121	-861.	1622.	1036.	-1528.	0.041	0.040	2008.	337.	-874.	746.	0.075	0.075	13.2
5	25	121	103.	108.	-45.	-50.	0.004	0.002	-13.	-13.	14.	14.	0.001	0.004	279.0
6	25	121	-9.	269.	81.	-223.	0.007	0.005	222.	-6.	-115.	113.	0.003	0.008	119.9
7	25	121	2804.	-3057.	-2952.	2896.	0.077	0.032	-3203.	-3203.	2.	3.	0.123	0.128	7.8
8	25	121	-394.	345.	366.	-373.	0.011	0.0	428.	429.	14.	14.	0.017	0.017	58.3
9	25	121	267.	-540.	-345.	462.	0.015	0.0	-293.	-294.	-14.	-14.	0.012	0.015	67.0
11	25	121	78.	260.	51.	-143.	0.009	0.007	248.	235.	-4.	9.	0.012	0.012	80.5
12	25	121	-1435.	2103.	1557.	-2058.	0.053	0.053	2859.	621.	-1201.	1038.	0.107	0.107	9.3
13	25	121	138.	301.	17.	-168.	0.010	0.008	171.	163.	6.	15.	0.009	0.010	99.5
14	25	121	-859.	1619.	1034.	-1526.	0.041	0.040	2004.	337.	-873.	745.	0.075	0.075	13.3
15	25	121	77.	37.	-51.	-8.	0.003	0.002	-19.	-54.	-3.	32.	0.003	0.003	373.3
16	25	121	18.	140.	20.	-112.	0.004	0.003	97.	-29.	-58.	68.	0.004	0.004	274.4

TABLE X.4.9-3. Normal and Shear Beam Stresses, Beam No. 26, Node No. 120

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES			RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1 RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	26	120	79.	259.	50.	-143.	0.009 0.007	241.	242.	3.	2.	0.012	0.012	82.8
2	26	120	913.	-1014.	-872.	1037.	0.026 0.027	-1777.	466.	1203.	-1035.	0.067	0.067	15.0
3	26	120	139.	302.	17.	-168.	0.010 0.003	167.	167.	10.	10.	0.003	0.010	99.4
4	26	120	679.	-610.	-596.	691.	0.017 0.017	-1252.	359.	875.	-725.	0.047	0.047	21.2
5	26	120	103.	108.	-45.	-50.	0.004 0.002	-13.	-13.	14.	14.	0.001	0.004	279.0
6	26	120	150.	-38.	-111.	86.	0.004 0.003	-209.	19.	144.	-84.	0.003	0.008	127.3
7	26	120	2804.	-3057.	-2952.	2896.	0.077 0.032	-3203.	-3203.	3.	2.	0.128	0.128	7.8
8	26	120	-394.	345.	366.	-373.	0.011 0.0	429.	423.	14.	14.	0.017	0.017	58.3
9	26	120	267.	-540.	-345.	462.	0.015 0.0	-294.	-293.	-14.	-14.	0.012	0.015	67.0
11	26	120	78.	260.	51.	-143.	0.009 0.007	236.	248.	9.	-4.	0.012	0.012	80.5
12	26	120	911.	-1012.	-870.	1035.	0.026 0.037	-1773.	466.	1206.	-1033.	0.067	0.067	15.0
13	26	120	138.	301.	17.	-168.	0.010 0.003	163.	171.	15.	6.	0.009	0.010	99.5
14	26	120	677.	-608.	-595.	639.	0.017 0.017	-1249.	363.	894.	-724.	0.047	0.047	21.3
15	26	120	77.	37.	-51.	-8.	0.003 0.002	-36.	-36.	14.	14.	0.002	0.003	383.8
16	26	120	105.	-31.	-84.	59.	0.003 0.002	-140.	-14.	87.	-40.	0.005	0.005	189.3

TABLE X.4.9-4. Normal and Shear Beam Stresses, Beam No. 26, Node No. 118

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES					RATIO NORMAL OVER ALLOWABLE			VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	BOT-RGT	BOT-LFT	SBL	RTOT1	RTOT2		22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	26	118	263.	68.	-152.	61.		0.009	0.007		-241.	-242.	-3.	-2.	0.012	0.012	82.8
2	26	118	269.	-628.	-218.	630.		0.016	0.017		1777.	-466.	-1208.	1035.	0.067	0.067	15.0
3	26	118	252.	155.	-119.	-17.		0.008	0.006		-167.	-167.	-10.	-10.	0.008	0.008	119.0
4	26	118	204.	-397.	-119.	447.		0.011	0.011		1252.	-369.	-895.	725.	0.047	0.047	21.2
5	26	118	71.	95.	-16.	-41.		0.003	0.002		13.	13.	-14.	-14.	0.001	0.003	315.9
6	26	118	30.	-12.	7.	47.		0.001	0.001		209.	-19.	-144.	84.	0.008	0.008	127.3
7	26	118	310.	-430.	-317.	408.		0.011	0.012		3203.	3203.	-3.	-2.	0.128	0.128	7.8
8	26	118	-67.	-32.	33.	-2.		0.002	0.0		-429.	-428.	-14.	-14.	0.017	0.017	58.3
9	26	118	51.	-274.	-123.	202.		0.007	0.0		294.	293.	14.	14.	0.012	0.012	85.2
11	26	118	263.	68.	-152.	61.		0.009	0.007		-236.	-248.	-9.	4.	0.012	0.012	80.5
12	26	118	269.	-627.	-217.	629.		0.016	0.017		1773.	-466.	-1206.	1033.	0.067	0.067	15.0
13	26	118	252.	155.	-118.	-17.		0.008	0.006		-163.	-171.	-15.	-6.	0.009	0.009	116.9
14	26	118	203.	-396.	-119.	447.		0.011	0.011		1249.	-368.	-894.	724.	0.047	0.047	21.3
15	26	118	27.	43.	-1.	-19.		0.001	0.001		36.	36.	-14.	-14.	0.002	0.002	548.9
16	26	118	9.	-9.	11.	27.		0.001	0.001		140.	14.	-87.	40.	0.005	0.005	189.4

X.4.10 Member 552 (cross beam No.4)Section Properties (22)Unstiffened $b = 3"$, $t = 0.25"$

$$\begin{aligned}
 b_x &= 15 \text{ in}, & t_x &= 0.25 \text{ in}, & b_y &= 12.25 \text{ in}, & t_y &= 0.25 \text{ in} \\
 A &= 15.5 \text{ in}^2, & A_3 &= 6.13 \text{ in}^2, & A_2 &= 7.5 \text{ in}^2, \\
 J &= 654.7 \text{ in}^4, & \bar{r}_2 &= 6.87 \text{ in}, & \bar{r}_3 &= 6.87 \text{ in}, \\
 I_2 &= 470.99 \text{ in}^4, & C_{\text{top}} &= 8.665 \text{ in}, & C_{\text{bottom}} &= 7.335 \text{ in}, \\
 I_3 &= 605.79 \text{ in}^4, & C_{\text{left}} &= 7.75 \text{ in}, & C_{\text{right}} &= 7.75 \text{ in},
 \end{aligned}$$

Forces at Joint 500 (case 1)

$$\begin{aligned}
 R_1 &= -325 \text{ (tension)} & R_2 &= -22040 \text{ Lbs.} & R_3 &= 17.64 \text{ Lbs.} \\
 M_T &= 0 \text{ in. Lbs.} & M_2 &= -35450 \text{ in. Lbs.} & M_3 &= -228800 \text{ in. Lbs.}
 \end{aligned}$$

Forces at Joint 152 (Load Case 1)

$$\begin{aligned}
 R_1 &= 325 \text{ Lbs.} & R_2 &= 22040 \text{ Lbs.} & R_3 &= -17.64 \text{ Lbs.} \\
 M_T &= 0 \text{ in. Lbs.} & M_2 &= 35280 \text{ in. Lbs.} & M_3 &= 13230 \text{ in. Lbs.}
 \end{aligned}$$

$$\text{unstiffened element } b/t = 3/0.25 = 12 < 95/\sqrt{F_y} = 13.4$$

$$Q_s = 1.0$$

$$f = 0.6(50) = 30 \text{ ksi}$$

$$\frac{b_x}{t_x} = \frac{15}{.25} = 60 > 33.7$$

$$\frac{b_y}{t_y} = \frac{12.25}{.25} = 50 > 33.7$$

$$b_{\text{ex}} = \frac{253(.25)}{\sqrt{30}} \left(1 - \frac{50.3}{60\sqrt{30}} \right) = 0.78"$$

$$b_x - b_{\text{ex}} = 5.22"$$

$$b_{\text{ey}} = \frac{253(.25)}{\sqrt{30}} \left(1 - \frac{50.3}{50\sqrt{30}} \right) = 9.43$$

$$b_y - b_{\text{ey}} = 2.82"$$

$$A_{\text{eff}} = 15.5 - 5.22(.25)(2) - 2.82(.25)(2) = 11.48 \text{ in}^2$$

$$I_{22} \text{ effect} = 470.99 - 5.22(.25)(\overline{7.085^2} + \overline{7.21^2}) - \frac{\overline{2.82^3} \times .25 \times 2}{12}$$

$$= 336.71 \text{ in}^4$$

$$I_{33} \text{ effect} = 605.79 - (2.82)(.25)(2)(7.5)^2 - \frac{\overline{5.22^3} \times .25 \times 2}{12}$$

$$= 520.55 \text{ in}^4$$

$$Q_a = \frac{11.48}{15.5} = 0.74$$

Tension Force, then check tension stresses for the whole section.

$$F_t = F_{bx} = F_{by} = 0.6(50) = 30 \text{ ksi}$$

$$f_t = \frac{325}{15.5} = .02 \text{ ksi}$$

$$f_{bx} = \frac{35.45 \times 8.665}{470.99} = 0.65 \text{ ksi}$$

$$f_{by} = \frac{228.8 \times 7.75}{605.79} = 2.93 \text{ ksi}$$

$$\frac{f_t}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.139 < 1.0$$

Stress is very small, no need to check compression side.

Case 2 is governing for shear; (increase allowable stresses by 1.33)

$$M_T = 238.3 \text{ k.in} \quad R_2 = 23.68 \text{ k} \quad R_3 = 2.449 \text{ k}$$

$$f_{vx} = \frac{2.449}{6.13} = 0.4 \text{ ksi}$$

$$f_{vy} = \frac{23.68}{7.5} = 3.16 \text{ ksi}$$

$$f_{Tx} = \frac{238.3 \times 6.87}{654.7} = 2.5 \text{ ksi}$$

$$f_{Ty} = \frac{238.3 \times 6.87}{654.7} = 2.50 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 2.9 \text{ ksi} < 26.6$$

$$f_{vy} + f_{Ty} = 5.66 < 26.6 \quad \text{O.K.}$$

$$\frac{d}{t} = 50 < 247$$

$$\frac{h}{t} = \frac{12.25}{.25} = 49 < 260 \quad \text{O.K.}$$

$$\frac{a}{h} = \frac{20}{12.25} = 1.633$$

The results of the computerized calculations, program AISCBM of appendix H are given in the following pages. Beams No. 552 and 553 are identical.

TABLE X.4.10-1. Normal and Shear Beam Stresses, Beam No. 552, Node No. 500

LOAD CASE	DEAM NO	NODE NO	VALUE OF NORMAL STRESSES					RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES					RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L					
1	552	500	3600.	-2576.	-4121.	2396.	0.120	0.133	-2939.	-2939.	3.	3.	0.147	0.147	6.8		
2	552	500	2468.	-3250.	-2261.	2771.	0.069	0.082	-657.	-5653.	-2900.	2101.	0.213	0.213	4.7		
3	552	500	2958.	-2063.	-3081.	1941.	0.104	0.0	-1953.	-1953.	12.	12.	0.093	0.104	9.6		
4	552	500	1936.	-2602.	-2176.	2363.	0.065	0.0	-420.	-4064.	-1431.	2104.	0.151	0.151	6.6		
5	552	500	-1115.	199.	701.	-613.	0.040	0.0	877.	877.	17.	17.	0.044	0.044	22.8		
6	552	500	-1079.	-300.	621.	-159.	0.029	0.0	933.	353.	-213.	367.	0.035	0.035	28.5		
7	552	500	1516.	-2452.	-1645.	2323.	0.056	0.0	-1125.	-1125.	3.	3.	0.045	0.056	15.2		
8	552	500	-2171.	727.	1713.	-1125.	0.030	0.0	1401.	1401.	16.	16.	0.056	0.060	16.7		
9	552	500	393.	80.	-104.	254.	0.010	0.007	-116.	-116.	-16.	-16.	0.005	0.010	95.5		
11	552	500	3598.	-2556.	-4107.	2381.	0.120	0.133	-2931.	-2931.	3.	3.	0.147	0.147	6.8		
12	552	500	2458.	-3229.	-2848.	2754.	0.069	0.081	-651.	-5645.	-2099.	2896.	0.212	0.212	4.7		
13	552	500	2946.	-2046.	-3067.	1925.	0.104	0.0	-1959.	-1952.	6	18.	0.093	0.104	9.7		
14	552	500	1927.	-2585.	-2164.	2347.	0.066	0.0	-415.	-3993.	-1473.	2100.	0.150	0.150	6.7		
15	552	500	-769.	-609.	293.	133.	0.023	0.0	557.	557.	17.	17.	0.028	0.028	35.3		
16	552	500	-799.	-754.	310.	265.	0.022	0.0	635.	316.	-109.	210.	0.024	0.024	41.9		

TABLE X.4.10-2. Normal and Shear Beam Stresses, Beam No. 552, Node No. 152

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	BOT-RGT	BOT-LFT		22-TOP	22-BOT	33-RGT	33-LFT			
			STL	STR	SBR	SBL	RTOT1	V2T	V2B	V3R	V3L	RV		
1	552	152	839.	500.	-883.	-486.	0.028	2939.	2939.	-3.	-3.	0.147	0.147	6.8
2	552	152	-1169.	-339.	835.	180.	0.022	657.	5653.	2101.	-2900.	0.213	0.213	4.7
3	552	152	791.	70.	-916.	-195.	0.032	1953.	1953.	-12.	-12.	0.098	0.098	10.2
4	552	152	-940.	-609.	632.	302.	0.025	420.	4004.	1431.	-2104.	0.151	0.151	6.6
5	552	152	-173.	-789.	-244.	372.	0.029	-877.	-877.	-17.	-17.	0.044	0.044	22.8
6	552	152	-480.	-1117.	5.	642.	0.030	-933.	-353.	213.	-367.	0.035	0.035	23.5
7	552	152	273.	-1218.	-404.	1023.	0.033	1125.	1125.	-3.	-3.	0.045	0.045	22.2
8	552	152	-652.	-839.	190.	377.	0.024	-1401.	-1401.	-16.	-16.	0.056	0.056	17.8
9	552	152	302.	207.	35.	130.	0.003	116.	116.	16.	16.	0.005	0.008	124.2
11	552	152	836.	509.	-878.	-494.	0.028	2931.	2931.	7.	-3.	0.147	0.147	6.8
12	552	152	-1168.	-328.	839.	172.	0.022	651.	5645.	7.	-2896.	0.212	0.212	4.7
13	552	152	787.	79.	-910.	-202.	0.032	1939.	1952.	-6.	-18.	0.098	0.098	10.2
14	552	152	-940.	-598.	635.	293.	0.025	415.	3993.	1478.	-2100.	0.150	0.150	6.7
15	512	152	-179.	-1245.	-300.	766.	0.044	-549.	-566.	-25.	-8.	0.028	0.044	22.6
16	552	152	-348.	-1349.	-152.	849.	0.036	-635.	-316.	109.	-210.	0.024	0.036	27.9

TABLE X.4.10-3. Normal and Shear Beam Stresses, Beam No. 553, Node No. 153

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SDR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	553	153	839.	500.	-883.	-486.	0.028	0.030	2939.	2939.	-3.	-3.	0.147	0.147	6.8
2	553	153	2627.	1217.	-2870.	-1216.	0.066	0.072	5150.	149.	-2107.	2894.	0.194	0.194	5.2
3	553	153	791.	70.	-916.	-195.	0.032	0.0	1953.	1953.	-12.	-12.	0.098	0.098	10.2
4	553	153	2508.	800.	-2442.	-735.	0.062	0.0	3415.	-170.	-1505.	2050.	0.128	0.128	7.8
5	553	153	-173.	-789.	-244.	372.	0.029	0.0	-877.	-877.	-17.	-17.	0.044	0.044	22.2
6	553	153	138.	-754.	-538.	354.	0.021	0.0	-620.	-1201.	-246.	334.	0.045	0.045	22.2
7	553	153	273.	-1218.	-404.	1038.	0.033	0.0	1125.	1125.	-3.	-3.	0.045	0.045	22.2
8	553	153	-652.	-839.	190.	377.	0.024	0.0	-1401.	-1401.	-16.	-16.	0.056	0.056	17.8
9	553	153	302.	207.	35.	130.	0.008	0.004	116.	116.	16.	16.	0.005	0.005	124.2
11	553	153	836.	509.	-878.	-494.	0.023	0.030	2931.	2931.	-3.	-3.	0.147	0.147	6.8
12	553	153	2618.	1222.	-2859.	-1221.	0.066	0.072	5136.	141.	-2105.	2890.	0.193	0.193	5.2
13	553	153	787.	79.	-910.	-202.	0.032	0.0	1952.	1959.	-18.	-6.	0.098	0.098	10.2
14	553	153	2500.	808.	-2433.	-741.	0.062	0.0	3405.	-173.	-1502.	2076.	0.128	0.128	7.8
15	553	153	845.	-221.	-1167.	-101.	0.042	0.0	-566.	-549.	-8.	-25.	0.023	0.042	24.0
16	553	153	-5.	-1138.	-453.	680.	0.031	0.0	-478.	-797.	-142.	177.	0.030	0.031	32.7

TABLE X.4.10-4. Normal and Shear Beam Stresses, Beam No. 553, Node No. 501

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL		22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	553	501	3600.	-2576.	-4121.	2396.	0.120	-2939.	-2939.	3.	3.	0.147	0.147	6.8
2	553	501	4677.	-1839.	-5313.	1973.	0.117	-5150.	-149.	2107.	-2894.	0.194	0.194	5.2
3	553	501	2958.	-2063.	-3081.	1941.	0.104	-1953.	-1953.	12.	12.	0.098	0.104	9.6
4	553	501	3887.	-1393.	-3884.	1396.	0.093	-1641.	-1605.	-270.	-306.	0.062	0.098	10.2
5	553	501	-1115.	199.	701.	-613.	0.040	877.	877.	17.	17.	0.044	0.044	22.8
6	553	501	-926.	186.	517.	-595.	0.025	620.	1201.	246.	-334.	0.045	0.045	22.2
7	553	501	1516.	-2452.	-1645.	2323.	0.066	-1125.	-1125.	3.	3.	0.045	0.066	15.2
8	553	501	-2171.	727.	1713.	-1185.	0.060	1401.	1401.	16.	16.	0.056	0.060	16.7
9	553	501	393.	80.	-104.	254.	0.010	-116.	-116.	-16.	-16.	0.005	0.010	95.5
11	553	501	3588.	-2556.	-4107.	2331.	0.120	-2931.	-2931.	3.	3.	0.147	0.147	6.8
12	553	501	4661.	-1820.	-5293.	1957.	0.117	-5136.	-141.	2105.	-2890.	0.193	0.193	5.2
13	553	501	2946.	-2046.	-3067.	1925.	0.104	-1952.	-1939.	18.	6.	0.098	0.104	9.7
14	553	501	3871.	-1375.	-3867.	1350.	0.093	-3404.	174.	1502.	-2076.	0.128	0.128	7.8
15	553	501	-609.	-769.	133.	293.	0.028	549.	549.	8.	25.	0.028	0.028	35.3
16	553	501	-731.	-462.	270.	0.	0.020	478.	797.	142.	-177.	0.030	0.030	33.4

X.4.11 Member 76Section Properties (24)

$$\begin{aligned}
 b_x &= 5.5 \text{ in}, & t_x &= 0.5 \text{ in}, & b_y &= 11.5 \text{ in}, & t_y &= 0.5 \text{ in}, \\
 A &= 26.25 \text{ in}^2, & A_3 &= 17.25 \text{ in}^2, & A_2 &= 8.25 \text{ in}^2, \\
 J &= 512.4 \text{ in}^4, & \bar{r}_2 &= 3.71 \text{ in}, & \bar{r}_3 &= 4.95 \text{ in}, \\
 I_2 &= 1623.2 \text{ in}^4, & C_{\text{top}} &= 12 \text{ in}, & C_{\text{bottom}} &= 12 \text{ in}, \\
 I_3 &= 176.3 \text{ in}^4, & C_{\text{left}} &= 3.125 \text{ in}, & C_{\text{right}} &= 3.125 \text{ in},
 \end{aligned}$$

Forces at Joint 165 (case 2)

$$\begin{aligned}
 R_1 &= -10760 \text{ (tension) Lbs.} & R_2 &= 25200 \text{ Lbs.} & R_3 &= -1753 \text{ Lbs.} \\
 M_T &= 87980 \text{ in. Lbs.} & M_2 &= 13010 \text{ in. Lbs.} & M_3 &= 1135000 \text{ in. Lbs.}
 \end{aligned}$$

Forces at Joint 157

$$\begin{aligned}
 R_1 &= 10760 \text{ Lbs.} & R_2 &= -25200 \text{ Lbs.} & R_3 &= 1753 \text{ Lbs.} \\
 M_T &= -87980 \text{ in. Lbs.} & M_2 &= 29050 \text{ in. Lbs.} & M_3 &= 530000 \text{ in. Lbs.}
 \end{aligned}$$

$$\frac{b_x}{t_x} = \frac{5.5}{0.5} = 11 < 33.7$$

$$\frac{b_y}{t_y} = \frac{11.5}{0.5} = 23 < 33.7$$

Whole section is effective

Tension Force, Then check tension stresses

$$F_t = F_{bx} = F_{by} = 1.33(.6)(50) = 40 \text{ ksi}$$

$$f_t = \frac{10.76}{26.25} = 0.41 \text{ ksi}$$

$$f_{bx} = \frac{13.01 \times 12}{1623.2} = 0.1 \text{ ksi}$$

$$f_{by} = \frac{1135 \times 3.125}{176.3} = 20.15$$

$$\frac{f_t}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.516 < 1.0 \quad \text{O.K.}$$

Stress is low, no need to check compression side

$$f_{vx} = \frac{1.753}{17.25} = 0.10 \text{ ksi}$$

$$f_{vy} = \frac{25.2}{8.25} = 3.05 \text{ ksi}$$

$$f_{Tx} = \frac{87.98 \times 3.71}{512.4} = 0.64 \text{ ksi}$$

$$f_{Ty} = \frac{87.98 \times 4.95}{512.4} = 0.85 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 0.74 \text{ ksi} < 26.6$$

$$f_{vy} + f_{Ty} = 3.9 \text{ ksi} < 26.6 \text{ O.K.}$$

$$\frac{d}{t} = 23 < 247$$

$$\frac{h}{t} = \frac{23}{.375} = 61.3 < 260 \text{ O.K.}$$

$$\frac{a}{h} = \frac{13.0}{23} = 0.565$$

The results of the computerized calculations described in appendix H are given in the succeeding pages. Beams No. 75 and 76 are identical.

TABLE X.4.11-1. Normal and Shear Beam Stresses, Beam No. 76, Node No. 165

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SBR	BOT-LFT SBL	RTOT1	RTOT2	22-TOP VZT	22-BOT VZB	33-RGT VZR	33-LFT V3L			
1	76	165	-8379.	9524.	10071.	-7832.	0.336	0.307	1903.	1426.	-391.	245.	0.095	0.336	3.0
2	76	165	-19772.	20400.	20592.	-19530.	0.516	0.506	2418.	3592.	748.	-952.	0.139	0.516	1.9
3	76	165	-3598.	5661.	5415.	-3844.	0.189	0.158	1190.	881.	-182.	230.	0.060	0.189	5.3
4	76	165	-11378.	12661.	12112.	-11928.	0.317	0.308	1402.	2335.	661.	-651.	0.090	0.317	3.2
5	76	165	9432.	-7784.	-8300.	8416.	0.314	0.304	-1151.	-943.	267.	-9.	0.058	0.314	3.2
6	76	165	7155.	-5852.	-7051.	5957.	0.179	0.178	-1079.	-623.	441.	-168.	0.041	0.179	5.6
7	76	165	-11322.	11232.	10556.	-11997.	0.322	0.0	1674.	1866.	192.	-64.	0.075	0.322	3.1
8	76	165	7856.	-6680.	-8165.	6372.	0.218	0.0	-1141.	-1098.	195.	133.	0.046	0.218	4.6
9	76	165	-9949.	8346.	9343.	-8952.	0.267	0.0	931.	1134.	22.	-250.	0.045	0.267	3.7
11	76	165	-8345.	9486.	10037.	-7795.	0.375	0.306	1897.	1417.	-394.	247.	0.095	0.335	3.0
12	76	165	-19722.	20344.	20540.	-19526.	0.515	0.505	2410.	3678.	744.	-948.	0.138	0.515	1.9
13	76	165	-3584.	5640.	5398.	-3826.	0.183	0.158	1187.	875.	-185.	232.	0.059	0.188	5.3
14	76	165	-11350.	12626.	12082.	-11894.	0.316	0.307	1397.	2375.	656.	-648.	0.039	0.316	3.2
15	76	165	6077.	-4524.	-5871.	4730.	0.203	0.199	-803.	-514.	353.	-32.	0.040	0.203	4.9
16	76	165	5444.	-4063.	-5449.	4058.	0.137	0.0	-829.	-417.	433.	-116.	0.031	0.137	7.3

TABLE X.4.11-3. Normal and Shear Beam Stresses, Beam No. 75, Node No. 164

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SER	BOT-LFT SBL	RTOT1 RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	75	164	-7832.	10071.	9524.	-8379.	0.336 0.307	1426.	1903.	391.	-245.	0.095	0.336	3.0
2	75	164	3632.	-412.	-1316.	2978.	0.097 0.065	-850.	1331.	1536.	-1444.	0.053	0.097	10.3
3	75	164	-3644.	5415.	5661.	-3593.	0.109 0.153	831.	1190.	152.	-230.	0.050	0.109	5.3
4	75	164	-2759.	-2603.	-2757.	2691.	0.069 0.059	-649.	975.	1642.	-1125.	0.042	0.069	14.5
5	75	164	8416.	-8800.	-7784.	9432.	0.314 0.304	-943.	-1151.	-267.	9.	0.053	0.314	3.2
6	75	164	8541.	-8632.	-7633.	9555.	0.240 0.229	-939.	-1000.	-149.	-135.	0.035	0.240	4.2
7	75	164	-11997.	10556.	11232.	-11322.	0.320 0.0	1366.	1674.	-192.	64.	0.075	0.320	3.1
8	75	164	6372.	-8165.	-6630.	7856.	0.218 0.0	-1093.	-1141.	-186.	-133.	0.046	0.218	4.6
9	75	164	-8933.	9353.	8331.	-9364.	0.266 0.0	1134.	931.	-22.	250.	0.045	0.266	3.8
11	75	164	-7795.	10037.	9486.	-8345.	0.335 0.306	1417.	1537.	354.	-247.	0.055	0.335	3.0
12	75	164	3899.	-430.	-1335.	2993.	0.093 0.066	-855.	1376.	1534.	-1443.	0.053	0.093	10.2
13	75	164	-3826.	5393.	5640.	-3534.	0.183 0.153	875.	1187.	155.	-232.	0.059	0.183	5.3
14	75	164	4211.	-1243.	-1315.	4139.	0.105 0.059	-653.	973.	1044.	-1126.	0.042	0.105	9.5
15	75	164	6730.	-5371.	-4524.	6077.	0.203 0.199	-514.	-803.	-353.	32.	0.040	0.203	4.9
16	75	164	5373.	-6250.	-4946.	6677.	0.167 0.162	-606.	-770.	-271.	-52.	0.029	0.167	6.0

TABLE X.4.11-4. Normal and Shear Beam Stresses, Beam No. 75, Node No. 156

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES						RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SDR	BOT-LFT SBL	RTOT1	RTOT2		22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	75	156	-2225.	4018.	3913.	-2326.	0.134	0.106	-1426.	-1903.	-1331.	-391.	245.	0.035	0.134	7.5
2	75	156	4673.	-1478.	-2107.	4044.	0.117	0.035	850.	-1331.	-1534.	-1534.	1444.	0.053	0.117	8.5
3	75	156	-140.	1859.	1957.	-42.	0.065	0.035	-837.	-1193.	-152.	-152.	230.	0.050	0.065	15.3
4	75	156	4903.	-1383.	-2006.	4584.	0.123	0.037	649.	-975.	-1042.	-1042.	1123.	0.042	0.123	8.1
5	75	156	5142.	-4737.	-4510.	5368.	0.179	0.133	943.	1151.	267.	267.	-9.	0.053	0.179	5.6
6	75	156	5491.	-4763.	-4537.	5555.	0.142	0.131	959.	1000.	169.	169.	135.	0.023	0.142	7.0
7	75	156	-5604.	4554.	6338.	-5320.	0.151	0.0	-1355.	-1674.	192.	192.	-64.	0.075	0.151	6.6
8	75	156	2953.	-3732.	-3235.	3423.	0.109	0.0	1373.	1141.	156.	156.	133.	0.046	0.109	10.0
9	75	156	-5659.	5392.	5033.	-5988.	0.161	0.0	-1134.	-931.	22.	22.	-259.	0.045	0.161	6.2
11	75	156	-2215.	4007.	3906.	-2313.	0.134	0.105	-1417.	-1397.	-394.	-394.	247.	0.035	0.134	7.5
12	75	156	4673.	-1432.	-2110.	4015.	0.117	0.035	855.	-1376.	-1534.	-1534.	1443.	0.053	0.117	8.5
13	75	156	-140.	1857.	1954.	-43.	0.065	0.035	-875.	-1187.	-135.	-135.	232.	0.039	0.065	15.4
14	75	156	4893.	-1678.	-2002.	4574.	0.123	0.036	653.	-973.	-1074.	-1074.	1123.	0.042	0.123	8.1
15	75	156	2914.	-374.	-2709.	3250.	0.109	0.106	514.	603.	353.	353.	-52.	0.040	0.109	9.1
16	75	156	3458.	-334.	-3031.	3772.	0.095	0.039	605.	769.	271.	271.	52.	0.029	0.095	10.6

X.4.12 Member 88Section Properties (27)

$$\begin{array}{llll}
 b_x = 15 \text{ in.}, & t_x = 1/4 \text{ in.}, & b_y = 12.5 \text{ in.}, & t_y = 1/4 \text{ in.}, \\
 A = 14 \text{ in}^2, & A_3 = 6.25 \text{ in}^2, & A_2 = 7.5 \text{ in}^2, & \\
 J = 674.8 \text{ in}^4, & \bar{r}_2 = 6.94 \text{ in.}, & \bar{r}_3 = 6.94 \text{ in.}, & \\
 I_2 = 396.4 \text{ in}^4, & C_{\text{top}} = 6.5 \text{ in.}, & C_{\text{bottom}} = 6.5 \text{ in.}, & \\
 I_3 = 518.4 \text{ in}^4, & C_{\text{left}} = 7.75 \text{ in.}, & C_{\text{right}} = 7.75 \text{ in.}, & \\
 L_2 = 63 \text{ in.}, & K_2 = 1.0 & L_3 = 63 \text{ in.}, & K_3 = 1.0
 \end{array}$$

Forces at Joint 171 (case 1)

$$\begin{array}{llll}
 R_1 = 5211 \text{ (compression) \#} & R_2 = 27.37 \# & R_3 = -4.82 \# \\
 M_T = 0 & M_2 = 19820 \text{ in. \#} & M_3 = -253600 \text{ in. \#}
 \end{array}$$

Forces at Joint 172

$$\begin{array}{llll}
 R_1 = -5211 & R_2 = -27.37 & R_3 = 4.82 \\
 M_T = 0 & M_2 = -19750 & M_3 = 254000
 \end{array}$$

$$\frac{b_x}{t_x} = \frac{15}{.25} = 60 > 33.7$$

$$\frac{b_y}{t_y} = \frac{12.5}{.25} = 50 > 33.7$$

$$Q_s = 1.0 \quad f = 30 \text{ ksi}$$

$$b_{\text{ex}} = \frac{253(.25)}{\sqrt{30}} \left(1 - \frac{50.3}{60\sqrt{30}} \right) = 9.78 \quad b_x - b_{\text{ex}} = 5.22''$$

$$b_{\text{ey}} = \frac{253(.25)}{\sqrt{30}} \left(1 - \frac{50.3}{50\sqrt{30}} \right) = 9.43 \quad b_y - b_{\text{ey}} = 3.07''$$

$$A_{\text{eff}} = 14 - (5.22)(.25)(2) - 3.07(.25)(2) = 9.855 \text{ in}^2$$

$$I_{22 \text{ eff}} = 396.4 - 2(5.22)(.25)(6.375) - \frac{3.07^3}{12} \times .25 \times 2 = 289.1 \text{ in}^4$$

$$I_{33 \text{ eff}} = 518.4 - 3.07(.25)(2)(7.625)^2 - \frac{5.22^3}{12} \times .25 \times 2 = 423.2 \text{ in}^4$$

$$Q_a = 0.704$$

$$r_2 = 5.42 \text{ in.}$$

$$r_3 = 6.55 \text{ in.}$$

2 direction governs

$$\frac{k_2^2}{r_2^2} = \frac{63(1.0)}{5.42^2} = 11.62$$

$$C_c' = \frac{2\pi^2(29 \times 10^3)}{(.704)(50)} = 127.5$$

$$\frac{k_2^2}{r_2^2 C_c'} = 0.0912$$

$$F_a = 20.57 \text{ ksi}$$

$$f_a = \frac{5.211}{9.355} = 0.53$$

$$\frac{f_a}{F_a} = 0.026 < 0.15$$

$$F_{bx} = F_{by} = 0.6(50) = 30 \text{ ksi}$$

$$f_{bx} = \frac{19.75 \times 6.5}{289.1} = 0.45 \text{ ksi}$$

$$f_{by} = \frac{254.0 \times 7.75}{432.2} = 4.68 \text{ ksi}$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.197 > 1.0 \text{ O.K.}$$

$$\frac{d}{t} = 50 < 247 \text{ O.K.}$$

$$\frac{h}{t} = \frac{12.5}{.25} = 50 < 260 \text{ O.K.}$$

Shear is governed by case 2.

$$M_T = 160.6 \text{ k.in}$$

$$R_2 = 2.494 \text{ K}$$

$$R_3 = 5.472 \text{ K}$$

$$f_{vx} = \frac{5.472}{6.25} = 0.88 \text{ ksi}$$

$$f_{vy} = \frac{2.494}{7.5} = 0.33 \text{ ksi}$$

$$f_{Tx} = \frac{160.6 \times 6.94}{674.8} = 1.65 \text{ ksi}$$

$$f_{Ty} = \frac{160.6 \times 6.94}{674.8} = 1.65 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 2.53 \text{ ksi} < 26.6$$

$$f_{vy} + f_{Ty} = 1.98 \text{ ksi} < 26.6$$

Results of computerized calculations for identical Beams No. 88 and 89 are given in the succeeding pages.

TABLE X.4.12-1. Normal and Shear Beam Stresses, Beam No. 88, Node No. 171

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SSR	BOT-LFT SBL		22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	88	171	3826.	-5162.	-4571.	4718.	0.123 0.0	4.	4.	-1.	-1.	0.000	0.103	5.3
2	88	171	6200.	-4335.	-6945.	3340.	0.178 0.0	1319.	-1934.	-776.	2527.	0.095	0.178	5.6
3	88	171	5282.	-2423.	-5946.	2124.	0.199 0.0	3.	3.	-3.	-3.	0.000	0.199	5.0
4	88	171	7093.	-1431.	-7659.	915.	0.195 0.0	1253.	-1547.	-640.	2160.	0.031	0.195	5.1
5	88	171	3522.	194.	-4320.	-1432.	0.171 0.0	-0.	0.	-4.	-4.	0.000	0.171	5.9
6	88	171	4829.	359.	-6162.	-1522.	0.151 0.0	223.	-276.	-53.	443.	0.017	0.151	6.2
7	88	171	8359.	-4578.	-9214.	3923.	0.259 0.0	4.	4.	-1.	-1.	0.000	0.259	4.0
8	88	171	2355.	4101.	-3423.	-5134.	0.103 0.142	-1.	-1.	-4.	-4.	0.000	0.142	7.0
9	88	171	-2074.	-4951.	1839.	4766.	0.133 0.0	1.	1.	4.	4.	0.000	0.133	7.5
11	88	171	3760.	-5335.	-4623.	4632.	0.135 0.0	4.	4.	-1.	-1.	0.000	0.135	5.4
12	88	171	6130.	-4312.	-6853.	3339.	0.176 0.0	1315.	-1932.	-777.	2522.	0.095	0.176	5.7
13	88	171	5214.	-2631.	-5767.	2073.	0.197 0.0	0.	5.	-1.	-5.	0.000	0.197	5.1
14	88	171	7031.	-1429.	-7376.	874.	0.193 0.0	1250.	-1545.	-640.	2153.	0.031	0.193	5.2
15	88	171	6927.	-229.	-7530.	-744.	0.260 0.0	-29.	-29.	-4.	-5.	0.001	0.260	3.8
16	88	171	6751.	-79.	-7762.	-952.	0.201 0.0	140.	-153.	-39.	253.	0.010	0.201	5.0

TABLE X.4.12-2. Normal and Shear Beam Stresses, Beam No. 88, Node No. 172

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOWED RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SER	BOT-LFT SBL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	88	172	3335.	-5468.	-4580.	4723.	0.123	0.0	-4.	-4.	1.	1.	0.000	0.123	5.3
2	88	172	3339.	-5468.	-4583.	4723.	0.141	0.0	-1319.	1934.	776.	-2527.	0.685	0.141	7.1
3	88	172	5394.	-2637.	-5853.	2123.	0.200	0.0	-3.	-3.	3.	3.	0.000	0.200	5.0
4	88	172	5316.	-2694.	-5832.	2123.	0.151	0.0	-1253.	1547.	640.	-2160.	0.631	0.151	6.6
5	88	172	3331.	193.	-4829.	-1491.	0.171	0.0	0.	-0.	4.	4.	0.000	0.171	5.8
6	88	172	4911.	34.	-5704.	-1247.	0.150	0.0	-223.	276.	53.	-446.	0.017	0.150	6.7
7	88	172	8565.	-4834.	-9220.	3829.	0.250	0.0	-4.	-4.	1.	1.	0.000	0.250	4.0
8	88	172	-4277.	10624.	4127.	-13155.	0.283	0.355	1.	1.	4.	4.	0.000	0.355	2.8
9	88	172	-2032.	-4351.	1397.	6776.	0.133	0.0	-1.	-1.	4.	-4.	0.000	0.133	7.5
11	88	172	3769.	-5391.	-4492.	4668.	0.135	0.0	-4.	-4.	1.	1.	0.000	0.135	5.4
12	88	172	3774.	-5390.	-4497.	4667.	0.139	0.0	-1313.	1932.	777.	-2522.	0.095	0.139	7.2
13	88	172	5226.	-2631.	-5779.	2077.	0.197	0.0	-0.	-5.	1.	5.	0.000	0.197	5.1
14	88	172	5245.	-2636.	-5802.	2030.	0.149	0.0	1553.	-1259.	-2164.	643.	0.031	0.149	6.7
15	88	172	6535.	-230.	-7559.	-753.	0.260	0.0	23.	23.	4.	5.	0.001	0.260	3.3
16	88	172	6527.	-278.	-7553.	-753.	0.195	0.0	-140.	153.	39.	-253.	0.010	0.195	5.1

TABLE X.4.12-3. Normal and Shear Beam Stresses, Beam No. 89, Node No. 170

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	BOT-RGT	BOT-LFT	RTOT1	RTOT2	22-TOP	22-BOT	33-RGT	33-LFT			
			STL	STR	SDR	SBL			V2T	V2B	V3R	V3L			
1	89	170	3826.	-5462.	-4571.	4718.	0.183	0.0	4.	4.	-1.	-1.	0.000	0.133	5.3
2	89	170	1459.	-6540.	-2204.	5795.	0.163	0.0	-1312.	1982.	775.	-2529.	0.095	0.133	5.9
3	89	170	5232.	-2623.	-5346.	2124.	0.199	0.0	3.	3.	-3.	-3.	0.000	0.199	5.0
4	89	170	3517.	-3910.	-4033.	3345.	0.106	0.0	-1248.	1552.	633.	-2166.	0.031	0.103	9.5
5	89	170	3522.	134.	-4820.	-1482.	0.171	0.0	0.	-6.	-4.	-4.	0.000	0.171	5.9
6	89	170	4039.	-319.	-5252.	-894.	0.139	0.0	-223.	276.	45.	-455.	0.017	0.139	7.2
7	89	170	8559.	-4578.	-9214.	3923.	0.250	0.0	4.	4.	-1.	-1.	0.000	0.250	4.0
8	89	170	2655.	4101.	-3423.	-5194.	0.109	0.142	-1.	-1.	-4.	-4.	0.000	0.142	7.0
9	89	170	-2074.	-4951.	1389.	4766.	0.133	0.0	1.	1.	4.	4.	0.000	0.133	7.5
11	89	170	3760.	-5335.	-4433.	4462.	0.135	0.0	4.	4.	-1.	-1.	0.000	0.135	5.4
12	89	170	1403.	-6457.	-2126.	5734.	0.166	0.0	-1310.	1989.	776.	-2524.	0.095	0.146	6.0
13	89	170	5214.	-2631.	-5737.	2073.	0.197	0.0	5.	0.	-6.	-1.	0.000	0.197	5.1
14	89	170	3447.	-3352.	-4003.	3297.	0.104	0.0	-1245.	1550.	633.	-2162.	0.031	0.104	9.7
15	89	170	6527.	-239.	-7560.	-714.	0.280	0.0	29.	23.	-5.	-4.	0.001	0.280	3.3
16	89	170	6285.	-495.	-7315.	-537.	0.159	0.0	-1456.	1469.	1343.	-1579.	0.059	0.159	5.3

TABLE X.4.12-4. Normal and Shear Beam Stresses, Beam No. 89, Node No. 172

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES						RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	EOT-RGT SER	BOI-LFT SEL	BOI-LFT SEL	RTOT1	RTOT2	22-TOP V2T	22-EOT V2B	33-RGT V3R	33-LFT V3L			
1	89	172	3835.	-5468.	-4530.	4723.	4723.	0.183	0.0	-4.	-4.	1.	1.	0.000	0.183	5.3
2	89	172	3537.	-5483.	-4533.	4723.	4723.	0.141	0.0	1312.	-1992.	-775.	2529.	0.035	0.141	7.1
3	89	172	5294.	-2687.	-5258.	2123.	2123.	0.200	0.0	-3.	-3.	3.	3.	0.000	0.200	5.0
4	89	172	5316.	-2694.	-5332.	2123.	2123.	0.151	0.0	1243.	-1552.	-633.	2166.	0.031	0.151	6.6
5	89	172	3531.	193.	-4829.	-1491.	-1491.	0.171	0.0	-32.	-32.	4.	4.	0.002	0.171	5.8
6	89	172	4491.	34.	-5704.	-1247.	-1247.	0.150	0.0	223.	-276.	-45.	455.	0.017	0.150	6.7
7	89	172	8565.	-4534.	-9220.	3929.	3929.	0.250	0.0	-4.	-4.	8.	8.	0.000	0.250	4.0
8	89	172	2661.	4109.	-3431.	-5204.	-5204.	0.110	0.142	1.	1.	4.	4.	0.000	0.142	7.0
9	89	172	-1897.	-4776.	1418.	3743.	3743.	0.100	0.130	-1.	-1.	-4.	-4.	0.000	0.130	7.7
11	89	172	3769.	-5391.	-4492.	4663.	4663.	0.135	0.0	-4.	-4.	1.	1.	0.000	0.135	5.4
12	89	172	3774.	-5390.	-4497.	4667.	4667.	0.139	0.0	1310.	-1989.	-776.	2524.	0.035	0.139	7.2
13	89	172	5225.	-2331.	-5779.	2077.	2077.	0.197	0.0	-5.	-0.	6.	1.	0.000	0.197	5.1
14	89	172	5247.	-2635.	-5302.	2080.	2080.	0.149	0.0	1245.	-1550.	-633.	2162.	0.031	0.149	6.7
15	89	172	6536.	-250.	-7539.	-753.	-753.	0.230	0.0	-29.	-23.	5.	4.	0.001	0.230	3.8
16	89	172	6527.	-278.	-7553.	-753.	-753.	0.195	0.0	140.	-153.	-30.	262.	0.010	0.195	5.1

X.4.13 Member 34Section Properties (7)

$$\begin{array}{lll}
 b_x = 5.5 \text{ in}, & t_x = 1/2 \text{ in}, & b_y = 11 \text{ in}, \quad t_y = 3/8 \text{ in}, \\
 A = 15.25 \text{ in}^2, & A_3 = 8.25 \text{ in}^2, & A_2 = 5.5 \text{ in}, \\
 J = 215.2 \text{ in}^4, & \bar{r}_2 = 3.188 \text{ in}, & \bar{r}_3 = 4.25 \text{ in}, \\
 I_2 = 314.77 \text{ in}^4, & C_{\text{top}} = 6 \text{ in}, & C_{\text{bottom}} = 6 \text{ in}, \\
 I_3 = 99.87 \text{ in}^4, & C_{\text{left}} = 3.5 \text{ in}, & C_{\text{right}} = 3.5 \text{ in}, \\
 L_2 = 242 \text{ in}, & K_2 = 2.0 & L_3 = 49 \text{ in}, \quad K_2 = 1.0
 \end{array}$$

Forces at Joint 125 (case 2)

$$\begin{array}{lll}
 R_1 = -1100 \text{ (comp) Lbs.} & R_2 = 4306 \text{ Lbs.} & R_3 = 428 \text{ Lbs.} \\
 M_T = 53380 \text{ in. Lbs.} & M_2 = 24570 \text{ in. Lbs.} & M_3 = 80300 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 112

$$\begin{array}{lll}
 R_1 = -1100 \text{ Lbs.} & R_2 = -4306 \text{ Lbs.} & R_3 = -428 \text{ Lbs.} \\
 M_T = 53380 \text{ in. Lbs.} & M_2 = 3595 \text{ in. Lbs.} & M_3 = 130700 \text{ in. Lbs.}
 \end{array}$$

Total section effect. (see member 11)

$$\begin{array}{ll}
 F_a = 13(1.33) = 17.3 \text{ ksi}, & F_{bx} = F_{by} = 40 \text{ ksi} \\
 f_a = \frac{1.1}{15.25} = 0.072 & f_a/F_a < 0.15 \\
 f_{bx} = \frac{3.595 \times 6}{314.77} = .07 \text{ ksi} & f_{by} = \frac{130.7 \times 3.5}{99.87} = 4.58 \text{ ksi} \\
 \frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.188 < 1.0 & \\
 f_{vx} = \frac{.428}{8.25} = 0.05 \text{ ksi} & f_{vy} = \frac{4.306}{5.5} = 0.78 \text{ ksi} \\
 f_{Tx} = \frac{53.38 \times 3.188}{215.2} = 0.79 \text{ ksi} & f_{Ty} = \frac{53.38 \times 4.25}{215.2} = 1.05 \text{ ksi} \\
 f_{Tx} + f_{vx} = 0.84 \text{ ksi} < 26.6 & f_{Ty} + f_{vy} = 1.83 < 26.6 \text{ O.K.}
 \end{array}$$

TABLE X.4.13-1. Normal and Shear Beam Stresses, Beam No. 34, Node No. 125

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW RV	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT	TOP-RGT	BOT-RGT	BOT-LFT		22-TOP	22-BOT	33-RGT	33-LFT			
			STL	STR	SER	SOL		V2T	V2B	V3R	V3L			
1	34	125	3064.	-1896.	-3079.	1881.	0.103 0.0	21.	-439.	-243.	437.	0.024	0.103	9.7
2	34	125	-2417.	3209.	2273.	-3354.	0.091 0.0	1574.	-8.	-1002.	1106.	0.059	0.071	11.0
3	34	125	2279.	-1013.	-2342.	951.	0.078 0.0	12.	-332.	-113.	341.	0.017	0.078	12.7
4	34	125	-1252.	2278.	1078.	-2451.	0.070 0.0	1103.	-40.	-686.	837.	0.041	0.070	14.3
5	34	125	622.	-211.	-708.	125.	0.024 0.0	8.	-6.	33.	52.	0.003	0.024	41.3
6	34	125	-237.	613.	189.	-725.	0.023 0.0	157.	33.	-49.	109.	0.006	0.023	42.9
7	34	125	6541.	-7039.	-6856.	7074.	0.139 0.0	-1995.	-1570.	275.	-290.	0.020	0.139	5.3
8	34	125	1696.	-2012.	-1781.	1927.	0.054 0.0	-254.	-390.	-87.	41.	0.016	0.054	18.6
9	34	125	6355.	-7323.	-6350.	7472.	0.199 0.198	-1293.	-1443.	-143.	53.	0.053	0.199	5.0
11	34	125	3062.	-1395.	-3077.	1390.	0.103 0.0	21.	-489.	-243.	436.	0.024	0.103	9.7
12	34	125	-2421.	3212.	2277.	-3356.	0.035 0.0	1572.	-8.	-1001.	1104.	0.059	0.035	11.8
13	34	125	2272.	-1009.	-2334.	946.	0.078 0.0	12.	-332.	-113.	340.	0.017	0.078	12.8
14	34	125	-1252.	2277.	1079.	-2450.	0.070 0.0	1101.	-40.	-635.	834.	0.041	0.070	14.4
15	34	125	-319.	443.	233.	-530.	0.023 0.0	23.	44.	23.	8.	0.002	0.023	43.2
16	34	125	-523.	645.	425.	-743.	0.023 0.0	107.	60.	-16.	47.	0.004	0.023	42.8

TABLE X.4.13-2. Normal and Shear Beam Stresses, Beam No. 34, Node No. 112

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES					RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES					RATIO SHEAR/ALLOW		MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SER	BOT-LFT SPL	RTOT1	RTOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L	ALCN RV	ALCN				
1	34	112	109.	-435.	-124.	421.	0.015	0.0	-21.	439.	243.	-437.	0.024	0.024	40.9			
2	34	112	4575.	-4533.	-4720.	4433.	0.125	0.0	-1574.	8.	1002.	-1105.	0.059	0.125	8.0			
3	34	112	-89.	-361.	26.	299.	0.012	0.0	-12.	332.	115.	-341.	0.017	0.017	53.7			
4	34	112	3180.	-3319.	-3353.	3146.	0.092	0.0	-1103.	40.	683.	-837.	0.041	0.032	10.8			
5	34	112	-70.	-176.	-16.	92.	0.087	0.0	-8.	6.	-33.	-52.	0.003	0.007	153.0			
6	34	112	394.	-534.	-501.	427.	0.019	0.0	-157.	-33.	49.	-109.	0.065	0.019	54.0			
7	34	112	-9932.	9800.	9917.	-9814.	0.235	0.0	1935.	1570.	-275.	230.	0.030	0.265	3.8			
8	34	112	-1353.	1391.	1273.	-1475.	0.039	0.0	294.	390.	87.	-41.	0.016	0.039	25.4			
9	34	112	-5620.	5999.	5705.	-5815.	0.157	0.156	1233.	1443.	148.	-53.	0.053	0.157	6.4			
11	34	112	105.	-432.	-120.	417.	0.014	0.0	-21.	439.	243.	-433.	0.024	0.157	40.9			
12	34	112	4561.	-4539.	4705.	4424.	0.119	0.0	-1572.	8.	1001.	-1104.	0.059	0.119	8.4			
13	34	112	-91.	-353.	23.	236.	0.012	0.0	-12.	332.	113.	-340.	0.017	0.017	53.8			
14	34	112	3172.	-3311.	-3345.	3133.	0.092	0.0	-1101.	40.	-6789.	-8309.	0.312	0.312	3.2			
15	34	112	-113.	-42.	26.	-44.	0.009	0.0	-29.	-64.	-23.	-8.	0.002	0.009	103.4			
16	34	112	149.	-259.	-238.	161.	0.011	0.0	-107.	-60.	13.	-47.	0.004	0.011	89.1			

TABLE X.4.13-3. Normal and Shear Beam Stresses, Beam No. 35, Node No. 124

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES				RATIO NORMAL OVER ALLOWABLE	VALUE OF SHEAR STRESSES				RATIO SHEAR/ ALLOW RV	MAX STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SER	BOT-LFT SBL		22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	35	124	1831.	-3079.	-1896.	3064.	0.103 0.0	-489.	21.	243.	-437.	0.024	0.103	9.7
2	35	124	8452.	-9766.	-8338.	9290.	0.248 0.246	-1355.	-1952.	-614.	181.	0.073	0.248	4.0
3	35	124	951.	-2342.	-1013.	2279.	0.078 0.0	-332.	12.	118.	-341.	0.017	0.078	12.7
4	35	124	5341.	-6767.	-5293.	6315.	0.171 0.170	-889.	-1372.	-464.	165.	0.052	0.171	5.9
5	35	124	125.	-703.	-211.	622.	0.024 0.0	-6.	8.	-33.	-52.	0.003	0.024	41.3
6	35	124	154.	-617.	-219.	552.	0.019 0.0	-50.	-165.	-118.	35.	0.006	0.019	53.8
7	35	124	7074.	-6356.	-7039.	6841.	0.189 0.0	-1570.	-1935.	-275.	230.	0.030	0.139	5.3
8	35	124	1927.	-1781.	-2012.	1695.	0.054 0.0	-390.	-234.	87.	-41.	0.016	0.054	18.6
9	35	124	7472.	-6850.	-7338.	6935.	0.199 0.198	-1443.	-1293.	143.	-53.	0.053	0.199	5.0
11	35	124	1830.	-3077.	-1595.	3052.	0.103 0.0	-489.	21.	243.	-435.	0.024	0.103	9.7
12	35	124	8436.	-9748.	-8321.	9332.	0.247 0.246	-1352.	-1939.	-541.	254.	0.073	0.247	4.0
13	35	124	947.	-2335.	-1009.	2272.	0.078 0.0	-332.	12.	118.	-340.	0.017	0.078	12.8
14	35	124	5328.	-6752.	-5280.	6300.	0.170 0.170	-883.	-1369.	-463.	164.	0.051	0.170	5.9
15	35	124	-530.	233.	443.	-319.	0.023 0.0	44.	29.	-23.	-8.	0.002	0.023	43.2
16	35	124	-253.	-26.	185.	-47.	0.010 0.0	11.	-70.	-76.	32.	0.003	0.010	100.1

TABLE X.4.13-4. Normal and Shear Beam Stresses, Beam No. 35, Node No. 113

LOAD CASE	BEAM NO	NODE NO	VALUE OF NORMAL STRESSES			RATIO NORMAL OVER ALLOWABLE		VALUE OF SHEAR STRESSES				RATIO SHEAR/ALLOW	MAX RATIO STRESS OVER ALLOW	MIN. SAFETY FACTOR
			TOP-LFT STL	TOP-RGT STR	BOT-RGT SER	BOT-LFT SBL	RTOT1 RIOT2	22-TOP V2T	22-BOT V2B	33-RGT V3R	33-LFT V3L			
1	35	113	421.	-124.	-436.	109.	0.015 0.0	459.	-21.	-243.	437.	0.024	0.024	40.9
2	35	113	-6049.	6949.	6163.	-6835.	0.174 0.173	1355.	1952.	542.	-254.	0.073	0.174	5.7
3	35	113	299.	25.	-351.	-89.	0.012 0.0	332.	-12.	-113.	341.	0.017	0.017	53.7
4	35	113	-4227.	5107.	4275.	-5058.	0.123 0.127	899.	1372.	464.	-155.	0.052	0.123	7.8
5	35	113	92.	-16.	-178.	-70.	0.007 0.0	6.	-8.	33.	52.	0.003	0.007	153.0
6	35	113	-544.	719.	479.	-734.	0.023 0.0	50.	155.	113.	-35.	0.006	0.023	44.0
7	35	113	-8814.	9917.	9200.	-9932.	0.245 0.0	1570.	1925.	275.	-299.	0.030	0.265	3.8
8	35	113	-1473.	1273.	1391.	-1358.	0.039 0.0	370.	224.	-87.	41.	0.016	0.039	25.4
9	35	113	-5815.	5705.	5399.	-5620.	0.157 0.156	1443.	1293.	-143.	53.	0.053	0.157	6.4
11	35	113	416.	-119.	-431.	104.	0.014 0.0	439.	-21.	-213.	433.	0.024	0.024	40.9
12	35	113	-6046.	6945.	6160.	-6831.	0.174 0.173	1352.	1949.	541.	-254.	0.073	0.174	5.7
13	35	113	296.	23.	-353.	-89.	0.012 0.0	332.	-12.	-113.	340.	0.017	0.017	53.8
14	35	113	-4221.	5099.	4239.	-5050.	0.123 0.127	898.	1359.	463.	-164.	0.051	0.123	7.8
15	35	113	-44.	26.	-42.	-113.	0.009 0.0	-44.	-29.	23.	8.	0.002	0.009	103.4
16	35	113	-367.	424.	293.	-493.	0.016 0.0	-11.	70.	76.	-32.	0.003	0.016	62.6

X.5 Analysis of Trunnion Block

The analysis procedure is as outlined for the cradle structure in previous sections. Summary of all loads acting on the structural components of the trunnion block is given in Chapter IX, Volume II.

X.5.1 Effective Lengths

The effective length factors and the buckling lengths in the 2- and 3- directions for each member are listed below.

TABLE X.5-1. EFFECTIVE LENGTH FACTORS (TRUNNION)

Member	k_2	ℓ_2 in	k_3	ℓ_3 in
106, 107, 112, 113	1.0	6.33	2.0	6.33
122, 123, 126, 127	1.0	10.68	2.0	10.68
132, 133, 142, 143	1.0	6.78	2.0	6.78
136, 137, 138, 139	1.0	8.0	1.0	16.0
114, 115, 120, 121	1.0	8.64	2.0	16.77
128 to 131	1.0	8.13	2.0	16.77
148, 149, 152, 153	1.0	18.0	1.0	18.0
150, 151	1.0	15.59	1.0	19.23
134, 135, 140, 141	1.0	38.3	1.0	38.3
154 to 165	0.0	0.0	0.0	0.0
186 to 197	0.0	0.0	0.0	0.0
144 to 147	1.0	38.3	1.0	38.3
104 and 105	1.0	7.0	1.0	7.0

X.5.2 Members 132, 133, 136, 137, 138, 139, 142, 143Section Properties (33) $b_y = 7 - 0.75 = 6.25$ $t = 3/8"$ (use 136 case 5)

$$b_x = 5.50 \text{ in}, \quad t_x = 1/4" \text{ in}, \quad b_y = 2.50 \text{ in}, \quad t_y = 1/4" \text{ in},$$

$$A = 11.75 \text{ in}, \quad A_3 = 3.0 \text{ in}, \quad A_2 = 7.5 \text{ in},$$

$$J = 21.73 \text{ in}, \quad \bar{r}_3 = 2.385 \text{ in}, \quad \bar{r}_2 = 2.385 \text{ in},$$

$$I_2 = 102.07 \text{ in}, \quad C_{\text{top}} = 6.266 \text{ in}, \quad C_{\text{bottom}} = 3.734 \text{ in},$$

$$I_3 = 95.63 \text{ in}, \quad C_{\text{left}} = 3.375 \text{ in}, \quad C_{\text{right}} = 3.375 \text{ in},$$

$$L_3 = 16.0 \text{ in}, \quad K_3 = 1.0, \quad L_2 = 8.0, \quad K_2 = 1.0 \text{ in},$$

$$h = 6.25 \text{ in}, \quad t = 3/8" \text{ in},$$

Forces at Joint 210

$$R_1 = 3366 \text{ (comp) Lbs.} \quad R_2 = -8432 \text{ Lbs.} \quad R_3 = -2763 \text{ Lbs.}$$

$$M_T = -2061 \text{ in. Lbs.} \quad M_2 = 28920 \text{ in. Lbs.} \quad M_3 = -73180 \text{ in. Lbs.}$$

Forces at Joint 204

$$R_1 = -3366 \text{ Lbs.} \quad R_2 = 8432 \text{ Lbs.} \quad R_3 = 2763 \text{ Lbs.}$$

$$M_T = 2061 \text{ in. Lbs.} \quad M_2 = -6812 \text{ in. Lbs.} \quad M_3 = 5731 \text{ in. Lbs.}$$

$$\frac{b_x}{t_x} = \frac{5.5}{\frac{1}{4}} = 22 < 33.7$$

$$\frac{b_y}{t_y} = \frac{2.5}{\frac{1}{4}} = 10 < 33.7$$

Total section is effective

$$r_3 = 2.85" \quad r_2 = 2.95"$$

$$\frac{k_3 l_3}{r_3} = \frac{1.0(16)}{2.85} = 5.6 \text{ (governs)}$$

$$\frac{k_2 l_2}{r_2} = \frac{8}{2.95}$$

$$C_c = 107$$

$$\frac{k_3 l_3}{r_3 C_c} = \frac{5.6}{107} = 0.052$$

$$F_a = 30 \text{ ksi}$$

$$F_{bx} = F_{by} = 30 \text{ ksi}$$

$$f_a = \frac{3.366}{11.75} = 0.286 \text{ ksi}$$

$$\frac{f_a}{F_a} = .0095 < 0.15$$

$$f_{bx} = \frac{28.92}{102.07} = (6.266) = 1.775 \text{ ksi}$$

$$f_{by} = \frac{73.18}{95.63} \times 3.375 = 2.583 \text{ ksi}$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = \frac{0.286}{30} + \frac{1.775}{30} + \frac{2.583}{30} = 0.155 < 1.0 \quad \text{O.K.}$$

$$f_{vx} = \frac{2.763}{7.5} = 0.3684 \text{ ksi}$$

$$f_{vy} = \frac{8.432}{3.0} = 2.81 \text{ ksi}$$

$$f_{Tx} = \frac{2.061 \times 2.385}{21.73} = 0.226 \text{ ksi}$$

$$F_{Ty} = \frac{2.061 \times 2.385}{21.73} = 0.226 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 0.5944 \text{ ksi}$$

$$f_{vy} + f_{Ty} = 3.036 \text{ ksi}$$

$$k = 5.34 + \frac{4.0}{\left(\frac{8.0}{6.25}\right)^2} = 7.8$$

$$C_v = \frac{190}{\left(\frac{6.25}{0.375}\right)} \sqrt{\frac{7.8}{50}} = 4.5 > 0.8$$

$$F_v = \frac{50}{2.89} (4.5) > 0.4 F_y \quad \text{Use } F_v = 0.4(50) = 20 \text{ ksi}$$

Shear stresses are O.K.

$$\frac{d}{t} = \frac{5.5}{0.25} = 22 < 247$$

$$\frac{h}{t} = \frac{6.25}{.375} = 16.7 < 260 \quad \text{O.K.}$$

X.5.3 Members 114, 115, 120, 121

(114 governs) Case 5

Section Properties (31)

$$\begin{aligned}
 b_x &= 5.50 \text{ in}, & t_x &= 1/4" \text{ in}, & b_y &= 2.50 \text{ in}, & t_y &= 1/4" \text{ in}, \\
 A &= 4.25 \text{ in}, & A_3 &= 2.875 \text{ in}, & A_2 &= 1.25 \text{ in}, \\
 J &= 14.71 \text{ in}, & \bar{r}_3 &= 1.86 \text{ in}, & \bar{r}_2 &= 1.86 \text{ in}, \\
 I_2 &= 6.338 \text{ in}, & C_{\text{top}} &= 1.5 \text{ in}, & C_{\text{bottom}} &= 1.5 \text{ in}, \\
 I_3 &= 19.34 \text{ in}, & C_{\text{left}} &= 3 \text{ in}, & C_{\text{right}} &= 3 \text{ in}, \\
 L_3 &= 16.77 \text{ in}, & K_3 &= 2.0 \text{ in}, & L_2 &= 8.64 \text{ in}, & K_2 &= 1.0 \text{ in}, \\
 h &= 6" \text{ in}, & t &= 1/4" \text{ in},
 \end{aligned}$$

Forces at Joint 194

$$\begin{aligned}
 R_1 &= 10680 \text{ (comp) Lbs.} & R_2 &= 1247 \text{ Lbs.} & R_3 &= -1935 \text{ Lbs.} \\
 M_T &= -2907 \text{ in. Lbs.} & M_2 &= 1864 \text{ in. Lbs.} & M_3 &= 4783 \text{ in. Lbs.}
 \end{aligned}$$

Forces at Joint 190

$$\begin{aligned}
 R_1 &= -10680 \text{ Lbs.} & R_2 &= -1247 \text{ Lbs.} & R_3 &= 1935 \text{ Lbs.} \\
 M_T &= 2907 \text{ in. Lbs.} & M_2 &= 1929 \text{ in. Lbs.} & M_3 &= 10290 \text{ in. Lbs.}
 \end{aligned}$$

$$\frac{b_x}{t_x} = 22 < 33.7$$

$$\frac{b_y}{t_y} = 10 < 33.7$$

whole section is effective

$$r_3 = 2.13" \quad r_2 = 1.22"$$

$$\frac{k_3 l_3}{r_3} = \frac{16.77 \times 2.0}{2.13} = 15.75$$

$$\frac{k_2 l_2}{r_2} = \frac{8.64}{1.22} = 7.09$$

3-direction governs

$$\frac{k_3 l_3}{r_3 C_c} = \frac{15.75}{107} = 0.147$$

$$F_a = 28.7 \text{ ksi}$$

$$F_{bx} = F_{by} = 30 \text{ ksi}$$

$$f_a = \frac{10.68}{4.25} = 2.51 \text{ ksi}$$

$$\frac{f_a}{F_a} = 0.088 < 0.15$$

$$f_{bx} = \frac{1.929 \times 1.5}{6.338} = 0.457 \text{ ksi}$$

$$f_{by} = \frac{10.29 \times 3}{19.34} = 1.596 \text{ ksi}$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.088 + \frac{0.457}{30} + \frac{1.596}{30} = 0.156 < 1.0 \quad \text{O.K.}$$

$$f_{vx} = \frac{1.935}{1.25} = 1.548 \text{ ksi}$$

$$f_{vy} = \frac{1.247}{2.875} = 0.434$$

$$f_{Tx} = \frac{2.907 \times 1.86}{14.71} = 0.368 \text{ ksi}$$

$$f_{Ty} = \frac{2.907 \times 1.86}{14.71} = 0.368$$

$$f_{vx} + f_{Tx} = 1.916 \text{ ksi}$$

$$f_{vy} + f_{Ty} = 0.802 \text{ ksi}$$

shear stress is too small O.K.

$$\frac{d}{t} = \frac{5.5}{0.25} = 22 < 247$$

$$\frac{h}{t} = \frac{6}{.25} = 24 < 260 \quad \text{O.K.}$$

X.5.4 Members 122, 123, 126, 127

(122 Case 5)

Section Properties (31)

$$\begin{aligned}
 b_x &= 5.5 \text{ in}, & t_x &= 1/4 \text{ in}, & b_y &= 2.5 \text{ in}, & t_y &= 1/4 \text{ in}, \\
 A &= 4.25 \text{ in}, & A_3 &= 2.875 \text{ in}, & A_2 &= 1.25 \text{ in}, \\
 J &= 14.71 \text{ in}, & \bar{r}_3 &= 1.86 \text{ in}, & \bar{r}_2 &= 1.86 \text{ in}, \\
 I_2 &= 6.338 \text{ in}, & C_{\text{top}} &= 1.5 \text{ in}, & C_{\text{bottom}} &= 1.5 \text{ in}, \\
 I_3 &= 19.34 \text{ in}, & C_{\text{left}} &= 3 \text{ in}, & C_{\text{right}} &= 3 \text{ in}, \\
 L_3 &= 10.68 \text{ in}, & K_3 &= 2.0 & L_2 &= 10.68 \text{ in}, & K_2 &= 1.0 \text{ in}, \\
 h &= 6 \text{ in}, & t &= 1/4 \text{ in},
 \end{aligned}$$

Forces at Joint 188

$$\begin{aligned}
 R_1 &= 3617 \text{ Lbs.} & R_2 &= -2616 \text{ Lbs.} & R_3 &= -2613 \text{ Lbs.} \\
 M_T &= 7184 \text{ in. Lbs.} & M_2 &= 24420 \text{ in. Lbs.} & M_3 &= -14960 \text{ in. Lbs.}
 \end{aligned}$$

Forces at Joint 194

$$\begin{aligned}
 R_1 &= -3617 \text{ Lbs.} & R_2 &= 2616 \text{ Lbs.} & R_3 &= 2613 \text{ Lbs.} \\
 M_T &= -7184 \text{ in. Lbs.} & M_2 &= 3487 \text{ Lbs.} & M_3 &= -12980 \text{ in. Lbs.}
 \end{aligned}$$

Whole section is effective

$$r_3 = 2.13" \quad r_2 = 1.22"$$

$$\frac{k_{33}}{r_3} = \frac{10.68 \times 2.0}{2.13} = 10$$

$$\frac{k_{22}}{r_2} = \frac{10.68}{1.22} = 8.75$$

3-direction governs

$$F_a = 29.26 \text{ ksi}$$

$$f_a = \frac{3.617}{4.25} = 0.85$$

$$\frac{f_a}{F_a} = 0.029 < 0.15$$

$$F_{bx} = F_{by} = 30 \text{ ksi}$$

$$f_{bx} = \frac{24.42 \times 1.5}{6.338} = 5.78 \text{ ksi}$$

$$f_{by} = \frac{14.96 \times 3}{19.34} = 2.32 \text{ ksi}$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.299 < 1.0 \text{ O.K.}$$

$$f_{vx} = \frac{2.613}{1.25} = 2.09 \text{ ksi}$$

$$f_{vy} = \frac{2.616}{2.875} = 0.91 \text{ ksi}$$

$$f_{Tx} = \frac{7.184 \times 1.86}{14.71} = 0.91 \text{ ksi}$$

$$f_{Ty} = \frac{7.184 \times 1.86}{14.71} = 0.91 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 3.00 \text{ ksi}$$

$$f_{vy} + f_{Ty} = 1.82 \text{ ksi}$$

low shear stress 0.K.

X.5.5 Member 128, 129, 130, 131

(use 130 Case 1)

Section Properties (31)

$$\begin{array}{llll}
 b_x = 5.5 \text{ in,} & t_x = 1/4 \text{ in,} & b_y = 2.5 \text{ in,} & t_y = 1/4 \text{ in,} \\
 A = 4.25 \text{ in,} & A_3 = 2.875 \text{ in,} & A_2 = 1.25 \text{ in,} & \\
 J = 14.71 \text{ in,} & \bar{r}_3 = 1.86 \text{ in,} & \bar{r}_2 = 1.86 \text{ in,} & \\
 I_2 = 6.338 \text{ in,} & C_{\text{top}} = 1.5 \text{ in,} & C_{\text{bottom}} = 1.5 \text{ in,} & \\
 I_3 = 19.34 \text{ in,} & C_{\text{left}} = 3.0 \text{ in,} & C_{\text{right}} = 3.0 \text{ in,} & \\
 L_3 = 16.77 \text{ in,} & K_3 = 2.0 \text{ in,} & L_2 = 8.13 \text{ in,} & K_2 = 1.0 \text{ in,} \\
 h = 6 \text{ in,} & t = 1/4 \text{ in,} & &
 \end{array}$$

Forces at Joint 218

$$\begin{array}{lll}
 R_1 = 10000 \text{ Lbs.} & R_2 = -3225 \text{ Lbs.} & R_3 = -1527 \text{ Lbs.} \\
 M_1 = +0538 \text{ in. Lbs.} & M_2 = +7298 \text{ in. Lbs.} & M_3 = -1308 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 200

$$\begin{array}{lll}
 R_1 = -10000 \text{ Lbs.} & R_2 = 3225 \text{ Lbs.} & R_3 = -1527 \text{ Lbs.} \\
 M_1 = -0538 \text{ in. Lbs.} & M_2 = -19710 \text{ in. Lbs.} & M_3 = -13130 \text{ in. Lbs.}
 \end{array}$$

$$\text{whole section is effective} \quad r_3 = 2.13" \quad r_2 = 1.22"$$

$$\frac{k_{33}}{r_3} = \frac{16.77 \times 2.0}{2.13} = 15.75 \quad \text{governs}$$

$$F_a = 28.7 \text{ ksi}$$

$$F_{bx} = F_{by} = 30 \text{ ksi}$$

$$f_a = \frac{10.0}{4.25} = 2.35 \text{ ksi}$$

$$\frac{f_a}{F_a} = 0.082$$

$$f_{bx} = \frac{19.71 \times 1.5}{6.338} = 4.66 \text{ ksi}$$

$$f_{by} = \frac{13.13 \times 3.0}{19.34} = 2.04 \text{ ksi}$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.305 < 1.0 \quad \text{O.K.}$$

$$f_{vx} = \frac{1.527}{1.25} = 1.22 \text{ ksi}$$

$$f_{Tx} = \frac{0.538 \times 1.86}{14.71} = 0.07 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 1.29 \text{ ksi}$$

low shear stress, O.K.

$$f_{vy} = \frac{3.225}{2.875} = 1.12 \text{ ksi}$$

$$f_{Ty} = \frac{0.538 \times 1.86}{14.71} = 0.07 \text{ ksi}$$

$$f_{vy} + f_{Ty} = 1.19 \text{ ksi}$$

X.5.6 Members 148, 149, 152, 153 (148 Case 5)

Section Properties (31)

$$\begin{array}{lll}
 b_x = 5.5 \text{ in,} & t_x = 1/4 \text{ in,} & b_y = 2.5 \text{ in, } t_y = 1/4 \text{ in,} \\
 A = 4.25 \text{ in,} & A_3 = 2.875 \text{ in,} & A_2 = 1.25 \text{ in,} \\
 J = 14.71 \text{ in,} & \bar{r}_3 = 1.86 \text{ in,} & \bar{r}_2 = 1.86 \text{ in,} \\
 I_2 = 6.338 \text{ in,} & C_{\text{top}} = 1.5 \text{ in,} & C_{\text{bottom}} = 1.5 \text{ in,} \\
 I_3 = 19.34 \text{ in,} & C_{\text{left}} = 3 \text{ in,} & C_{\text{right}} = 3 \text{ in,} \\
 L_3 = 18.0 \text{ in,} & K_3 = 1.0 & L_2 = 18.0 \quad K_2 = 1.0 \text{ in,} \\
 h = 6 \text{ in,} & t = 1/4 \text{ in,} &
 \end{array}$$

Forces at Joint 220

$$\begin{array}{lll}
 R_1 = 22040 \text{ Lbs.} & R_2 = 1793 \text{ Lbs.} & R_3 = 2301 \text{ Lbs.} \\
 M_T = 0144 \text{ in. Lbs.} & M_2 = -15340 \text{ in. Lbs.} & M_3 = 15310 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 202

$$\begin{array}{lll}
 R_1 = -22040 \text{ Lbs.} & R_2 = -1793 \text{ Lbs.} & R_3 = -2301 \text{ Lbs.} \\
 M_T = -0144 \text{ in. Lbs.} & M_2 = -26200 \text{ in. Lbs.} & M_3 = 17070 \text{ in. Lbs.}
 \end{array}$$

$$\text{whole section is effective} \quad r_3 = 2.13 \quad r_2 = 1.22$$

$$\frac{k_3^{\ell_3}}{r_3} = \frac{18 \times 1.0}{2.13} = 8.45$$

$$\frac{k_2^{\ell_2}}{r_2} = \frac{18}{1.22} = 14.75$$

2-direction governs

$$F_a = 28.80 \text{ ksi}$$

$$F_{bx} = F_{by} = 30 \text{ ksi}$$

$$f_a = \frac{22.04}{4.25} = 5.18$$

$$\frac{f_a}{F_a} = 0.18 > 0.15$$

$C_{mx} = C_{my} = 0.85$ (no transverse load, and end-joint translation is not prevented)

$$F_{ex}' = \frac{12\pi^2 E}{23 \left(\frac{k_2^{\ell_2}}{r_2} \right)^2} = 686.4$$

$$F_{ey}' = \frac{12\pi^2 E}{23 \left(\frac{k_3^{\ell_3}}{r_3} \right)^2} = 2091$$

$$f_{bx} = \frac{26.2 \times 1.5}{6.338} = 6.2 \text{ ksi}$$

$$f_{by} = \frac{17.07 \times 3}{19.34} = 2.65 \text{ ksi}$$

Equation (6.1a) condition is between two ends

$$\frac{f_a}{F_a} + \frac{C_{mx} f_{bx}}{\left(1 - \frac{f_a}{F_{ex}}\right) F_{bx}} + \frac{C_{my} f_{by}}{\left(1 - \frac{f_a}{F_{ey}}\right) F_{by}} \leq 1.0$$

$$\frac{5.18}{28.8} + \frac{0.85(6.2)}{\left[1 - \frac{5.18}{686.4}\right]30} + \frac{0.85(2.65)}{\left[1 - \frac{5.18}{2091}\right]30} = 0.432 < 1.0 \quad \text{O.K.}$$

Check Equation (6.1b) condition at the ends

$$\frac{f_a}{0.6 F_y} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0$$

$$\frac{5.18}{30} + \frac{6.2}{30} + \frac{2.65}{30} = 0.468 < 1.0 \quad \text{O.K.}$$

Normal stresses are O.K.

$$f_{vx} = \frac{2.301}{1.25} = 1.84 \text{ ksi}$$

$$f_{vy} = \frac{1.793}{2.875} = 0.62 \text{ ksi}$$

$$f_{Tx} = \frac{0.144 \times 1.86}{14.71} = 0.02 \text{ ksi}$$

$$f_{Ty} = \frac{0.144 \times 1.86}{14.71} = 0.02 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 1.86 \text{ ksi}$$

$$f_{vy} + f_{Ty} = 0.64 \text{ ksi}$$

low shear stress, O.K.

X.5.7 Members 150, 151

(case 5)

Section Properties (31)

$$\begin{array}{llll}
 b_x = 5.5 \text{ in,} & t_x = 1/4 \text{ in,} & b_y = 2.5 \text{ in,} & t_y = 1/4 \text{ in} \\
 A = 4.25 \text{ in,} & A_3 = 2.875 \text{ in,} & A_2 = 1.25 \text{ in,} & \\
 J = 14.71 \text{ in,} & \bar{r}_3 = 1.86 \text{ in,} & \bar{r}_2 = 1.86 \text{ in,} & \\
 I_2 = 6.338 \text{ in,} & C_{\text{top}} = 1.5 \text{ in,} & C_{\text{bottom}} = 1.5 \text{ in,} & \\
 I_3 = 19.34 \text{ in,} & C_{\text{left}} = 3 \text{ in,} & C_{\text{right}} = 3 \text{ in,} & \\
 L_3 = 19.23 \text{ in,} & K_3 = 1.0 & L_2 = 15.59 \text{ in,} & K_2 = 1.0 \text{ in} \\
 h = 6 \text{ in,} & t = 1/4 \text{ in,} & &
 \end{array}$$

Forces at Joint 226

$$\begin{array}{lll}
 R_1 = 16430 \text{ Lbs.} & R_2 = -1872 \text{ Lbs.} & R_3 = -3310 \text{ Lbs.} \\
 M_T = -0835 \text{ in. Lbs.} & M_2 = 17420 \text{ in. Lbs.} & M_3 = -13850 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 210

$$\begin{array}{lll}
 R_1 = -16430 \text{ Lbs.} & R_2 = -1872 \text{ Lbs.} & R_3 = 3310 \text{ Lbs.} \\
 M_T = 0835 \text{ in. Lbs.} & M_2 = 34200 \text{ in. Lbs.} & M_3 = -15350 \text{ in. Lbs.}
 \end{array}$$

whole section is effective

$$r_3 = 2.13$$

$$r_2 = 1.22$$

$$\frac{k_3 l_3}{r_3} = \frac{19.23 \times 1.0}{2.13} = 9.65$$

$$\frac{k_2 l_2}{r_2} = \frac{15.59 \times 1.0}{1.22} = 12.78$$

2-direction governs

$$F_a = 29.0 \text{ ksi}$$

$$f_a = \frac{16.43}{4.25} = 3.87$$

$$\frac{f_a}{F_a} = 0.133 < 0.15$$

$$F_{bx} = F_{by} = 30 \text{ ksi}$$

$$f_{bx} = \frac{34.2 \times 1.5}{6.338} = 8.10 \text{ ksi}$$

$$f_{by} = \frac{15.35 \times 3}{19.34} = 2.38 \text{ ksi}$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.482 < 1.0 \quad \text{O.K.}$$

$$f_{vx} = \frac{3.31}{1.25} = 2.65 \text{ ksi}$$

$$f_{Tx} = \frac{.835 \times 1.86}{14.71} = .11 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 2.76 \text{ ksi}$$

low shear stress, O.K.

$$f_{vy} = \frac{1.872}{2.875} = .65 \text{ ksi}$$

$$f_{Ty} = \frac{.835 \times 1.86}{14.71} = .11 \text{ ksi}$$

$$f_{vy} + f_{Ty} = 0.76 \text{ ksi}$$

X.5.8 Members 134, 135, 140, 141 (135 Case 2)Section Properties (72)

$$\begin{array}{llll}
 b_x = 3.625 \text{ in.} & t_x = 3/8 \text{ in.} & b_y = 3.625 \text{ in.} & t_y = 3/8 \text{ in.} \\
 A = 5.4375 \text{ in.} & A_3 = 2.4375 \text{ in.} & A_2 = 2.4375 \text{ in.} & \\
 J = 17.86 \text{ in.} & \bar{r}_3 = 1.81 \text{ in.} & \bar{r}_2 = 1.81 \text{ in.} & \\
 I_2 = 12.04 \text{ in.} & C_{\text{top}} = 2 \text{ in.} & C_{\text{bottom}} = 2 \text{ in.} & \\
 I_3 = 12.04 \text{ in.} & C_{\text{left}} = 2 \text{ in.} & C_{\text{right}} = 2 \text{ in.} & \\
 L_3 = 38.3 & K_3 = 1.0 & L_2 = 38.3 & \\
 h = 4" & t = 3/8" & & K_2 = 1.0 \text{ in.}
 \end{array}$$

Forces at Joint 213

$$\begin{array}{lll}
 R_1 = 6557 \text{ Lbs.} & R_2 = 0 \text{ Lbs.} & R_3 = 1011 \text{ Lbs.} \\
 M_T = -0825 \text{ in. Lbs.} & M_2 = -5887 \text{ in. Lbs.} & M_3 = -0122 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 211

$$\begin{array}{lll}
 R_1 = -6557 \text{ Lbs.} & R_2 = 0 \text{ Lbs.} & R_3 = -1011 \text{ Lbs.} \\
 M_T = 0825 \text{ in. Lbs.} & M_2 = -13130 \text{ in. Lbs.} & M_3 = 0 \text{ in. Lbs.}
 \end{array}$$

Accidental condition, allowable stresses are increased by 33%

$$\frac{b_x}{t_x} = \frac{b_y}{t_y} = \frac{3.625}{.375} = 9.67 < 33.7$$

∴ whole section is effective

$$r_3 = r_2 = 1.49"$$

$$\frac{k_3 l_3}{r_3} = \frac{k_2 l_2}{r_2} = \frac{38.3 \times 1.0}{1.49} = 25.7$$

$$F_a = 27.63 \times 1.33 = 36.75 \text{ ksi}$$

$$F_{bx} = F_{by} = 40 \text{ ksi}$$

$$f_a = \frac{6.557}{5.4375} = 1.21$$

$$\frac{f_a}{F_a} = 0.033 < 0.15$$

$$f_{bx} = \frac{13.13 \times 2}{12.04} = 2.18 \text{ ksi} \qquad f_{by} = 0$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.088 < 1.0 \quad \text{O.K.}$$

By inspection, it is obvious that shear stresses are low.

X.5.9 Member 144, 145, 146, 147 (145 case 2)Section Properties (34)

$$\begin{array}{lll}
 b_x = 3.625 \text{ in,} & t_x = 3/8 \text{ in,} & b_y = 3.625 \text{ in, } t_y = 3/8 \text{ in.} \\
 A = 5.4375 \text{ in,} & A_3 = 2.4375 \text{ in,} & A_2 = 2.4375 \text{ in,} \\
 J = 17.86 \text{ in,} & \bar{r}_3 = 1.81 \text{ in,} & \bar{r}_2 = 1.81 \text{ in,} \\
 I_2 = 12.04 \text{ in,} & C_{\text{top}} = 2 \text{ in,} & C_{\text{bottom}} = 2 \text{ in,} \\
 I_3 = 12.04 \text{ in,} & C_{\text{left}} = 2 \text{ in,} & C_{\text{right}} = 2 \text{ in,} \\
 L_3 = 38.3 \text{ in,} & K_3 = 1.0 & L_2 = 38.3 \quad K_2 = 1.0 \text{ in.} \\
 h = 4 \text{ in,} & t = 3/8 \text{ in,} &
 \end{array}$$

Forces at Joint 215

$$\begin{array}{lll}
 R_1 = 6578 \text{ Lbs.} & R_2 = 0 \text{ Lbs.} & R_3 = 1011 \text{ Lbs.} \\
 M_T = -0826 \text{ in. Lbs.} & M_2 = 2105 \text{ in. Lbs.} & M_3 = 0 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint

$$\begin{array}{lll}
 R_1 = -6578 \text{ Lbs.} & R_2 = 0 \text{ Lbs.} & R_3 = 1011 \text{ Lbs.} \\
 M_T = 0826 \text{ in. Lbs.} & M_2 = 5887 \text{ in. Lbs.} & M_3 = 0122 \text{ in. Lbs.}
 \end{array}$$

$$F_a = 36.75 \text{ ksi} \quad F_{bx} = F_{by} = 40 \text{ ksi (see computations for member 135)}$$

$$f_a = 1.21 \text{ ksi} \quad \frac{f_a}{F_a} = 0.033 < 0.15$$

$$f_{bx} = \frac{21.05 \times 2}{12.04} = 3.5 \text{ ksi} \quad f_{by} = 0$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.121 < 1.0 \quad \text{O.K.}$$

By inspection, shear stresses are low.

X.5.10 Members 106, 107, 112, 113 (107 governs) case 6Sections Properties (35)

$$\begin{array}{llll}
 b_x = 6.0 \text{ in,} & t_x = 3/8" \text{ in,} & b_y = 4.25 \text{ in,} & t_y = 3/8 \text{ in} \\
 A = 6.0 \text{ in,} & A_3 = 2.25 \text{ in,} & A_2 = 3.18 \text{ in,} & \\
 J = 0.281 \text{ in,} & \bar{r}_3 = 0.375 \text{ in,} & \bar{r}_2 = 0.375 \text{ in,} & \\
 I_2 = 12.91 \text{ in,} & C_{\text{top}} = 1.425 \text{ in,} & C_{\text{bottom}} = 3.2 \text{ in,} & \\
 I_3 = 45.61 \text{ in,} & C_{\text{left}} = 3.75 \text{ in,} & C_{\text{right}} = 3.75 \text{ in,} & \\
 L_3 = 6.33 \text{ in,} & K_3 = 2.0 & L_2 = 6.33 & K_2 = 1.0 \text{ in} \\
 h = 6.75 \text{ in,} & t = 3/8 \text{ in,} & &
 \end{array}$$

Forces at Joint 185

$$\begin{array}{lll}
 R_1 = 6553 \text{ Lbs.} & R_2 = -8505 \text{ Lbs.} & R_3 = -1860 \text{ Lbs.} \\
 M_T = -01556 \text{ in. Lbs.} & M_2 = 10020 \text{ in. Lbs.} & M_3 = 44030 \text{ in. Lbs.}
 \end{array}$$

Forces at Joint 189

$$\begin{array}{lll}
 R_1 = -6553 \text{ Lbs.} & R_2 = 8505 \text{ Lbs.} & R_3 = -1860 \text{ Lbs.} \\
 M_T = 01556 \text{ in. Lbs.} & M_2 = 1757 \text{ in. Lbs.} & M_3 = -9806 \text{ in. Lbs.}
 \end{array}$$

Accidental loading, therefore increase allowable stresses by 33%

$$\frac{b_x}{t_x} = \frac{6}{.375} = 16 < 33.7$$

$$\frac{b_y}{t_y} = \frac{4.25}{.375} = 11.3 < 33.7$$

whole section is effective

$$r_3 = 2.76 \quad r_2 = 1.47$$

$$\frac{k_{33}}{r_3} = \frac{6.33 \times 2}{2.76} = 4.59$$

$$\frac{k_{22}}{r_2} = \frac{6.33 \times 1.0}{1.47} = 4.31$$

3-direction governs

$$F_a = 29.70 \times 1.33 = 39.5 \text{ ksi}$$

$$f_a = \frac{6.553}{6} = 1.09 \text{ ksi}$$

$$\frac{f_a}{F_a} = 0.028 < 0.15$$

$$F_{bx} = F_{by} = 40 \text{ ksi}$$

$$f_{bx} = \frac{10.02 \times 3.2}{12.91} = 2.48 \text{ ksi}$$

$$f_{by} = \frac{44.03 \times 3.75}{45.61} = 3.62 \text{ ksi}$$

$$\frac{f_a}{F_a} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} = 0.180 < 1.0 \quad \text{O.K.}$$

$$f_{vx} = \frac{1.86}{3.18} = 0.58 \text{ ksi}$$

$$f_{vy} = \frac{8.505}{2.25} = 3.78 \text{ ksi}$$

$$f_{Tx} = \frac{0.1556 \times 0.375}{0.281} = 0.21 \text{ ksi}$$

$$f_{Ty} = \frac{0.1556 \times 0.375}{0.281} = 0.21 \text{ ksi}$$

$$f_{vx} + f_{Tx} = 0.79 \text{ ksi}$$

$$f_{vy} + f_{Ty} = 3.99 \text{ ksi}$$

low shear stress, O.K.

$$\frac{d}{t} = 16 < 247$$

$$\frac{h}{t} = \frac{6.75}{0.375} = 18 < 260 \quad \text{O.K.}$$

Chapter XI

Cradle Structure Weld Analysis

XI.1 Introduction

In this chapter, all welds in the cradle structure are analyzed and the maximum stresses are checked to ensure that the welds satisfy the AISC design requirements. The welds in the cradle are classified into two types, namely, joint welds and local welds. The joint welds are defined as the welds connecting two members and the local welds are welds that connect components of a built-up section (see Figure XI.1-1)

Fig. XI.1-1 Local and Connecting Welds

Computer programs were developed, to check the two types of welds, on the basis of the approaches outlined below. In this chapter, some sample cases are worked out by hand computation for the analysis of either type of weld in order to illustrate the adopted approach. These sample computations will also serve as verification of the computer output.

XI.2 Connecting Welds

The acting forces are member end forces at the connection and the weld section is responsible for transmitting such forces from the connected member, such as a secondary member, to the main member. The section properties of the joint weld are computed, then the stress components S_x , S_y and S_z in the x , y and z directions respectively, are obtained using the conventional strength of material approach. It should be pointed out that the weld properties are computed using the weld size, which is done for convenience. Therefore, all stresses must be multiplied by $\sqrt{2}$ to convert them into stresses at the throat of the weld. This is taken care of later, in the computation of the factor of safety. The resultant stress $S_{\max}$ is obtained as follows

$$S_{\max} = \sqrt{S_x^2 + S_y^2 + S_z^2} \quad \text{XI.1}$$

The allowable weld stress S_{all} is 40% of the yield stress for the normal condition. This allowable stress shall be increased by 25% and 33% for the travelling and accidental loading conditions, respectively. Finally the factor of safety is computed according to the following

$$\text{Factor of Safety} = \frac{S_{all}}{\sqrt{2} S_{\max}} \quad \text{XI.2}$$

It should be noted that the factor of safety, as defined above, is only a measure of the margin between allowable stresses and actual max applied stresses. Thus, the minimum value for the factor of safety that satisfies the requirements for a safe design according to the AISC specification, is unity.

The shear stresses transferred through an interior weld due to flexural shear force, is dependent on the orientation of the weld and the direction of the applied shear. Therefore, the approach can be best illustrated using a typical example for an interior weld as shown in Figure IX3.1-1

FIG. XI.3.1-2. Shear Transferred by Force in Direction 2.

In Figure XI.3.1-2 the shear flow at Joint A is detailed in which f_{A2}^R , f_{A2}^L and f_{A2}^T are the shear flow to the right, left, and top of joint A. Equilibrium at joint A yields.

$$f_{A2}^T = f_{A2}^L - f_{A2}^R \quad \text{XI.5}$$

f_{A2}^T is the force carried by the weld. Now f_{A2}^R and f_{A2}^L can be routinely obtained from section A-A and B-B in Figure XI.3.1-1.

$$f_{A2}^R = \frac{F_2 \cdot Q_3^A}{2 I_{33}} \quad , \quad f_{A2}^L = \frac{F_2 \cdot Q_3^B}{2 I_{33}} \quad \text{XI.6,7}$$

in which Q_3^A and Q_3^B are the first moment of area to the right of sections A-A and B-B about 3-3 axis, respectively. I_{33} is the moment of inertia of the section about 3-3 axis. Therefore, from equations (5, 6 and 7), the force on the weld due to F_2 is

$$V_2 = f_{A2}^T = \frac{F_2 \cdot Q_3}{2 I_{33}} \quad \text{XI.8}$$

where Q_3 is the first moment of area of the connected plate "a", see Fig. XI.3.1-1 about the 3-3 direction.

Figure XI.3.1-3. Shear Transferred by Force in Direction 3.

Again, similar to the previous case, the shear force transferred through the interior weld at joint A is the same as the shear force on plate "a" which is $f_{A_3}^a$. The total shear flow at section C-C Fig. XI.3.1-1 is

$$f_3^C = 2(f_{A_3}^a + f_{B_3}^b) = \frac{F_3 \cdot Q_2^C}{I_{22}} \quad \text{XI.9}$$

in which $f_{A_3}^a$ and $f_{B_3}^b$ are the shear forces in plates "a" and "b", respectively, due to the force F_3 . Q_2^C is the first moment of area below section C-C about 2-2 axis. f_3^C is divided among $f_{A_3}^a$ and $f_{B_3}^b$ according to the ratio of t_a and t_b . Therefore the force in the interior weld due to F_3 is

$$V_3 = f_{A_3}^a = \frac{1}{2} f_3^C \left(\frac{t_a}{t_a + t_b} \right) = \frac{F_3 Q_2^C}{2 I_{22}} \left(\frac{t_a}{t_a + t_b} \right) \quad \text{XI.10}$$

iii Shear transferred due to torsion

As before, the force transferred through the weld due to torsion, V_T , is equal to the force in the connected plate "a" which is the difference between

XI.4.2 Resultant Straining Actions on Welds

The resultant forces and moments acting at the center of the section must be transferred to the center of the welds using routine static transformation. These transferred forces and moments at the center of the weld constitute the effective straining actions applied to the connecting welds.

XI.4.3 Beam No. 3 and 4

Figure XI.4.3-1 Welds in Beams 3 and 4.

Weld Section Properties

$$\text{Weld Areas: } A_{w2} = 2 \times 3 \times 0.25 + 3 \times 3 \times .25 = 3.75 \text{ in}^2$$

$$A_{w3} = 2 \times 10 \times 0.25 = 5.0 \text{ in}^2$$

$$\text{Center of weld: } \bar{y} = \frac{\sum A_y}{\sum A} = \frac{1.5 \times 6 - 2.25 \times 6}{(3.75 + 5.0)} = -0.514''$$

$$\text{Eccentricity from C.G. of Beam, } E_y = -0.514''$$

Moment of Inertia:

$$I_{22} = (2 \times 3 \times 6.514^2 + 2 \times \frac{10^3}{12} + 2 \times 10 \times 0.514^2 + 3 \times 3 \times 5.486^2)0.25$$

$$= 174.35 \text{ in}^4$$

$$I_{33} = (2 \times 10 \times 6.5^2 + 2 \times 3 \times 4^2 + 5 \times \frac{3^3}{12} + 2 \times 3 \times 5^2)0.25$$

$$= 275.56 \text{ in}^4$$

$$\text{Polar } J = I_{22} + I_{33} = 449.91 \text{ in}^4$$

Sample Weld Section Forces & Moments: Beam No. 3, Node 105, Case No. 2

$$P_1 = -(-318)\# \quad WT_1 = 31990 + 900 \times (-.514) = 31527$$

$$F_2 = 900 \quad WM_2 = -(-9320) - [318 \times (-.514)] = 9483 \text{ in.}\#$$

$$F_3 = 343 \quad WM_3 = -(20150)$$

The calculations that follow show how the stresses are determined in each of the beam corners and the least factor of safety evaluated. The procedure is the basis of the computer program described in appendix H, the results of which are given in the succeeding tables.

	S _{UL2}	S _{UL3}	S _{UR2}	S _{UR3}	S _{DR2}	S _{DR3}	S _{DL2}	S _{DL3}
$S_{P_x} = \frac{P_1}{Aw_2 + Aw_3} = \frac{318}{3.75 + 5.0} = 36$	+	+	+	+	+	+	+	+
$S_{F_y} = \frac{F_2}{Aw_2} = \frac{900}{3.75} = 240$	+		+		+		+	
$S_{F_z} = \frac{F_3}{Aw_3} = \frac{343}{5.0} = 69$		+		+		+		+
$S_{TULY} = -\frac{WT_1 \times D_u}{J} = -\frac{31527 \times 6.514}{449.91} = -456$	-	-						
$S_{TULZ} = -\frac{WT_1 \times D_L}{J} = -\frac{31527 \times 6.5}{449.91} = -455$	-	-						
$S_{TURY} = -\frac{WT_1 \times D_u}{J} = -456$			-	-				
$S_{TURZ} = \frac{WT_1 \times D_r}{J} = 455$			+	+				
$S_{TDRY} = \frac{WT_1 \times D_d}{J} = \frac{31527 \times 5.486}{449.91} = 384$					+	+		
$S_{TDRZ} = \frac{WT_1 \times D_r}{J} = 455$					+	+		
$S_{TDLY} = \frac{WT_1 \times D_d}{J} = 384$							+	+

$$S_{TDLZ} = -\frac{WT_1 \times D_u}{J} = -455$$

$$S_{M2UX} = \frac{WM_2 \times D_u}{I_2} = \frac{9483 \times 6.514}{174.35} = 354$$

$$S_{M2DX} = -\frac{WM_2 \times D_d}{I_2} = -\frac{(9483) \times 5.486}{174.35} = -298$$

$$S_{M3LX} = \frac{WM_3 \times D_L}{I_3} = \frac{-20150 \times 6.5}{275.56} = -475$$

$$S_{M3RX} = -\frac{WM_3 \times D_r}{I_3} = -\frac{(-20150) \times 6.5}{275.56} = 475$$

$$S_{MAX} = \sqrt{(\sum S_x)^2 + (\sum S_y)^2 + (\sum S_z)^2}$$

Allowable Shear Stress for Faulted Condition

$$= 1.33 \times 0.4 \times 50,000$$

$$= 26,600 \text{ psi}$$

$$S.F. = \frac{26,600}{\sqrt{2} S_{MAX}}$$

S_{UL2}	S_{UL3}	S_{UR2}	S_{UR3}	S_{DR2}	S_{DR3}	S_{DL2}	S_{DL3}
						-	-
+	+	+	+				
				-	-	-	-
-	-					-	-
		+	+	+	+		
511	603	1001	1109	801	684	1068	916
			17.0				

TABLE XI.4.3-1. Connecting Weld Stresses Beam No. 3, Node No. 105

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	3	105	83.	33.	85.	26.	79.	18.	77.	12.	161.6
2	3	105	511.	604.	1002.	1110.	862.	634.	1069.	917.	16.9
3	3	105	68.	42.	63.	32.	54.	22.	52.	19.	203.9
4	3	105	378.	445.	751.	825.	577.	495.	733.	637.	22.8
5	3	105	30.	29.	31.	23.	19.	17.	20.	22.	450.0
6	3	105	62.	77.	93.	100.	78.	63.	103.	100.	132.4
7	3	105	1607.	554.	1811.	1009.	1570.	647.	1703.	925.	9.8
8	3	105	211.	23.	212.	39.	203.	23.	204.	27.	83.3
9	3	105	933.	244.	929.	204.	633.	223.	835.	219.	13.9
11	3	105	87.	33.	84.	26.	78.	13.	76.	12.	163.1
12	3	105	510.	603.	1000.	1109.	801.	633.	1063.	916.	12.8
13	3	105	67.	42.	63.	32.	54.	22.	51.	19.	210.1
14	3	105	377.	444.	750.	823.	576.	494.	736.	636.	22.9
15	3	105	14.	22.	23.	26.	5.	15.	13.	22.	713.0
16	3	105	36.	50.	47.	47.	45.	30.	59.	60.	311.3

TABLE XI.4.3-2. Connecting Weld Stresses Beam No. 3, Node No. 107

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	3	107	138.	111.	104.	65.	123.	97.	111.	80.	102.8
2	3	107	504.	598.	676.	828.	778.	656.	847.	646.	22.2
3	3	107	6091.	6091.	6076.	6076.	6076.	6076.	6092.	6091.	2.3
4	3	107	376.	443.	527.	627.	561.	476.	630.	493.	29.9
5	3	107	21.	19.	39.	57.	17.	15.	44.	45.	317.6
6	3	107	63.	78.	99.	102.	75.	60.	103.	100.	133.5
7	3	107	2624.	2150.	2939.	2533.	2651.	2233.	2330.	2500.	5.9
8	3	107	348.	278.	259.	154.	332.	264.	262.	167.	50.8
9	3	107	1466.	1152.	1496.	1190.	1432.	1146.	1472.	1196.	11.8
11	3	107	136.	110.	103.	65.	122.	96.	110.	79.	103.8
12	3	107	503.	597.	674.	826.	777.	655.	846.	645.	16.7
13	3	107	87.	69.	76.	54.	72.	53.	85.	70.	162.2
14	3	107	375.	442.	526.	626.	560.	475.	629.	497.	29.9
15	3	107	22.	28.	22.	26.	25.	29.	25.	31.	611.7
16	3	107	42.	55.	53.	58.	52.	40.	66.	67.	279.3

TABLE XI.4.3-3. Connecting Weld Stresses Beam No. 4, Node No. 108

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	4	108	138.	111.	104.	65.	123.	97.	111.	80.	102.8
2	4	108	700.	668.	1039.	1131.	752.	789.	967.	925.	16.6
3	4	108	88.	70.	77.	54.	73.	54.	85.	70.	161.0
4	4	108	508.	474.	804.	840.	549.	587.	701.	665.	22.4
5	4	108	21.	19.	39.	37.	17.	15.	44.	45.	317.4
6	4	108	71.	64.	95.	113.	90.	101.	85.	69.	166.4
7	4	108	2624.	2150.	2939.	2533.	2651.	2233.	2831.	2500.	5.9
8	4	108	348.	278.	259.	154.	332.	264.	262.	167.	50.8
9	4	108	1466.	1152.	1496.	1190.	1432.	1166.	1472.	1186.	11.8
11	4	108	136.	110.	103.	65.	122.	96.	110.	79.	103.8
12	4	108	699.	667.	1039.	1131.	751.	783.	967.	924.	12.5
13	4	108	87.	69.	76.	54.	72.	53.	85.	70.	162.2
14	4	108	507.	473.	803.	839.	548.	586.	700.	664.	22.4
15	4	108	22.	28.	22.	26.	25.	29.	25.	31.	611.7
16	4	108	52.	46.	53.	67.	62.	74.	43.	34.	255.8

TABLE XI.4.3-4. Connecting Weld Stresses Beam No. 4, Node No. 106

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	4	106	88.	33.	85.	26.	79.	18.	77.	12.	161.6
2	4	106	653.	619.	1251.	1233.	691.	731.	1101.	1064.	14.6
3	4	106	68.	42.	63.	32.	54.	22.	52.	19.	203.9
4	4	106	470.	433.	949.	980.	490.	533.	820.	789.	19.2
5	4	106	30.	29.	31.	23.	19.	17.	20.	22.	449.3
6	4	106	60.	52.	154.	166.	70.	84.	130.	120.	113.5
7	4	106	1607.	564.	1811.	1009.	1570.	647.	1703.	925.	9.8
8	4	106	211.	23.	212.	38.	203.	23.	204.	27.	83.3
9	4	106	933.	244.	929.	204.	833.	223.	635.	219.	13.9
11	4	103	87.	33.	84.	26.	78.	13.	76.	12.	163.1
12	4	103	652.	618.	1250.	1237.	690.	730.	1100.	1063.	11.0
13	4	106	67.	42.	63.	32.	54.	22.	51.	19.	210.1
14	4	106	469.	432.	947.	978.	469.	532.	818.	787.	19.2
15	4	106	14.	22.	23.	26.	5.	15.	13.	22.	713.0
16	4	106	30.	27.	96.	106.	43.	53.	82.	73.	177.8

XI.4.4 Beams 25 & 26

All Welds are 0.25" Fillet

Figure XI.4.4-1 Welds in beams 25 and 26.

Weld Section Properties

Weld Areas

$$Aw_2 = [2(1.5 + 2.0 + 1.25) + 3] \times 0.25 = 3.125 \text{ in}^2$$

$$Aw_3 = 2(3 \times 2.0 + 3.0) \times 0.25 = 4.5 \text{ in}^2$$

Center of Weld

$$\bar{y} = \frac{\sum Ay}{A} = \frac{(6.5 \times 18.5 + 12 \times 12.5 + 6 \times 1.5) \times 0.25}{7.625} = 9.15"$$

$$\text{Eccentricity from C.G. of Beam} = 9.15 - 9.25 = -0.1"$$

Moment of Inertia

$$I_{22} = (6.0 \times 9.15^2 + 6.0 \times 7.65^2 + 4.0 \times 2.65^2 + 4.0 \times 3.35^2 + 4.0 \times 8.35^2 + 6.5 \times 9.35^2 + 6 \times \frac{2.0^3}{12} + 2 \times \frac{3.0^3}{12}) \times 0.25$$

$$= 445.52 \text{ in}^4$$

$$I_{33} = 2(9.0 \times 7.5^2 + 1.25 \times 6.875^2 + 1.5 \times 6.75^2 + 2.0 \times 2.5^2 + \frac{2^3}{12} + \frac{1.5^3}{12} + \frac{1.25^3}{12}) 0.25 + \frac{.25 \times 3^3}{12}$$

$$= 324.25 \text{ in}^4$$

$$\text{Polar } J = I_{22} + I_{33} = 769.77 \text{ in}^4$$

Sample Weld Section Forces x Moments: Beam No. 25, Node 119, Load Case 2

$$\begin{aligned} P_1 &= -(-867) \# & WT_1 &= 104800 + [-10450 \times (-0.10)] = 105840 \text{ in } \# \\ F_2 &= 10450 & WM_2 &= -(-24210) - [867 \times (-0.10)] = 24297 \text{ in.} \# \\ F_3 &= 609 & WM_3 &= -(34490) \text{ in. } \# \end{aligned}$$

The sample calculation for this particular case and the results of the computerized calculations are given in the following pages.

	S_{UL-2}	S_{UL-3}	S_{UR-2}	S_{UR-3}	S_{DR-2}	S_{DR-3}	S_{DL-2}	S_{DL-3}
$S_{Px} = \frac{P_1}{Aw_2 + Aw_3} = \frac{867}{3.125 + 4.5} = 114$	+	+	+	+	+	+	+	+
$S_{Fy} = \frac{F_2}{Aw_2} = \frac{-10450}{3.125} = -3344$	-		-		-		-	
$S_{F2} = \frac{F_3}{Aw_3} = \frac{609}{4.5} = 135$		+		+		+		+
$S_{TULY} = -\frac{WT_1 \times D_u}{J} = -\frac{105840 \times 9.35}{769.77} = -1286$	-	-						
$S_{TULZ} = -\frac{WT_1 \times D_L}{J} = -\frac{105840 \times 7.5}{769.77} = -1031$	-	-						
$S_{TURY} = -\frac{WT_1 \times D_u}{J} = -1286$			-	-				
$S_{TURZ} = \frac{WT_1 \times D_r}{J} = 1031$			+	+				
$S_{TDry} = \frac{WT_1 \times D_d}{J} = \frac{105840 \times 9.15}{769.77} = 1258$					+	+		
$S_{TDRZ} = \frac{WT_1 \times D_r}{J} = 1031$					+	+		
$S_{TDLY} = \frac{WT_1 \times D_d}{J} = 1258$							+	+
$S_{TDLZ} = -\frac{WT_1 \times D_\ell}{J} = -1031$							-	-

$$S_{M2UX} = \frac{WM_2 \times D_u}{I_2} = \frac{24297 \times 9.35}{445.52} = 510$$

$$S_{M2DX} = -\frac{WM_2 \times D_d}{I_2} = -\frac{24297 \times 9.15}{445.52} = -499$$

$$S_{M3LX} = \frac{WM_3 \times D_L}{I_3} = \frac{-34490 \times 7.5}{324.25} = -798$$

$$S_{M3RX} = -\frac{WM_3 \times D_r}{I_3} = -\frac{(-34490) \times 7.5}{324.25} = 798$$

$$S_{MAX} = \sqrt{(\Sigma S_x)^2 + (\Sigma S_y)^2 + (\Sigma S_z)^2}$$

Allowable Shear Stress for faulted condition

$$= 1.33 \times 0.4 \times 50,000 = 26,600 \text{ psi}$$

$$S.F. = \frac{26,600}{S_{MAX} \times \sqrt{2}}$$

S_{UL_2}	S_{UL_3}	S_{UR_2}	S_{UR_3}	S_{DR_2}	S_{DR_3}	S_{DL_2}	S_{DL_3}
+	+	+	+				
				-	-	-	-
-	-					-	-
		+	+	+	+		
4747	1577	4952	2244	2363	1764	2610	1945
		3.80					

TABLE XI.4.4-1. Connecting Weld Stresses Beam No. 25, Node No. 119

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-LEFT		DOWN-RIGHT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDL2	SDL3	SDR2	SDR3	
1	25	119	646.	447.	469.	68.	513.	221.	496.	179.	21.9
2	25	119	4752.	1577.	4957.	2244.	2368.	1765.	2615.	1945.	3.8
3	25	119	513.	400.	330.	203.	348.	133.	326.	63.	27.6
4	25	119	3316.	1127.	3543.	1774.	1600.	1270.	1357.	1477.	5.3
5	25	119	101.	101.	143.	143.	25.	25.	47.	47.	95.3
6	25	119	357.	174.	453.	336.	137.	171.	239.	253.	41.1
7	25	119	6221.	686.	6232.	772.	6171.	643.	6191.	814.	2.8
8	25	119	833.	103.	828.	38.	822.	49.	821.	36.	21.2
9	25	119	591.	172.	730.	460.	631.	236.	659.	355.	24.2
11	25	119	652.	447.	477.	48.	568.	221.	491.	179.	21.7
12	25	119	4746.	1574.	4950.	2240.	2366.	1761.	2613.	1942.	2.9
13	25	119	513.	399.	330.	202.	343.	138.	326.	63.	27.6
14	25	119	3310.	1125.	3537.	1770.	1598.	1267.	1854.	1474.	5.3
15	25	119	64.	55.	87.	73.	91.	24.	93.	49.	203.1
16	25	119	150.	101.	222.	187.	64.	90.	129.	150.	84.7

TABLE XI.4.4-2. Connecting Weld Stresses Beam No. 25, Node No. 121

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	25	121	471.	68.	638.	436.	489.	159.	508.	210.	22.2
2	25	121	5666.	3466.	6233.	4403.	4063.	3744.	4463.	4112.	3.0
3	25	121	357.	154.	534.	487.	333.	111.	391.	225.	24.2
4	25	121	3370.	2291.	4497.	3239.	2764.	2537.	3166.	2530.	4.2
5	25	121	146.	146.	154.	154.	45.	45.	52.	52.	91.6
6	25	121	374.	206.	580.	490.	250.	270.	392.	404.	32.4
7	25	121	8468.	5786.	8521.	5863.	8405.	5743.	8517.	5906.	2.1
8	25	121	1120.	756.	1068.	676.	1079.	701.	1099.	731.	15.8
9	25	121	833.	611.	1103.	953.	919.	727.	1008.	837.	16.0
11	25	121	479.	67.	645.	437.	425.	161.	504.	212.	21.9
12	25	121	5659.	3461.	6231.	4397.	4053.	3738.	4463.	4106.	2.3
13	25	121	361.	154.	536.	486.	334.	111.	337.	225.	24.1
14	25	121	3863.	2287.	4489.	3282.	2759.	2532.	3180.	2375.	4.2
15	25	121	130.	127.	65.	43.	114.	73.	91.	45.	144.3
16	25	121	150.	100.	272.	244.	92.	111.	187.	202.	69.1

TABLE XI.4.4-3. Connecting Weld Stresses Beam No. 26, Node No. 120

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	26	120	471.	68.	639.	436.	489.	159.	508.	210.	22.2
2	26	120	3355.	2455.	3317.	2532.	1998.	2423.	2337.	2593.	5.6
3	26	120	357.	154.	534.	437.	333.	111.	391.	225.	24.2
4	26	120	2331.	1736.	2241.	1721.	1363.	1703.	1601.	1735.	7.9
5	26	120	146.	145.	154.	154.	65.	45.	52.	52.	91.6
6	26	120	432.	313.	346.	227.	224.	276.	227.	233.	43.6
7	26	120	8463.	5766.	8521.	5863.	8405.	5743.	8517.	5906.	2.1
8	26	120	1120.	755.	1033.	676.	1079.	701.	1099.	731.	15.8
9	26	120	833.	611.	1103.	953.	919.	727.	1003.	837.	16.0
11	26	120	466.	66.	635.	437.	488.	151.	516.	211.	22.3
12	26	120	3349.	2430.	3310.	2547.	1993.	2413.	2332.	2593.	4.2
13	26	120	352.	153.	531.	437.	343.	112.	394.	224.	24.4
14	26	120	2376.	1732.	2237.	1713.	1361.	1700.	1593.	1731.	7.9
15	26	120	133.	121.	30.	45.	99.	74.	71.	26.	136.0
16	26	120	300.	209.	244.	143.	175.	183.	155.	153.	62.6

TABLE XI.4.4-4. Connecting Weld Stresses Beam No. 26, Node No. 118

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	26	118	646.	447.	469.	48.	513.	221.	496.	179.	21.9
2	26	118	2836.	1721.	2910.	1993.	1149.	1729.	1536.	1950.	6.5
3	26	118	513.	400.	330.	203.	348.	133.	326.	63.	27.6
4	26	118	1598.	1230.	2014.	1413.	797.	1295.	1140.	1337.	9.3
5	26	118	101.	101.	143.	143.	25.	25.	47.	47.	95.3
6	26	118	338.	159.	330.	202.	119.	209.	152.	168.	55.7
7	26	118	6221.	636.	6232.	772.	6171.	643.	6191.	814.	2.8
8	26	118	833.	103.	828.	38.	822.	49.	821.	36.	21.2
9	26	118	591.	172.	730.	460.	631.	235.	659.	345.	24.2
11	26	118	642.	446.	463.	46.	520.	221.	504.	179.	22.0
12	26	118	2330.	1717.	2904.	1550.	1147.	1785.	1533.	1947.	4.9
13	26	118	510.	399.	376.	203.	352.	133.	330.	62.	27.7
14	26	118	1994.	1223.	2010.	1410.	796.	1293.	1133.	1334.	9.4
15	26	118	479.	42.	99.	74.	71.	27.	73.	32.	190.3
16	26	118	230.	80.	223.	121.	99.	122.	110.	90.	81.7

XI.4.5 Beams 552 & 553

All Welds are 0.25" Fillet

Figure XI.4.5-1 Welds in Beams 552 and 553

Weld Section Properties

Weld areas

$$Aw_2 = 2(1.25 + 2 + 1.75 + 3) 0.25 = 4.0 \text{ in}^2$$

$$Aw_3 = 6 \times 2 \times 0.25 = 3.0$$

Center of weld

$$E_y = \frac{2(3.25 - 4.75) 0.25 \times 6}{4.0 + 3.0} = -0.643$$

Moment of Inertia

$$I_{22} = (6.5 \times 6.643^2 + 4 \times 5.643^2 + 4 \times .643^2 + 4 \times 4.357^2 + 9.5 \times 5.357^2 + 6 \times \frac{2^3}{12}) 0.25$$

$$= 192.1 \text{ in}^4$$

$$\begin{aligned} I_{33} &= 2(6 \times 7.75^2 + 1.25 \times 7.5^2 + 1.75 \times 6.875^2 + 2 \times 2.5^2 + 3 \times 3.5^2 + \frac{2^3}{12} \\ &\quad + \frac{1.25^3}{12} + \frac{1.75^3}{12} + \frac{3^3}{12}) 0.25 \\ &= 283.1 \text{ in}^4 \end{aligned}$$

$$\text{Polar J} = 475.2 \text{ in}^4$$

Sample Weld Forces x Moments: Beam 552, Node 500, Load Case 2

$$\begin{aligned} P_1 &= -(-345)\# & WT_1 &= -238300 + (-23680 \times -.643) = -223070 \text{ in.}\# \\ F_2 &= -23680 & WM_2 &= -(8930) - (345 \times -.643) = -8708 \text{ in.}\# \\ F_3 &= -2449 & WM_3 &= -(-204000) \text{ in.}\# \end{aligned}$$

The sample calculations for the above and the results of the computerized calculations are given in the following pages.

	S_{UL2}	S_{UL3}	S_{UR2}	S_{UR3}	S_{DR2}	S_{DR3}	S_{DL2}	S_{DL3}
$S_{Px} = \frac{P_1}{Aw_2 + Aw_3} = \frac{345}{4.0 + 3.0} = 49$	+	+	+	+	+	+	+	+
$S_{Fy} = \frac{F_2}{Aw_2} = \frac{-23680}{4} = -5920$	-		-		-		-	
$S_{Fz} = \frac{F_3}{Aw_3} = \frac{-2449}{3.0} = -816$		-		-		-		-
$S_{TULY} = -\frac{WT_1 \times D_u}{J} = -\frac{(-223070) \times 6.643}{475.2} = 3118$	+	+						
$S_{TULZ} = -\frac{WT_1 \times D_L}{J} = -\frac{(-223070) \times 7.75}{475.2} = 3638$	+	+						
$S_{TURV} = -\frac{WT_1 \times D_u}{J} = 3118$			+	+				
$S_{TURZ} = \frac{WT_1 \times D_r}{J} = -3638$			-	-				
$S_{TDRY} = \frac{WT_1 \times D_d}{J} = \frac{223070 \times 5.357}{475.2} = -2515$					-	-		
$S_{TDRI} = \frac{WT_1 \times D_r}{J} = -3638$					-	-		
$S_{TDLY} = \frac{WT_1 \times D_d}{J} = -2515$							-	-
$S_{TDLZ} = -\frac{WT_1 \times D_l}{J} = 3638$							+	+

$$S_{M2UX} = \frac{WM_2 \times D_u}{I_2} = \frac{-8708 \times 6.643}{192.1} = -301$$

$$S_{M2DX} = -\frac{WM_2 \times D_d}{I_2} = -\frac{(-8708) \times 5.357}{192.1} = 243$$

$$S_{M3LX} = \frac{WM_3 \times D_L}{I_3} = \frac{204000 \times 7.75}{283.1} = 5585$$

$$S_{M3RX} = -\frac{WM_3 \times D_r}{I_3} = -5585$$

$$S_{MAX} = \sqrt{(\Sigma S_x)^2 + (\Sigma S_y)^2 + (\Sigma S_z)^2}$$

Allowable Shear Stress for faulted condition

$$= 1.33 \times 0.4 \times 50000 = 26600 \text{ psi}$$

$$S.F. = \frac{26,600}{\sqrt{2} \times S_{MAX}}$$

S_{UL2}	S_{UL3}	S_{UR2}	S_{UR3}	S_{DR2}	S_{DR3}	S_{DL2}	S_{DL3}
-	-	-	-				
				+	+	+	+
+	+					+	+
		-	-	-	-		
7038	6792	7427	7977	10602	7307	10906	6504
						1.72	

TABLE XI.4.5-1. Connecting Weld Stresses Beam No. 552, Node No. 500

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	552	500	9461.	7548.	7531.	4994.	8953.	7218.	7545.	5322.	1.5
2	552	500	7038.	6792.	7427.	7977.	10504.	7352.	10507.	6359.	1.7
3	552	500	6375.	5125.	5543.	4044.	6494.	5435.	5155.	3732.	2.2
4	552	500	4796.	5301.	5738.	5801.	7668.	4366.	7749.	5320.	2.4
5	552	500	2833.	2075.	1735.	333.	1975.	1161.	2022.	1343.	5.3
6	552	500	2578.	2033.	1784.	748.	1362.	1050.	1109.	892.	7.3
7	552	500	3332.	2902.	4858.	4340.	3770.	3165.	4532.	4076.	3.6
8	552	500	4762.	3910.	3054.	1356.	3672.	2912.	3439.	2352.	3.7
9	552	500	916.	839.	314.	221.	251.	133.	574.	535.	19.3
11	552	500	9432.	7523.	7546.	4959.	8952.	7190.	7513.	5230.	1.5
12	552	500	7013.	7596.	7390.	7161.	10373.	6482.	10371.	7762.	1.3
13	552	500	6343.	5102.	5503.	4012.	6463.	5403.	5139.	3703.	2.2
14	552	500	4776.	5234.	5571.	5571.	7441.	4346.	7719.	5595.	2.4
15	552	500	1749.	1376.	1530.	1032.	1069.	337.	1016.	94.	10.8
16	552	500	1323.	1471.	1760.	1349.	821.	428.	791.	503.	10.3

TABLE XI.4.5-2. Connecting Weld Stresses Beam No. 552, Node No. 152

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	552	152	5941.	1662.	5784.	961.	5513.	1337.	5337.	643.	2.4
2	552	152	4946.	5740.	4604.	4218.	9347.	4154.	9191.	5121.	2.0
3	552	152	3974.	1183.	3799.	262.	3359.	1503.	3534.	241.	3.6
4	552	152	3536.	4238.	3370.	3131.	6564.	2324.	6509.	3729.	2.9
5	552	152	1739.	365.	2251.	1471.	1693.	576.	1691.	562.	6.3
6	552	152	1237.	1119.	2600.	2034.	1022.	541.	1361.	1190.	7.2
7	552	152	2277.	645.	3022.	2039.	2339.	907.	2742.	1223.	5.9
8	552	152	2947.	1139.	3094.	1472.	2557.	164.	2536.	492.	5.7
9	552	152	725.	691.	535.	466.	222.	74.	345.	277.	24.4
11	552	152	5924.	1655.	5771.	978.	5496.	1326.	5375.	656.	2.4
12	552	152	4936.	5733.	4591.	4213.	9323.	4152.	9170.	5114.	1.5
13	552	152	3949.	1179.	3774.	242.	3347.	1491.	3557.	242.	3.6
14	552	152	3578.	4232.	3356.	3121.	6547.	2322.	6490.	3722.	2.9
15	552	152	1110.	297.	2478.	2334.	1273.	756.	1569.	1191.	7.6
16	552	152	1293.	715.	2646.	2393.	921.	599.	1492.	1362.	7.1

TABLE XI.4.5-3. Connecting Weld Stresses Beam No. 553, Node No. 153

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	553	153	5941.	1662.	5784.	961.	5513.	1337.	5397.	643.	2.4
2	553	153	10722.	7917.	9647.	5255.	6342.	6143.	4806.	5812.	1.8
3	553	153	3974.	1188.	3799.	262.	3559.	1503.	3554.	241.	3.6
4	553	153	7355.	5782.	6362.	3493.	4920.	4912.	3170.	4101.	2.6
5	553	153	1739.	365.	2251.	1671.	1683.	576.	1691.	562.	6.3
6	553	153	1441.	592.	2055.	1537.	2262.	1117.	2039.	793.	8.3
7	553	153	2277.	645.	3022.	2059.	2239.	967.	2742.	1823.	5.9
8	553	153	2947.	1139.	3054.	1472.	2557.	164.	2556.	492.	5.7
9	553	153	725.	691.	535.	486.	222.	74.	345.	277.	24.4
11	553	153	5924.	1655.	5771.	978.	5496.	1327.	5374.	656.	2.4
12	553	153	10392.	7859.	9626.	5254.	6321.	6127.	4797.	5506.	1.3
13	553	153	3965.	1183.	3792.	264.	3535.	1494.	3544.	257.	3.6
14	553	153	7334.	5767.	6286.	3490.	4903.	4896.	3165.	4096.	2.6
15	553	153	1631.	1214.	1319.	737.	2203.	1966.	1007.	191.	8.5
16	553	153	1044.	290.	2335.	2102.	1667.	1096.	1729.	1117.	8.1

TABLE XI.4.5-4. Connecting Weld Stresses Beam No. 553, Node No. 501

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDL2	SDL3	
1	553	501	9461.	7563.	7531.	4994.	8933.	7218.	1.5
2	553	501	13471.	11366.	10233.	6266.	10122.	9928.	1.4
3	553	501	6375.	5125.	5543.	4044.	6434.	5435.	2.2
4	553	501	7262.	6572.	4441.	3134.	7232.	6622.	2.6
5	553	501	2683.	2075.	1735.	333.	1975.	1161.	5.3
6	553	501	2273.	1855.	1457.	509.	2181.	941.	8.1
7	553	501	3632.	2902.	4838.	4340.	3770.	3135.	3.6
8	553	501	4762.	2210.	3054.	1366.	3372.	2912.	3.7
9	553	501	916.	839.	314.	221.	251.	139.	19.3
11.	553	501	9432.	7523.	7516.	4959.	8952.	7120.	1.5
12	553	501	13429.	11331.	10196.	6238.	10053.	9982.	1.1
13	553	501	6353.	5102.	5515.	4013.	6461.	5409.	2.2
14	553	501	9009.	7789.	6951.	4554.	7261.	7257.	2.1
15	553	501	1539.	1086.	1757.	1375.	1088.	63.	10.7
16	553	501	1697.	1369.	1344.	878.	1355.	339.	11.1
							574.	555.	
							7512.	5290.	
							6519.	7294.	
							5120.	3704.	
							4236.	5021.	
							1061.	350.	
							1357.	318.	

XI.4.6 Beams 44 & 45

Figure XI.4.6-1 Welds in Beams 44 and 45.

For a .25" thick plate welded on both sides with .25" fillet welds, the effective size of the combined welds, w , is:

Plate capacity = $0.4 \times 50 \text{ ksi} \times 0.25" = 5 \text{ k/in.}$

Weld capacity (the smaller of)

- $0.3 \times 70 \text{ ksi} \times 0.707 w" = 14.847 w"$
- $0.4 \times 50 \text{ ksi} \times 0.707 w" = 14.14 w"$

$$w = 5.0 \div 14.14 = 0.354"$$

Weld Section Properties

Weld Areas: $A_{w2} = 2(1.75 \times 2 + 3.0 \times 3) \times \frac{5}{16} = 7.81$

$$A_{w3} = 2 \times 10 \times .354 + 11 \times .50 = 12.58$$

Center of weld:

$$\bar{z} = \frac{3.54(6 + 4.625) - 3.54 \times 3.125 - 5.5(3.125 + 10.375)}{(7.81 + 12.58)}$$

$$= 2.339$$

$$E_z = 6.375 - 3.125 + 2.339 = 5.589"$$

$$E_y = 0$$

Moment of Inertia:

$$I_{22} = 2(1.75" \times 2 + 3" \times 3) \times \frac{5}{16} \times 6^2 + 2 \times .354 \times \frac{10^3}{12} + .50$$

$$\times \frac{11^3}{12}$$

$$= 395.71$$

$$I_{33} = 3.54(12.625 - 3.125 + 2.339)^2 + 3.54(3.125 - 2.339)^2$$

$$+ 5.5(10.375 + .786)^2 + 2 \times \frac{5}{16} (1.75 \times 13.714^2 + 3 \times 8.339^2$$

$$+ 3 \times 2.339^2 + 3 \times 3.661^2 + 1.75 \times 9.036)$$

$$+ 2 \times \frac{5}{16} (2 \times \frac{1.75^3}{12} + 3 \times \frac{3.0^3}{12})$$

$$= 1649.03$$

$$\text{Polar } J = I_{22} + I_{33} = 2044.74$$

Sample Weld Forces & Moments: Beam 45, Node 129, Load Case 2

$$P_1 = 222 \text{ lbs} \quad WT_1 = -161700 - (-7661 \times 5.589) = -118880 \text{ in.lbs}$$

$$F_2 = 41950 \quad WM_2 = -248500$$

$$F_3 = -7661 \quad WM_3 = -149500 + (222 \times 5.589) = -148260$$

The calculation for the above case and the computerized calculation results are indicated in the following pages.

	S_{UL2}	S_{UL3}	S_{UR2}	S_{UR3}	S_{DR2}	S_{DR3}	S_{DL2}	S_{DL3}
$S_{Px} = \frac{P_1}{Aw_2 + Aw_3} = \frac{222}{7.81 + 12.58} = 11$	+	+	+	+	+	+	+	+
$S_{Fy} = \frac{F_2}{Aw_2} = \frac{41950}{7.81} = 5371$	+		+		+		+	
$S_{Fz} = \frac{F_3}{Aw_3} = \frac{-7661}{12.58} = -609$		-		-		-		-
$S_{TULY} = -\frac{WT_1 \times D_u}{J} = -\frac{(-118880) \times 6}{2044.74} = 349$	+	+						
$S_{TULZ} = -\frac{WT_1 \times D_L}{J} = -\frac{(-118880) \times 14.589}{2044.74} = 848$	+	+						
$S_{TURY} = -\frac{WT_1 \times D_u}{J} = 349$			+	+				
$S_{TURZ} = \frac{WT_1 \times D_r}{J} = \frac{-118880 \times 11.161}{2044.74} = -649$			-	-				
$S_{TDRY} = \frac{WT_1 \times D_d}{J} = -349$					-	-		
$S_{TDRZ} = \frac{WT_1 \times D_r}{J} = -649$					-	-		
$S_{TDLY} = \frac{WT_1 \times D_d}{J} = -349$							-	-
$S_{TDLZ} = -\frac{WT_1 \times D_\ell}{J} = 848$							+	+

$$S_{M2UX} = \frac{WM_2 \times D_u}{I_2} = \frac{-248500 \times 6}{395.71} = -3768$$

$$S_{M2DX} = - \frac{WM_2 \times D_d}{I_2} = 3768$$

$$S_{M3LX} = \frac{WM_3 \times D_L}{I_3} = \frac{-148260 \times 14.589}{1649.03} = -1312$$

$$S_{M3RX} = - \frac{WM_3 \times D_r}{I_3} = - \frac{(-148260) \times 11.161}{1649.03} = 1003$$

$$S_{MAX} = \sqrt{(\Sigma S_x)^2 + (\Sigma S_y)^2 + (\Sigma S_z)^2}$$

Allowable shear stress for faulted condition

$$= 1.33 \times 0.4 \times 50000 = 26,600$$

$$S.F. = \frac{26,600}{\sqrt{2} \times S_{MAX}}$$

S_{UL2}	S_{UL3}	S_{UR2}	S_{UR3}	S_{DR2}	S_{DR3}	S_{DL2}	S_{DL3}
-	-	-	-				
				+	+	+	+
-	-					-	-
		+	+	+	+		
7690	5087	6382	3048	6965	4957	5659	2503
2.45							

TABLE XI.4.6-1. Connecting Weld Stresses Beam No. 44, Node No. 128

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	44	128	3678.	1472.	4178.	2468.	3633.	1353.	4109.	2349.	3.4
2	44	128	2648.	2202.	3212.	3158.	3590.	3185.	3045.	2171.	5.2
3	44	128	2832.	1747.	3307.	2334.	2847.	1689.	3265.	2326.	4.3
4	44	128	1807.	1529.	2177.	274.	2442.	2239.	2659.	1499.	7.7
5	44	128	820.	761.	680.	608.	867.	811.	725.	653.	16.3
6	44	128	203.	265.	85.	269.	229.	336.	93.	180.	55.0
7	44	128	1855.	1555.	723.	723.	2255.	2255.	324.	324.	7.8
8	44	128	403.	403.	71.	71.	426.	426.	93.	93.	41.5
9	44	128	1613.	1613.	476.	476.	1907.	1907.	182.	182.	9.3
11	44	128	3673.	1489.	4173.	2465.	3629.	1350.	4105.	2346.	3.4
12	44	128	2644.	2198.	3207.	3153.	3534.	3181.	3040.	2167.	3.9
13	44	128	2873.	1739.	3297.	2574.	2839.	1680.	3256.	2316.	4.3
14	44	128	1204.	1528.	2173.	2269.	2433.	2295.	2066.	1496.	7.7
15	44	128	355.	347.	216.	202.	392.	354.	252.	240.	43.0
16	44	128	117.	143.	53.	145.	106.	175.	31.	94.	107.6

TABLE XI.4.6-2. Connecting Weld Stresses Beam No. 44, Node No. 130

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	44	130	3564.	1434.	7113.	6264.	4165.	2445.	6241.	5252.	2.0
2	44	130	2322.	1797.	6796.	6770.	3623.	3233.	5920.	5521.	2.8
3	44	130	2303.	233.	5463.	4959.	2462.	888.	4857.	4234.	2.6
4	44	130	1108.	550.	5334.	5374.	1914.	1723.	4725.	4505.	3.5
5	44	130	566.	494.	986.	946.	571.	465.	973.	915.	14.3
6	44	130	407.	439.	773.	814.	391.	462.	753.	767.	23.1
7	44	130	1860.	1660.	726.	726.	2260.	2260.	326.	326.	7.8
8	44	130	411.	411.	79.	79.	433.	433.	101.	101.	40.8
9	44	130	1606.	1606.	435.	435.	1900.	1900.	191.	191.	9.3
11	44	130	3356.	1433.	7105.	6253.	4163.	2443.	6237.	5247.	2.0
12	44	130	2318.	1793.	6737.	6761.	3617.	3217.	5912.	5514.	2.1
13	44	130	2297.	233.	5454.	4951.	2460.	897.	4851.	4237.	2.6
14	44	130	1107.	549.	5325.	5355.	1911.	1724.	4713.	4483.	3.5
15	44	130	234.	274.	239.	279.	301.	292.	307.	297.	61.3
16	44	130	270.	282.	304.	333.	282.	314.	316.	328.	53.5

TABLE XI.4.6-3. Connecting Weld Stresses Beam No. 45, Node No. 129

CASE NO	BEAM NO	NODE NO	UP-LEFT			UP-RIGHT			DOWN-RIGHT			DOWN-LEFT			MIN FACTOR OF SAFETY
			SUL2	SUL3		SUR2	SUR3		SDR2	SDR3		SDL2	SDL3		
1	45	129	3678.	1472.		4178.	2468.		3633.	1353.		4109.	2349.		3.4
2	45	129	7470.	4773.		6273.	2368.		7201.	5306.		5775.	2793.		2.5
3	45	129	2332.	1747.		3307.	2334.		2347.	1639.		3265.	2326.		4.3
4	45	129	6200.	4783.		5050.	3339.		6120.	5181.		4340.	3334.		3.0
5	45	129	820.	781.		650.	608.		867.	811.		726.	653.		16.3
6	45	129	1524.	1452.		1047.	975.		1603.	1563.		1117.	1648.		11.7
7	45	129	1354.	1894.		722.	722.		2254.	2254.		323.	323.		7.8
8	45	129	403.	403.		71.	71.		426.	426.		93.	93.		41.5
9	45	129	1614.	1614.		477.	477.		1908.	1908.		183.	183.		9.3
11	45	129	3576.	1469.		4176.	2465.		3625.	1350.		4102.	2346.		3.4
12	45	129	7461.	4767.		6271.	2364.		7193.	5300.		5768.	2794.		1.9
13	45	129	2879.	1745.		2303.	2350.		2341.	1637.		3259.	2322.		4.3
14	45	129	6183.	4779.		5041.	3362.		6109.	5171.		4831.	3377.		3.0
15	45	129	355.	347.		216.	202.		392.	394.		252.	240.		43.0
16	45	129	823.	805.		498.	478.		832.	875.		550.	529.		21.3

TABLE XI.4.6-4. Connecting Weld Stresses Beam No, 45, Node No. 130

CASE NO	BEAM NO	NODE NO	UP-LEFT			UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3		SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	45	130	3564.	1434.		7113.	6264.	4165.	2446.	6241.	5252.	2.0
2	45	130	6020.	1756.		8777.	6770.	5339.	3224.	7434.	5521.	2.1
3	45	130	2303.	233.		5463.	4959.	2652.	838.	4867.	4294.	2.6
4	45	130	3977.	551.		6550.	5374.	3633.	1729.	5631.	4505.	2.9
5	45	130	577.	490.		992.	944.	552.	460.	963.	913.	14.3
6	45	130	615.	442.		900.	815.	571.	464.	830.	769.	20.9
7	45	130	1860.	1860.		726.	726.	2260.	2260.	326.	326.	7.8
8	45	130	411.	411.		79.	79.	433.	433.	101.	101.	40.8
9	45	130	1606.	1606.		485.	485.	1900.	1900.	191.	191.	9.3
11	45	130	3662.	1432.		7103.	6253.	4153.	2443.	6233.	5247.	2.0
12	45	130	6012.	1792.		8765.	6761.	5331.	3217.	7475.	5514.	1.6
13	45	130	2302.	233.		5455.	4951.	2456.	837.	4859.	4267.	2.6
14	45	130	3970.	550.		6549.	5366.	3682.	1726.	5671.	4493.	2.9
15	45	130	234.	274.		239.	279.	301.	292.	307.	297.	61.3
16	45	130	334.	284.		352.	334.	334.	316.	363.	330.	51.9

XI.4.7 Beams 84 & 85

Figure XI.4.7-1 Welds in Beams 84 and 85.

Weld Section Properties

$$\text{Weld Areas: } Aw_2 = 2 \times 15.5 \times 0.25 = 7.75 \text{ in}^2$$

$$Aw_3 = 2 \times 12 \times 0.25 = 6.0 \text{ in}^2$$

Center of Weld: No eccentricity: $E_y = 0$ $E_z = 0$

Moment of Inertia:

$$I_{22} = 2 \left(\frac{12^3}{12} + 15.5 \times 6^2 \right) 0.25 = 351.0 \text{ in}^4$$

$$I_{33} = 2 \left(\frac{15.5^3}{12} + 12 \times 7.75^2 \right) 0.25 = 515.54 \text{ in}^4$$

$$\text{Polar } J = I_{22} + I_{33} = 866.54$$

Sample weld section forces & moments: Beam 84, Node 167, Case No. 2

$$P_1 = -(5214) \# \quad WT_1 = T_1 = -207100 \text{ in.}\#$$

$$F_2 = -2419 \# \quad WM_2 = BM_2 = -(-136100) \text{ in.}\#$$

$$F_3 = 5459 \# \quad WM_3 = BM_3 = -(-279800) \text{ in.}\#$$

The calculations for the above and the results of the computerized calculations are given in the following pages.

	S_{UL2}	S_{UL3}	S_{UR2}	S_{UR3}	S_{DR2}	S_{DR3}	S_{DL2}	S_{DL3}
$S_{Px} = \frac{P_1}{Aw_2 + Aw_3} = \frac{-5214}{7.75 + 6.0} = -379$	-	-	-	-	-	-	-	-
$S_{Fy} = \frac{F_2}{Aw_2} = \frac{-2419}{7.75} = -312$	-		-		-		-	
$S_{Fz} = \frac{F_3}{Aw_3} = \frac{5459}{6.0} = 910$		+		+		+		+
$S_{TULY} = -\frac{WT_1 \times D_u}{J} = -\frac{(-207100) \times 6.0}{866.54} = 14.34$	+	+						
$S_{TULZ} = -\frac{WT_1 \times D_L}{J} = -\frac{(-207100) \times 7.75}{866.54} = 1852$	+	+						
$S_{TURY} = -\frac{WT_1 \times D_u}{J} = 1434$			+	+				
$S_{TURZ} = \frac{WT_1 \times D_r}{J} = \frac{-207100 \times 7.75}{866.54} = -1852$			-	-				
$S_{TDRY} = \frac{WT_1 \times D_d}{J} = \frac{-207100 \times 6.0}{866.54} = -1434$					-	-		
$S_{TDRZ} = \frac{WT_1 \times D_r}{J} = -1852$					-	-		
$S_{TDLY} = \frac{WT_1 \times D_d}{J} = -1434$								
$S_{TDLZ} = -\frac{WT_1 \times D_\ell}{J} = 1852$							-	-
$S_{M2UX} = \frac{WM_2 \times D_u}{I_2} = \frac{136100 \times 6.0}{351.0} = 2326$	+	+	+	+			+	+

$$S_{M2DX} = - \frac{WM_2 \times D_d}{I_2} = -2326$$

$$S_{M3LX} = \frac{WM_3 \times D_L}{I_3} = \frac{279800 \times 7.75}{515.54} = 4206$$

$$S_{M3RX} = - \frac{WM_3 \times D_r}{I_3} = -4206$$

$$S_{MAX} = \sqrt{(\Sigma S_x)^2 + (\Sigma S_y)^2 + (\Sigma S_z)^2}$$

Allowable Shear Stress for Faulted Condition

$$= 1.33 \times 0.4 \times 50000 = 26,600 \text{ psi}$$

$$S.F. = \frac{26,600}{\sqrt{2} S_{MAX}}$$

S_{UL_2}	S_{UL_3}	S_{UR_2}	S_{UR_3}	S_{DR_2}	S_{DR_3}	S_{DL_2}	S_{DL_3}
				-	-	-	-
+	+					+	+
		-	-	-	-		
6523	6895	3129	2836	7365	7121	2955	3455
				2.55			

TABLE XI.4.7-1. Connecting Weld Stresses Beam No. 84, Node No. 167

CASE NO	BEAM NO	NODE NO	UP-LEFT			UP-RIGHT			DOWN-RIGHT			DOWN-LEFT			MIN FACTOR OF SAFETY
			SUL2	SUL3		SUR2	SUR3		SDR2	SDR3		SDL2	SDL3		
1	84	167	2402.	2402.		3346.	3346.		3160.	3160.		3023.	3033.		3.7
2	84	167	6523.	6523.		3129.	2637.		7366.	7122.		2955.	3455.		2.6
3	84	167	3648.	3648.		1853.	1358.		4222.	4222.		1283.	1283.		3.4
4	84	167	6743.	6990.		1914.	1456.		7343.	7191.		2154.	2715.		2.6
5	84	167	1425.	1425.		1007.	1007.		2747.	2747.		2329.	2329.		5.1
6	84	167	2996.	3024.		1366.	1340.		4227.	4216.		2531.	2609.		4.4
7	84	167	6207.	6207.		3350.	3350.		6374.	6374.		2693.	2693.		2.6
8	84	167	3014.	3014.		3972.	3972.		2736.	2736.		3694.	3694.		4.5
9	84	167	1657.	1657.		3680.	3680.		1469.	1469.		3491.	3491.		4.8
11	84	167	2370.	2370.		3800.	3800.		3106.	3106.		3064.	3064.		3.7
12	84	167	6433.	6433.		3093.	2304.		7305.	7060.		2943.	3442.		1.9
13	84	167	3801.	3801.		1817.	1817.		4164.	4164.		1254.	1254.		3.4
14	84	167	6693.	6941.		1910.	1453.		7233.	7130.		2155.	2713.		2.6
15	84	167	4035.	4035.		340.	339.		5138.	5138.		1392.	1392.		3.7
16	84	167	4448.	4453.		693.	676.		5497.	5497.		1722.	1735.		3.4

TABLE XI.4.7-2. Connecting Weld Stresses Beam No. 84, Node No. 169

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	84	169	2429.	2429.	3364.	3364.	3187.	3187.	3106.	3106.	3.7
2	84	169	4790.	5286.	3769.	3570.	5638.	5316.	3448.	3835.	3.3
3	84	169	3681.	3831.	1854.	1254.	4255.	4255.	1230.	1280.	3.3
4	84	169	5422.	5727.	2133.	1740.	6020.	5334.	2113.	2683.	3.1
5	84	169	1451.	1451.	1033.	1033.	2772.	2773.	2354.	2354.	5.1
6	84	169	2670.	2701.	1135.	1104.	3901.	3288.	2342.	2372.	4.6
7	84	169	6235.	6235.	3377.	3377.	6902.	6902.	2710.	2710.	2.6
8	84	169	3036.	3036.	4001.	4001.	2758.	2758.	3723.	3723.	4.4
9	84	169	1679.	1679.	3709.	3709.	1491.	1491.	3521.	3521.	4.8
11	84	169	2397.	2397.	3818.	3818.	3133.	3133.	3032.	3032.	3.7
12	84	169	4757.	5254.	3732.	3492.	5585.	5231.	3432.	3683.	2.5
13	84	169	3636.	3636.	1815.	1815.	4199.	4199.	1252.	1252.	3.4
14	84	169	5375.	5630.	2118.	1713.	5933.	5776.	2105.	2673.	3.2
15	84	169	4111.	4111.	366.	365.	5163.	5163.	1417.	1417.	3.6
16	84	169	4291.	4296.	565.	544.	5340.	5338.	1537.	1601.	3.5

TABLE XI.4.7-3. Connecting Weld Stresses Beam No. 85, Node No. 168

CASE	BEAM	NODE	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	85	168	2429.	2429.	3964.	3964.	3187.	3187.	3106.	3106.	3.7
2	85	168	2233.	3175.	5120.	4951.	2899.	2181.	4657.	4933.	3.7
3	85	168	3531.	3681.	1854.	1854.	4255.	4255.	1230.	1230.	3.3
4	85	168	3006.	3549.	3351.	3122.	3577.	3239.	3033.	3465.	5.3
5	85	168	1451.	1451.	1033.	1033.	2772.	2773.	2354.	2354.	5.1
6	85	168	1993.	2049.	675.	613.	3223.	3207.	1833.	1837.	5.8
7	85	168	6235.	6235.	3377.	3377.	6902.	6902.	2710.	2710.	2.6
8	85	168	3036.	3036.	4001.	4001.	2758.	2758.	3723.	3723.	4.4
9	85	168	1679.	1679.	3709.	3709.	1491.	1491.	3521.	3521.	4.8
11	85	168	2397.	2397.	3318.	3318.	3133.	3133.	3082.	3082.	3.7
12	85	168	2222.	3163.	5071.	4902.	2372.	2150.	4630.	4956.	2.8
13	85	168	3635.	3636.	1815.	1815.	4199.	4199.	1252.	1252.	3.4
14	85	168	2969.	3516.	3323.	3032.	3531.	3189.	3006.	3439.	5.3
15	85	168	4111.	4111.	365.	365.	5163.	5163.	1417.	1417.	3.6
16	85	168	3936.	3945.	509.	257.	4935.	4931.	1279.	1305.	3.8

TABLE XI.4.7-4. Connecting Weld Stresses Beam No. 85, Node No. 166

CASE NO	BEAM NO	NODE NO	UP-LEFT		UP-RIGHT		DOWN-RIGHT		DOWN-LEFT		MIN FACTOR OF SAFETY
			SUL2	SUL3	SUR2	SUR3	SDR2	SDR3	SDL2	SDL3	
1	85	166	2402.	2402.	3546.	3846.	3160.	3160.	3033.	3033.	3.7
2	85	166	2350.	3253.	6224.	6036.	2572.	1724.	5993.	5963.	3.0
3	85	166	3647.	3647.	1853.	1853.	4221.	4221.	1224.	1284.	3.4
4	85	166	2096.	2820.	4170.	3979.	2543.	2040.	3769.	4124.	4.5
5	85	166	1426.	1425.	1007.	1007.	2747.	2747.	2329.	2329.	5.1
6	85	166	1627.	1639.	465.	369.	2846.	2823.	1552.	1610.	6.6
7	85	166	6207.	6207.	3330.	3360.	6374.	6374.	2693.	2693.	2.6
8	85	166	3014.	3014.	3972.	3972.	2736.	2736.	3694.	3694.	4.5
9	85	166	1656.	1656.	3678.	3678.	1470.	1470.	3493.	3493.	4.8
11	85	166	2370.	2370.	3800.	3800.	3106.	3106.	3054.	3054.	3.7
12	85	166	2546.	3358.	5792.	5644.	2637.	1824.	5302.	5539.	2.4
13	85	166	3601.	3601.	1817.	1817.	4164.	4164.	1254.	1254.	3.4
14	85	166	2075.	2802.	4126.	3934.	2511.	2002.	3736.	4093.	4.6
15	85	166	4086.	4085.	340.	340.	5138.	5138.	1392.	1392.	3.7
16	85	166	3726.	3735.	230.	153.	4775.	4771.	1097.	1126.	3.9

XI.5 Analysis of Local Welds

XI.5.1 Beam No. 59

Beams 11, 12, 34, 35, 58, 59, 90, 91, 536, and 537 have cross section shown below

All Welds Indicated are

$\frac{5}{16}$ Fillet x 3" long @ 7" O.C.

C.G. of Beam Section:

$$\begin{aligned}\bar{x} &= \frac{13 \times .375 \times (3.5 + .1875)}{.375 (11 + 11 + 13) + 2 \times 7 \times .5} \\ &= .893''\end{aligned}$$

Figure XI.5.1-1 Cross Section of all Listed Beams.

Beam Section Properties

Moment of Inertia:

$$\begin{aligned}I_{22} &= 0.375 \left(2 \times \frac{11^3}{12} + \frac{13^3}{12} \right) + 2 \times 0.5 \times 7 \times 5.75^2 \\ &= 383.43 \text{ in}^4\end{aligned}$$

$$\begin{aligned}I_{33} &= 2 \times .5 \times 7 \left(\frac{7^2}{12} + 0.893^2 \right) + \frac{3}{8} \times 11 (3.831^2 + 2.044^2) + 13 \times \frac{3}{8} \times 2.794^2 \\ &\quad + \frac{.375^3}{12} (11 + 11 + 13) \\ &= 150.15 \text{ in}^4\end{aligned}$$

First moment of area contributing to the force in the different welds along axis 2-2 is given below. Note that for the interior weld B, the contributing first moments are computed according to section XI.3.1.

For weld A and B $Q_2^A = Q_2^B = \frac{1}{3} (7 \times 0.5 \times 5.75 + .375 \times 1.0 \times 6) = 7.46 \text{ in}^3$

For weld C $Q_2^C = .375 (0.5) (6.25) = 1.172 \text{ in}^3$

First moment of areas contributing to the force in the different welds along axis 3-3 is

For weld A $Q_3^A = 11 \times .375 \times 3.831 = 15.80 \text{ in}^3$

For weld B $Q_3^B = 11 \times .375 \times 2.044 = 8.43 \text{ in}^3$

For weld C $Q_3^C = \frac{13}{2} \times .375 \times 2.794 = 6.81 \text{ in}^3$

Weld Force due to Torsion

Using the formulas derived in Chapter XIII with $A_3 = 0$ yields:

$$Q_6 = 23$$

$$Q_1 = \left\{ \frac{8.625 + 67.562}{8.625} \right\} (11.5 + \frac{.375}{.375} \times 11.5) - 11.5 = 191.67$$

$$Q_2 = \left\{ (5.875 + \frac{.5}{.5} \times 5.875) + \left(\frac{8.625 + 67.562}{8.625} \right) \left(\frac{.5 \times 11.5}{.375} \right) + \left(\frac{.5 \times 11.5}{.375} \right) \left(\frac{11.5}{23} \right) \right\}$$

$$= 154.86$$

$$Q_1' = \frac{.5 \times 11.5}{.375} \left(\frac{191.67}{154.86} \right) = 18.98$$

$$f_1 = \frac{.375 M_t}{2 \left\{ 8.625 (.375) + 67.562 (.5) \left(\frac{191.67}{154.86} \right) \right\}} = \frac{M_t}{240.2} \text{ lb/in}$$

$$f_2 = \frac{0.5 M_t}{2 \left\{ 8.625 (.375) \left(\frac{154.86}{191.67} \right) + 67.562 (.5) \right\}} = \frac{M_t}{140.35} \text{ lb/in}$$

Sample Computations for Beam 59, Node 149, Load Case 2:

$$F_2 = 4858 \text{ lbs}$$

$$T_1 = 91060 \text{ in.lb}$$

$$F_3 = -1408 \text{ lbs}$$

Analysis of weld A

$$V_2 = \frac{F_2 Q_3^A}{2I_{33}} = \frac{4858(15.8)}{2(150.15)} = 256 \text{ lb/in}$$

$$V_3 = \frac{F_3 Q_2^A}{I_{22}} = \frac{1408(7.46)}{383.43} = 27.4 \text{ lb/in}$$

$$V_T = \frac{M_t}{140.35} = \frac{91060}{140.35} = 648.8 \text{ lb/in}$$

$$V_{\max} = 256 + 27.4 + 648.8 = 932.2 \text{ lb/in}$$

Analysis of weld B

$$V_2 = \frac{4858(8.43)}{2(150.15)} = 136.4 \text{ lb/in}$$

$$V_3 = \frac{1408(7.46)}{383.43} = 27.4 \text{ lb/in}$$

$$V_T = \frac{91060}{140.35} - \frac{91060}{240.2} = 269.7 \text{ lb/in}$$

$$V_{\max} = 136.4 + 27.4 + 269.7 = 433.1 \text{ lb/in}$$

Analysis of weld C

$$V_2 = \frac{4858(6.81)}{150.15} = 220.7$$

$$V_3 = \frac{1408(1.172)}{383.43} = 4.3$$

no torsional stress contribution

$$V_{\max} = 220.7 + 4.3 = 225 \text{ lb/in}$$

Capacity of weld according to equation XI.4

$$\text{Capacity} = 1.33(.707)\left(\frac{5}{16}\right)(0.4)(50,000)\left(\frac{3}{7}\right) = 2518.7 \text{ lb/in}$$

$$\text{factor of safety} = \frac{2518.7}{932.2} = 2.72$$

XI.5.2 For Beams no. 71 and 72

All welds indicated are
 $\frac{5}{16}$ " fillet x 3" long @ 7" o.c.

From symmetry, welds A and B are identical and so are welds C and D.

Figure XI.5.2-1 Cross Section of Beams 71 and 72.

Beam Section Properties

Moment of Inertia

$$I_{22} = 474.9 \text{ in}^4 \qquad I_{33} = 259.5 \text{ in}^4$$

First moment of area about 3-3 axis for contributing areas to weld force due to F_2 force

For welds A and B $Q_3^A = Q_3^B = 0.375 \times 11 \times 2.9375 = 12.12 \text{ in}^3$

For weld C $Q_3^C = \frac{13}{2} \times 0.5 \times 3.75 = 12.19 \text{ in}^3$

For weld D $Q_3^D = \frac{13}{2} \times .375 \times 3.6875 = 8.99 \text{ in}^3$

First moment of area about 2-2 axis for contributing area to weld force due to F_3 force. For weld A and B, C and D:

$$Q_2 = \frac{1}{4} (7.875 \times 0.5 \times 5.75 + 0.375 \times 0.5 \times 6.25) = 6 \text{ in}^3$$

For torsion stresses use formulas developed in Chapter XIII.

$$S_1 = S_3 = S_4 = S_6 = 11.5 \text{ in}$$

$$h_1 = h_2 = h_5 = 0.5 \text{ in}$$

$$S_2 = S_5 = 5.875 \text{ in}$$

$$h_3 = h_4 = h_6 = 0.375 \text{ in}$$

$$A_2 = 5.875 \times 11.5 = 67.5625 \text{ in}^2$$

$$A_3 = 0.75 \times 11.5 = 8.625 \text{ in}^2$$

$$A_1 = 0.8125 \times 11.5 = 9.344 \text{ in}^2$$

$$Q_6 = 11.5 + \frac{0.375}{0.375} (11.5) = 23$$

$$Q_1 = \left\{ \frac{9.344 + 67.5625 + 8.625}{9.344} - \frac{(8.625)(11.5)}{(23)(9.344)} \right\} [11.5 + \frac{0.5}{.375} (11.5)] - 11.5$$

$$= 221.7$$

$$Q_2 = \left[\left\{ 5.875 + \left(\frac{0.5}{0.5} \right) 5.875 \right\} + \frac{9.344 + 67.5625 + 8.625}{9.344} \left(\frac{0.5}{.375} \right) (11.5) \right.$$

$$\left. + \left\{ \left(\frac{0.5}{.375} \right) (11.5) - \frac{8.625}{9.344} \left(\frac{0.5}{.375} \right) (11.5) \right\} \left(\frac{11.5}{23} \right) \right]$$

$$= 152.7$$

$$Q_1' = \left[\frac{8.625}{9.344} (11.5 + \frac{0.5}{.375} (11.5)) + \left(\frac{0.5}{0.375} (11.5) - \frac{8.625}{9.344} \left(\frac{0.5}{.375} \right) (11.5) \right) \frac{221.7}{152.7} \right]$$

$$= 26.5$$

$$f_1 = \frac{M_t (0.5)}{2 \left\{ 9.344 (.5) + 67.5625 (0.5) \left(\frac{221.7}{152.7} \right) + 8.625 (.375) \left(\frac{26.5}{23} \right) \right\}}$$

$$= \frac{M_t}{229.8}$$

$$f_2 = \frac{M_t (0.5)}{2 \left\{ 9.344 (.5) \left(\frac{152.7}{221.7} \right) + 67.5625 (0.5) + 8.625 (.375) \left(\frac{26.5}{23} \right) \left(\frac{152.7}{221.7} \right) \right\}}$$

$$= \frac{M_t}{158.3}$$

$$f_3 = \frac{M_t}{229.8} \left(\frac{26.5}{23} \right) \left(\frac{.375}{.5} \right) = \frac{M_t}{265.9}$$

Sample computations using Beam 72, Node 155, Load Case 2

$$F_2 = 25030 \text{ lbs} \quad F_3 = -1753 \text{ lbs} \quad M_T = 78340 \text{ lb.in}$$

Analysis of weld A

$$V_2 = \frac{F_2 Q_3^A}{2 I_{33}} = \frac{25030 (12.12)}{2(259.5)} = 584.5 \text{ lb/in}$$

$$V_3 = \frac{F_3 Q_2^A}{I_{22}} = \frac{1753 (6)}{474.9} = 22.1 \text{ lb/in}$$

$$V_T = f_2 - f_1 = \frac{78340}{158.3} - \frac{78340}{229.8} = 154 \text{ lb/in}$$

$$V_{\max} = 760.6 \text{ lb/in}$$

Analysis of weld B

$$V_2 = \frac{25030 (12.12)}{2(259.5)} = 584.5 \text{ lb/in}$$

$$V_3 = 22.1 \text{ lb/in}$$

$$V_T = f_2 - f_3 = \frac{78340}{158.3} - \frac{78340}{265.9} = 200.3 \text{ lb/in}$$

$$V_{\max} = 806.9 \text{ lb/in}$$

Analysis of weld C

$$V_2 = \frac{25030 (12.19)}{259.5} = 1175.8 \text{ lb/in}$$

$$V_3 = 22.1 \text{ lb/in}$$

$$V_T = f_1 = \frac{78340}{229.8} = 340.9 \text{ lb/in}$$

$$V_{\max} = 1538.8 \text{ lb/in}$$

Analysis of weld D

$$V_2 = \frac{25030 (8.99)}{259.5} - 867.1 \text{ lb/in}$$

$$V_3 = 22.1 \text{ lb/in}$$

$$V_T = f_3 = \frac{78340}{265.9} = 294.6 \text{ lb/in}$$

$$V_{\max} = 1183.8 \text{ lb/in}$$

$$\text{Factor of safety} = \frac{2519}{1538.8} = 1.64$$

$$V_{\max} = 272.4 + 14.94 + 280.5 = 567.84 \text{ lbs/in}$$

Capacity of weld from eqn. X1.4

$$= .707 (.25) (.4) (50000) \frac{2}{5} = 1414 \text{ lbs/in}$$

$$\text{Safety factor} = \frac{1414}{567.84} = 2.49$$

Chapter XII

PLATE ANALYSIS FOR CRITICAL CROSS BEAM CONNECTION

XII.1 Side Plate Stress Analysis Using Rayleigh Ritz Method

The side plate of the longitudinal beam under consideration is welded to one vertical plate of the cross beam No. 4 (beam 552 and 553). Two welding conditions were investigated. Case 1 is three intermittent welds (see Fig. XII. 1-1). Case 2 is a continuous weld. The side plate is subjected to the end forces R_1 , M_2 , M_3 from the cross beam (see Figure XII, 1-2). Due to the effect of R_1 and M_2 , the loading on the welds of the side plate will be constant. The moment M_3 will cause an antisymmetric loading on the plate. Two sets of equations based on these two loading cases were derived using Rayleigh Ritz Method to find out the maximum bending stresses in the plate.

XII.2 Effect Of Force R_1 and Moment M_2 (constant loading, see Figure XII.2-1)

In order to analyze this plate due to constant loading, it is necessary to derive plate equations for fixed-fixed boundary conditions on the opposite edges perpendicular to the line load. The other two edges were kept free.

Fig. XII.2-1 Two Welding Cases of Side Plate

FIG. XII.1-1 Welding Between Cross Beam and Side Plate

FIG. XII.1-2. Member Forces at End of Cross Beam.

An assumption was made that the R_1 and M_2 are resisted only by the welding on two vertical plates of the cross beam. The horizontal welding of the cross beam has no contribution to resist R_1 and M_2 . The assumption is conservative. So, in the case of three intermittent welds, the loading intensity P will be

$$P = \frac{\frac{R_1}{2} + \frac{M_2}{15.5}}{(v_1 - u_1 + v_2 - u_2 + v_3 - u_3)} \quad \#/\text{in.}$$

In continuous welding

$$P = \frac{\frac{R_1}{2} + \frac{M_2}{15.5}}{b} \quad \#/\text{in.}$$

where 15.5" is the width of the cross beam. A displacement function W is assumed which satisfied the fixed-fixed boundary conditions

$$w = (A + BX + CX^2)(1 - \cos \frac{2\pi y}{b})$$

$$\frac{dw}{dy} = (A + BX + CX^2)(\frac{2\pi}{b}) \sin \frac{2\pi y}{b}$$

$$\frac{d^2 w}{dy^2} = (A + BX + CX^2)(\frac{2\pi}{b})^2 \cos \frac{2\pi y}{b}$$

$$\frac{dw}{dx} = (B + 2CX)(1 - \cos \frac{2\pi y}{b})$$

$$\frac{d^2 w}{dx^2} = 2C(1 - \cos \frac{2\pi y}{b})$$

The strain energy U could be expressed as

$$U = \frac{1}{2} D \int_0^a \int_0^b \left(\frac{d^2 w}{dx^2} + \frac{d^2 w}{dy^2} \right)^2 dx dy$$

$$= \frac{D}{2} \int_0^a \int_0^b \left\{ 2C(1 - \cos \frac{2\pi y}{b}) + (A + BX + CX^2)(\frac{2\pi}{b})^2 \cos \frac{2\pi y}{b} \right\}^2 dx dy$$

$$\begin{aligned}
&= \frac{D}{2} \int_0^a \int_0^b \left\{ 4C^2 \left(1 - 2 \cos \frac{2\pi y}{b} + \cos^2 \frac{2\pi y}{b} \right) \right. \\
&\quad - 4C \left(\frac{2\pi}{b} \right)^2 (A + BX + CX^2) \left(\cos \frac{2\pi y}{b} - \cos^2 \frac{2\pi y}{b} \right) \\
&\quad \left. + \left(\frac{2\pi}{b} \right)^4 (A^2 + 2ABX + (B^2 + 2AC) X^2 + 2BCX^3 + C^2 X^4) \cos^2 \frac{2\pi y}{b} \right\} dx dy
\end{aligned}$$

$$\begin{aligned}
U &= \frac{D}{2} \left\{ 4C^2 a \left[y - \frac{b}{\pi} \sin \frac{2\pi y}{b} + \frac{b}{2\pi} \left(\frac{\pi y}{b} + \frac{\sin \frac{4\pi y}{b}}{4} \right) \right] \right. \\
&\quad - 4C \left(\frac{2\pi}{b} \right)^2 \left(Aa + \frac{Ba^2}{2} + C \frac{a^3}{3} \right) \left(\frac{b}{2\pi} \sin \frac{2\pi y}{b} - \frac{y}{2} - \frac{b}{8\pi} \sin \frac{4\pi y}{b} \right) \\
&\quad + \left(\frac{2\pi}{b} \right)^4 \left(A^2 a + ABa^2 + (B^2 + 2AC) \frac{a^3}{3} + BC \frac{a^4}{2} + C^2 \frac{a^5}{5} \right) \left(\frac{y}{2} + \frac{b}{8\pi} \sin \frac{4\pi y}{b} \right) \\
&\quad \left. \right\} \Big|_0^b
\end{aligned}$$

$$\begin{aligned}
&= \frac{D}{2} \left\{ 4C^2 a \left[b + \frac{b}{2} \right] + 4C \left(\frac{2\pi}{b} \right)^2 \left(Aa + \frac{Ba^2}{2} + C \frac{a^3}{3} \right) \left(-\frac{b}{2} \right) \right. \\
&\quad \left. + \left(\frac{2\pi}{b} \right)^4 \left[A^2 a + ABa^2 + (B^2 + 2AC) \frac{a^3}{3} + BC \frac{a^4}{2} + C^2 \frac{a^5}{5} \right] \left(\frac{b}{2} \right) \right\}
\end{aligned}$$

$$\begin{aligned}
&= \frac{D}{2} \left\{ 6abC^2 + 4\pi \left(\frac{2\pi}{b} \right) a (AC + \frac{1}{2} BCa + \frac{1}{3} C^2 a^2) \right. \\
&\quad \left. + \pi \left(\frac{2\pi}{b} \right)^3 \left[A^2 a + ABa^2 + (B^2 + 2AC) \frac{a^3}{3} + BC \frac{a^4}{2} + C^2 \frac{a^5}{5} \right] \right\}
\end{aligned}$$

$$\text{where } D = \frac{Eh^3}{12(1 - \nu^2)} = \frac{30 \times 10^6 \times (0.375)^3}{12(1 - 0.09)} = 144875 \text{ lb.in}$$

The potential energy Ω could be expressed as

$$\begin{aligned}
\Omega &= - \iint P w dx dy \\
&= -P (A + B\xi + C\xi^2) \int_{u_1}^{u_1} (1 - \cos \frac{2\pi y}{b}) dy + \int_{u_2}^{u_2} (1 - \cos \frac{2\pi y}{b}) dy
\end{aligned}$$

$$+ \int_{u_3}^{v_3} (1 - \cos \frac{2\pi y}{b}) dy$$

$$= -P(A + B\xi + C\xi^2)[v_1 - u_1] - \frac{b}{2\pi} (\sin \frac{2\pi v_1}{b} - \sin \frac{2\pi u_1}{b}) + (v_2 - u_2) \\ - \frac{b}{2\pi} (\sin \frac{2\pi u_2}{b} - \sin \frac{2\pi v_2}{b}) + (v_3 - u_3) - (\sin \frac{2\pi v_3}{b} - \sin \frac{2\pi u_3}{b})]$$

$$\text{From } \frac{\partial V}{\partial A} = \frac{\partial(U + \Omega)}{\partial A} = 0$$

yields

$$2\pi a (\frac{2\pi}{b})^3 A + \pi a^2 (\frac{2\pi}{b})^3 B + [\frac{2\pi a^3}{3} (\frac{2\pi}{b})^3 - 4\pi a (\frac{2\pi}{b})] C = \frac{2PK}{D} \quad (\text{XII.2.1})$$

where

$$k = (v_1 - u_1) - \frac{b}{2\pi} (\sin \frac{2\pi v_1}{b} - \sin \frac{2\pi u_1}{b}) \\ + (v_2 - u_2) - \frac{b}{2\pi} (\sin \frac{2\pi v_2}{b} - \sin \frac{2\pi u_2}{b}) \\ + (v_3 - u_3) - \frac{b}{2\pi} (\sin \frac{2\pi v_3}{b} - \sin \frac{2\pi u_3}{b})$$

$$\text{From } \frac{\partial V}{\partial B} = \frac{\partial(U + \Omega)}{\partial B} = 0$$

yields

$$\pi a^2 (\frac{2\pi}{b})^3 A + \frac{2\pi}{3} a^3 (\frac{2\pi}{b})^3 B + [\frac{\pi a^4}{2} (\frac{2\pi}{b})^3 - 2\pi a^2 (\frac{2\pi}{b})] C = \frac{2PK}{D} \xi \quad (\text{XII.2.2})$$

$$\text{From } \frac{\partial V}{\partial C} = \frac{\partial(U + \Omega)}{\partial C} = 0$$

yields

$$[\frac{2}{3} \pi a^3 (\frac{2\pi}{b})^3 - 4\pi a (\frac{2\pi}{b})] A + [\frac{\pi a^4}{2} (\frac{2\pi}{b})^3 - 2\pi a^2 (\frac{2\pi}{b})] B + [\frac{2}{5} \pi a^5 (\frac{2\pi}{b})^3 - \frac{8}{3} \pi a^3 (\frac{2\pi}{b}) \\ + 12ab] C = \frac{2PK}{D} \xi^2 \quad (\text{XII.2.3})$$

The three unknowns A, B, and C could be solved from the three simultaneous equations (XII.2.1), (XII.2.2) and (XII.2.3). Once they are solved, the bending moments M_x , M_y of the plate are expressed as

$$\begin{aligned}
 M_x &= -D \left[\frac{\partial^2 w}{\partial x^2} + \nu \frac{\partial^2 w}{\partial y^2} \right] \\
 &= -D \left[2C(1 - \cos \frac{2\pi y}{b}) + \nu (\frac{2\pi}{b})^2 (A + Bx + Cx^2) \cos \frac{2\pi y}{b} \right] \\
 M_y &= -D \left[\frac{\partial^2 w}{\partial y^2} + \nu \frac{\partial^2 w}{\partial x^2} \right] \\
 &= -D \left[2 \nu C(1 - \cos \frac{2\pi y}{b}) + (\frac{2\pi}{b})^2 (A + Bx + Cx^2) \cos \frac{2\pi y}{b} \right]
 \end{aligned}$$

To find out maximum M_x , M_y

$$\begin{cases} \frac{\partial M_x}{\partial x} = 0 \rightarrow B + 2Cx = 0, & x = -\frac{B}{2C} = 19'' \\ \frac{\partial M_x}{\partial y} = 0 \rightarrow \sin \frac{2\pi y}{b} = 0, & y = 0, \frac{b}{2}, b \end{cases}$$

$$\begin{cases} \frac{\partial M_y}{\partial x} = 0 \rightarrow B + 2Cx = 0, & x = 19'' \\ \frac{\partial M_y}{\partial y} = 0 \rightarrow \sin \frac{2\pi y}{b} = 0, & y = 0, b, \frac{b}{2} \end{cases}$$

The maximum M_x , M_y are located on the two fixed edges and center line of the plate. Once M_x , M_y are solved, the bending stress of $\pm \frac{h}{2}$ plane are expressed as

$$\sigma = \pm \frac{6M}{h^2}$$

XII.3 Effect of Moment M_3

$$P = \frac{M_3}{15.5 \times b}$$

$$q = \pm \frac{P \cdot y}{\frac{b}{2}}$$

Fig. XII.3-1 Welding of Cross Beam

The left vertical plate of the cross beam is welded to the side plate. The loading intensity q imposed by side plate due to M_3 , is assumed to be linearly proportional to the distance y from the center line in all three intermittent welds and continuous weld. The maximum intensity is P at $y = \pm \frac{b}{2}$. To find out the P value, it is assumed that the moment M_3 is only resisted by the top and bottom horizontal welding (see Figure XII.3-1).

$$P = \frac{M_3}{15.5 \times b}$$

The P value obtained from this assumption is a conservative value. So the loading intensity q used in the side plate analysis, is also a conservative value. The distribution of loading and intensity q on both welding cases are shown on Figure XII.3-2.

$$a = 24.75" \quad b = 11.5" \quad P = \frac{M_3}{15.5 \times b} \quad q = \pm \frac{p \cdot y}{\frac{b}{2}}$$

$$\xi = 4"$$

Fig. XII.3- 2 Two Welding Cases of Side Plate

Due to antisymmetric loading, a displacement function W was chosen such that it satisfies the antisymmetric deformed shape.

Choose

$$w = (A + BX + CX^2) \left(y - \frac{8}{b^2} y^3 + \frac{16}{b^4} y^5 \right)$$

which satisfies the boundary conditions:

$$w = 0 \quad \text{at} \quad y = 0 \quad \text{and} \quad y = \pm \frac{b}{2}$$

$$\frac{dw}{dy} = 0 \quad \text{at} \quad y = \pm \frac{b}{2}$$

and w is antisymmetric in y .

$$\frac{dw}{dx} = (B + 2CX) \left(y - \frac{8}{b^2} y^3 + \frac{16}{b^4} y^5 \right)$$

$$\frac{d^2w}{dx^2} = 2C \left(y - \frac{8}{b^2} y^3 + \frac{16}{b^4} y^5 \right)$$

$$\frac{dw}{dy} = (A + BX + CX^2) \left(1 - \frac{24}{b^2} y^2 + \frac{80}{b^4} y^4\right)$$

$$\frac{d^2w}{dy^2} = (A + BX + CX^2) \left(-\frac{48}{b^2} y + \frac{320}{b^4} y^3\right)$$

$$U = \frac{D}{2} \int_0^a \int_{-b/2}^{b/2} \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right)^2 dx dy$$

$$= \left\{ 1.8470 \times 10^{-2} ab^3 c^2 - 0.8218 ab \left(AC + \frac{a}{2} BC + \frac{a^2}{3} C^2 \right) + 18.2857 \frac{a}{b} \left[A^2 + aAB + \frac{a^2}{3} (B^2 + 2AC) + \frac{a^3}{2} BC + \frac{a^4}{5} C^2 \right] \right\} D$$

for three intermittent weldings

$$\Omega = - \int q w dx dy \quad \text{assume } \frac{v_2 - u_2}{2} = S$$

$$= -2 \int_0^S \frac{P \cdot y}{b/2} (A + B\xi + C\xi^2) \left(y - \frac{8}{b^2} y^3 + \frac{16}{b^4} y^5\right) dy$$

$$= -2 \int_{u_1}^{u_1} \frac{P \cdot y}{b/2} (A + B\xi + C\xi^2) \left(y - \frac{8}{b^2} y^3 + \frac{16}{b^4} y^5\right) dy$$

$$= -\frac{4P}{b} (A + B\xi + C\xi^2) \cdot K$$

where

$$K = \left[\left(\frac{S^3}{3} - \frac{8}{5b^2} S^5 + \frac{16}{7b^4} S^7 \right) + \left(\frac{u_1^3}{3} - \frac{v_1^3}{3} \right) - \frac{8}{5b^2} (u_1^5 - v_1^5) + \frac{16}{7b^4} (u_1^7 - v_1^7) \right]$$

For continuous welding

$$\Omega = - \int_{b/2}^{b/2} \frac{P \cdot y}{b/2} (A + B\xi + C\xi^2) \left(y - \frac{8}{b^2} y^3 + \frac{16}{b^4} y^5\right) dy$$

$$= -3.895 \times 10^{-2} Pb^2 (A + B\xi + C\xi^2)$$

$$\frac{\partial V}{\partial A} = \frac{\partial (U + \Omega)}{\partial A} = 0$$

yields

$$\begin{aligned}
 & 36.5714 \left(\frac{a}{b} \right) A + 18.2857 \frac{a^2}{b} B + [12.1905 \frac{a^3}{b} - 0.8218 ab] C \\
 & = \frac{4P}{Db} \cdot K \quad \text{three welds} \\
 & = 3.8095 \times 10^{-2} \frac{Pb}{D} \quad \text{continuous weld}
 \end{aligned}$$

$$\frac{\partial V}{\partial B} = \frac{\partial (U + \Omega)}{\partial B} = 0$$

yields

$$\begin{aligned}
 & 18.2857 \frac{a^2}{b} A + 12.1905 \frac{a^3}{b} B + [9.14285 \frac{a^4}{b} - 0.4109 a^2 b] C \\
 & = \frac{4P\xi}{Db} K \quad \text{three welds} \\
 & = 3.8095 \times 10^{-2} \frac{Pb\xi}{D} \quad \text{continuous weld}
 \end{aligned}$$

$$\frac{\partial V}{\partial C} = \frac{\partial (U + \Omega)}{\partial C} = 0$$

yields

$$\begin{aligned}
 & (12.1905 \frac{a^3}{b} - 0.8218 ab) A + (9.14285 \frac{a^4}{b} - 0.4109 a^2 b) B \\
 & + (3.694 \times 10^{-2} ab^3 - 0.5479 a^3 b + 7.3143 \frac{a^5}{b}) C \\
 & = \frac{4P\xi^2}{Db} K \quad \text{three welds} \\
 & = 3.8095 \times 10^{-2} \frac{Pb\xi^2}{D} \quad \text{continuous weld}
 \end{aligned}$$

$$M_x = -D \left(\frac{\partial^2 w}{\partial x^2} + \nu \frac{\partial^2 w}{\partial y^2} \right)$$

$$= -D\left[2C\left(y - \frac{8}{b^2}y^3 + \frac{16}{b^4}y^5\right) + \nu(A + BX + CX^2)\left(-\frac{48}{b^2}y + \frac{320}{b^4}y^3\right)\right]$$

$$M_y = -D\left(\frac{\partial^2 w}{\partial y^2} + \nu \frac{\partial^2 w}{\partial x^2}\right)$$

$$= -D\left[2\nu C\left(y - \frac{8}{b^2}y^3 + \frac{16}{b^4}y^5\right) + (A + BX + CX^2)\left(-\frac{48}{b^2}y + \frac{320}{b^4}y^3\right)\right]$$

To find maximum M_x and M_y

$$\begin{cases} \frac{\partial M_x}{\partial x} = 0 \quad \rightarrow B + 2Cx = 0 & x = -\frac{B}{2C} = 19.9'' \\ \frac{\partial M_x}{\partial y} = 0 \quad \rightarrow y = \pm \frac{b}{\sqrt{20}} = \pm 2.9'' \end{cases}$$

$$\begin{cases} \frac{\partial M_y}{\partial x} = 0 \quad \rightarrow B + 2Cx = 0 & x = -\frac{B}{2C} = 19.9'' \\ \frac{\partial M_y}{\partial y} = 0 \quad \rightarrow y = \pm \frac{b}{\sqrt{20}} = \pm 2.9'' \end{cases}$$

XII.4 Results Obtained from Computer Program

A computer program was written to solve the simultaneous equations for both constant loading and antisymmetric loading (see Appendix H). Table XII.4-1 shows the input data for R_1 , M_2 , and M_3 for all the load cases.

Table XII.4-1 Input Data of R_1 , M_2 and M_3

Load Case	R_1 (lb)	M_2 (in.lb)	M_3 (in.lb)
1	325.0	13220.	35280.
2	344.7	-27640.	-32880.
2	-344.7	-55110.	-103200.
3	-1605.0	24010.	22610.
4	-1582.	-11020.	-28470.
4	1582.0	-56880.	-74360.
5	-2882.0	20530.	-12510.
6	-2959.	21220.	-25730.
6	2959.	-29740.	4953.
7	-4840.	49680.	-18670.
8	-2914.	6232.	-23600.
9	2501.	3722.	5059.
11	332.6	12780.	35390.
12	351.6	-28000.	-32630.
12	-351.6	-54580.	-103200.
13	-1594.	23590.	22690.
14	-1570.	-11380.	-28290.
14	1570.	-56370.	-74340.
15	-3105.	35520.	-21680.
16	-3105.	33340.	-27440.
16	3105.	-37750.	15730.

Load case 2, 4, 6, 12, 14, and 16 have two sets of inputs. This is due to these cases being unsymmetric loading cases (one lifting cylinder is assumed failed). Left-hand side member forces are not equal to right-hand side member forces. The location of three intermittent welds is shown on Fig. XII.4-1.

Fig. XII.4-1 Location of Three Intermittent Welds

The program calculates the stresses along the fixed edge, center line where the maximum moment occurs. It is observed from the output that the stress σ_x is small compared with σ_y . The bending stresses σ_y of load case 1 are tabulated in Table XII.4-2 and Table XII.4-3.

Table XII. 4 -2 Stress (σ_y) of Load Case 1 (Three intermittent welds)

x (in)	along fixed edge (psi)		along centerline (psi)	
	$R_1 + M_2$	M_3	$R_1 + M_2$	M_3
0.00	2850.48	-1728.11	-2819.02	769.71
1.00	2556.38	-1555.06	-2524.92	692.32
2.00	2277.93	-1390.82	-2246.47	618.87
3.00	2015.14	-1235.37	-1983.68	549.35
4.00	1768.00	-1088.73	-1736.54	483.77
5.00	1536.51	-950.89	-1505.05	422.13
6.00	1320.67	-821.85	-1289.21	364.42
7.00	1120.49	-701.61	-1089.03	310.65
8.00	935.95	-590.18	-904.49	260.81
9.00	767.07	-487.54	-735.61	214.91
10.00	613.84	-393.71	-582.38	172.95
11.00	476.26	-308.68	-444.80	134.92
12.00	354.33	-232.45	-322.87	100.83
13.00	248.05	-165.02	-216.59	70.68
14.00	157.43	-106.40	-125.97	44.46
15.00	82.45	-56.57	-50.99	22.18
16.00	23.13	-15.55	8.33	3.83
17.00	-20.54	16.67	52.00	-10.58
18.00	-48.56	40.09	80.01	-21.05
19.00	-60.92	54.71	92.38	-27.59
20.00	-57.64	60.53	89.10	-30.19
21.00	-38.70	57.55	70.16	-28.86
22.00	-4.11	45.76	35.57	-23.59
23.00	46.13	25.17	-14.67	-14.38
24.00	112.02	-4.22	-80.56	-1.24
24.75	171.71	-32.04	-140.25	11.20

Table XII.4 -3 Stress σ_y of Load Case 1 (continuous weld)

x (in)	along fixed edge (psi)		along centerline (psi)	
	$R_1 + M_2$	M_3	$R_1 + M_2$	M_3
0.00	2996.13	-3111.42	-2963.06	1385.85
1.00	2687.01	-2799.85	-2653.94	1246.51
2.00	2394.33	-2504.13	-2361.27	1114.26
3.00	2118.11	-2224.26	-2085.04	989.10
4.00	1858.34	-1960.23	-1825.28	871.02
5.00	1615.02	-1712.05	-1581.96	760.03
6.00	1388.16	-1479.72	-1355.09	656.13
7.00	1177.74	-1263.24	-1144.68	559.31
8.00	983.78	-1062.60	-950.71	469.59
9.00	806.26	-877.81	-773.20	386.95
10.00	645.20	-708.87	-612.14	311.39
11.00	500.59	-555.77	-467.53	242.92
12.00	372.43	-418.52	-339.37	181.54
13.00	260.73	-297.12	-227.66	127.25
14.00	165.47	-191.56	-132.40	80.05
15.00	86.67	-101.85	-53.60	39.93
16.00	24.31	-27.99	8.75	6.89
17.00	-21.59	30.02	54.65	-19.05
18.00	-51.04	72.19	84.10	-37.91
19.00	-64.04	98.51	97.10	-49.68
20.00	-60.58	108.98	93.65	-54.36
21.00	-40.68	103.61	73.74	-51.96
22.00	-4.32	82.39	37.39	-42.47
23.00	48.49	45.32	-15.42	-25.89
24.00	117.74	-7.59	-84.68	-2.23
24.75	180.48	-57.68	-147.42	20.17

It is seen that the total stress (stress due to R_1 , M_2 plus stress due to M_3) along the fixed edge is greater than the total stress along the centerline. Meanwhile, the maximum stress along the fixed edge occurs at $x = 0$ " position. In other words, it is the location of the maximum stress of the side plate. This is true in all the loading cases (1 through 16). Since the analysis performed here is a linear elastic analysis, we only consider the stress at $x = 0$ " located on the fixed edge. Table XII.4-4 shows the maximum stress on the side plate of every loading case.

Table XII.4-4 Maximum Stress of Side Plate (psi)

Loading case	Intermittent Welds			Continuous Weld		
	$R_1 + M_2$	M_3	$R_1 + M_2 + M_3$	$R_1 + M_2$	M_3	$R_1 + M_2 + M_3$
1	2850.5	1728.1	4578.6	2996.1	3111.4	6107.5
2	8074.0	1610.5	9657.5	8486.6	2899.7	11386.3
2	13967.9	5055.0	19022.9	14681.7	9101.4	23783.1
3	9708.8	1107.5	10816.3	10204.9	1994.0	12198.9
4	330.4	1394.5	1724.9	347.3	2510.8	2858.1
4	18416.8	3642.4	22059.2	19357.9	6557.9	25915.8
5	11418.0	612.8	12028.8	12001.4	1103.3	13104.7
6	11760.7	1260.3	13021.0	12361.7	2269.2	14630.9
6	14030.2	242.6	14272.8	14747.1	436.8	15184.6
7	14232.3	914.5	15146.8	14959.8	1646.5	16606.3
8	7675.5	1155.9	8831.4	8067.7	2081.3	10149.0
9	4171.5	247.8	4419.3	4384.7	446.2	4830.9
11	2717.6	1733.5	4450.6	2856.5	3121.2	5977.7
12	8184.1	1598.3	9782.4	8602.3	2877.7	11480
12	13812.6	5055.0	18867.6	14518.3	9101.4	23619.7
13	9574.2	1111.4	10685.6	10063.4	2001.1	12064.5
14	209.7	1385.7	1595.4	220.4	2495.9	2716.3
14	18256.2	3641.4	21897.6	19189.1	6556.2	25745.3
15	15871.2	1061.9	16933.1	16682.0	1912.1	18594.1
16	15290.5	1344.1	16634.1	16071.8	2419.9	18491.7
16	16465.2	770.	17235.2	17306.6	1387.3	18693.9

From the table, it is seen that the maximum bending stress of the side plate is 25915.8 psi, occurring in loading case 4.

For normal loading conditions the maximum stress is 18594.1 occur loading case 15. The AISC allowable stress for the side plate is 0.6 of the yield stress for normal conditions, and this value is increased by 33% for the accidental condition. Therefore, the factor of safety for the above two cases are:

For normal condition (loading 15)

$$= \frac{0.6 (50,000)}{18594.1} = 1.61$$

For accidental condition (loading 4)

$$= \frac{1.33 (0.6) (50,000)}{25915.8} = 1.54$$

Chapter XIII

Torsional Shear Stress in Reinforced Box Sections

XIII.1 Introduction

In this chapter, the formulas for the shear stresses in a reinforced box section are derived. These formulas are obtained using the membrane analogy approach and neglect the high stress concentrations in reentrant corners. These formulas are necessary for the local weld stress analysis in particular, in which the stresses around the welds are necessary to evaluate the safety of such welds. However, for the case of member stress analysis, simplified analysis was adopted for evaluating the torsional rigidity and member stresses for beams having reinforced sections that are composed of some very narrow cells adjoining a large cell.

$$\text{Area } A = \left(c + \frac{c}{2} + \frac{d}{2} \right) \left(B + \frac{a}{2} + \frac{b}{2} \right)$$

Figure XIII.1-1 Cell Dimensions

Figure XIII.1-1 shows how the area A in Formula XIII.2 is obtained. In this chapter, in addition to deriving the complete formulas for shear stresses in a 3-cell section, these stresses are used to verify the validity of the simplified approach.

$$\tau_1 = \frac{f_1}{h_1} \quad \tau_2 = \frac{f_2}{h_2} \quad \tau_3 = \frac{f_1 - f_2}{h_3} \quad \tau_4 = \frac{f_2 - f_3}{h_4} \quad \tau_5 = \frac{f_2}{h_5} \quad \tau_6 = \frac{f_3}{h_6}$$

Figure XIII.2-2 Reinforced Box Section

XIII.2 Derivation of Formulas

Following the membrane analogy of Reference 7, the torsional shearing stress formulas can be derived for cross-sections with two internal reinforcement plates of the SLSF-Cradle Structure cross-sections, as shown in the attached Figure XIII.2-2

Figure XIII.2-1 Membrane With Plate

h is the thickness of the wall, f is the difference in the levels of the two boundaries and ds is the element arc length differential at the broken line. The shearing stress is given by

$$\tau = \frac{f}{h} \quad \text{XIII.1}$$

If A is the area bounded by the broken line, then from the membrane analogy, Reference 7 gives the torsional moment.

$$M_t = 2Af \quad \text{XIII.2}$$

or

$$\tau = \frac{M_t}{2Ah} \quad \text{XIII.3}$$

Reference 7 also calculates the angle of twist θ per unit length of tubular member by considering the strain energy of torsion.

$$\theta = \frac{M_t}{4A^2G} \int_0^S \frac{ds}{h} = \frac{1}{2AG} \int_0^S \tau ds \quad \text{XIII.4}$$

Reference 7 provides the method of analysis with one reinforcing plate. For two reinforcing plates, it is only a simple extension of the method of Reference 7.

For beams 71 and 72 of the SLSF Cradle Structure, for example, the different loops forming the cross-sections are enclosed by the broken lines $B_1, B_2, B_3, B_4, B_5, B_6, B_7$, and B_8 as shown in the attached figure.

Let A_1, A_2 , and A_3 be the areas enclosed by the broken lines in the above figure. Let S_1, S_2, S_3, S_4, S_5 , and S_6 be the centerline lengths measured along B_1, B_2, B_3 and $B_4; B_4$ and $B_5; B_4$ and $B_1; B_5$ and $B_8; B_1$ and $B_8; B_5, B_6, B_7$, and B_8 ; respectively.

Then the shearing stresses in the various walls, which are the slopes of the membranes, are given by $\tau_1, \tau_2, \tau_3, \tau_4, \tau_5$, and τ_6 , respectively.

$$\tau_1 = \frac{f_1}{h_1} \quad \text{XIII.5}$$

$$\tau_2 = \frac{f_2}{h_2} \quad \text{XIII.6}$$

$$\tau_3 = \frac{f_1 - f_2}{h_3} = \frac{\tau_1 h_1 - \tau_2 h_2}{h_3} \quad \text{XIII.7}$$

$$\tau_4 = \frac{f_2 - f_3}{h_4} = \frac{\tau_2 h_2 - \tau_6 h_6}{h_4} \quad \text{XIII.8}$$

$$\tau_5 = \frac{f_2}{h_5} = \frac{h_2}{h_5} \tau_2 \quad \text{XIII.9}$$

$$\tau_6 = \frac{f_3}{h_6} \quad \text{XIII.10}$$

Where f_1 , f_2 , and f_3 denote elevations of three cells. Further,

$$M_t = 2A_1 f_1 + 2A_2 f_2 + 2A_3 f_3 \quad \text{XIII.11}$$

Substituting for f_1 , f_2 , and f_3 from Equations XIII.5 to XIII.10 we get

$$M_t = 2A_1 h_1 \tau_1 + 2A_2 h_2 \tau_2 + 2A_3 h_6 \tau_6 \quad \text{XIII.12}$$

Now equation XIII.4 gives

$$\tau_1 S_1 + \tau_3 S_3 = 2G\theta A_1 \quad \text{XIII.13}$$

$$-\tau_3 S_3 + \tau_2 S_2 + \tau_5 S_5 + \tau_4 S_4 = 2G\theta A_2 \quad \text{XIII.14}$$

$$-\tau_4 S_4 + \tau_6 S_6 = 2G\theta A_3 \quad \text{XIII.15}$$

Adding Equations XIII.13, XIII.14, XIII.15 and using Equation XIII.9, we get

$$\tau_1 S_1 + \tau_2 \left\{ S_2 + \frac{h_2}{h_5} S_5 \right\} + \tau_6 S_6 = 2G\theta (A_1 + A_2 + A_3) \quad \text{XIII.16}$$

Further, using Equations XIII.7 and XIII.8, Equations XIII.13 and XIII.15 become

$$\tau_1 \left\{ S_1 + \frac{h_1}{h_3} S_3 \right\} - \tau_2 \frac{h_2}{h_3} S_3 = 2G\theta A_1 \quad \text{XIII.17}$$

$$-\tau_2 \frac{h_2}{h_4} S_4 + \left\{ \frac{h_6}{h_4} S_4 + S_6 \right\} \tau_6 = 2G\theta A_3 \quad \text{XIII.18}$$

Determining $2G\theta$ from Equation XIII.17 and substituting in Equations XIII.16 and XIII.18, we get

$$\begin{aligned} & \left[S_1 - \left(\frac{A_1 + A_2 + A_3}{A_1} \right) \left(S_1 + \frac{h_1}{h_3} S_3 \right) \right] \tau_1 + \left[\left(S_2 + \frac{h_2}{h_5} S_5 \right) + \left(\frac{A_1 + A_2 + A_3}{A_1} \right) \right. \\ & \quad \left. \left(\frac{h_2 S_3}{h_3} \right) \right] \tau_2 \\ & = -\tau_6 S_6 \end{aligned} \quad \text{XIII.19}$$

$$\left(\frac{A_3}{A_1}\right)\left(s_1 + \frac{h_1}{h_3} s_3\right) \tau_1 + \left(\frac{h_2}{h_4} s_4 - \frac{A_3}{A_1} \frac{h_2}{h_3} s_3\right) \tau_2 = \left(s_6 + \frac{h_6}{h_4} s_4\right) \tau_6 \quad \text{XIII.20}$$

Substituting for τ_6 from Equation 20 into Equation 19, we get

$$\tau_2 = \frac{Q_1}{Q_2} \tau_1 \quad \text{XIII.21}$$

$$\tau_6 = \frac{Q'_1}{Q_6} \tau_1 = \left(\frac{Q'_1}{Q_6}\right)\left(\frac{Q_2}{Q_1}\right) \tau_2 \quad \text{XIII.22}$$

where

$$Q_6 = s_6 + \frac{h_6}{h_4} s_4 \quad \text{XIII.23}$$

$$Q_1 = \left\{ \left(\frac{A_1 + A_2 + A_3}{A_1} \right) - \left(\frac{A_3}{Q_6} \frac{s_6}{A_1} \right) \right\} \left(s_1 + \frac{h_1}{h_3} s_3 \right) - s_1 \quad \text{XIII.24}$$

$$Q_2 = \left[\left(s_2 + \frac{h_2}{h_5} s_5 \right) + \left(\frac{A_1 + A_2 + A_3}{A_1} \right) \left(\frac{h_2}{h_3} s_3 \right) + \left(\frac{h_2}{h_4} s_4 - \frac{A_3}{A_1} \frac{h_2}{h_3} s_3 \right) \left(\frac{s_6}{Q_6} \right) \right] \quad \text{XIII.25}$$

$$Q'_1 = \left[\left(\frac{A_3}{A_1} \right) \left(s_1 + \frac{h_1}{h_3} s_3 \right) + \left(\frac{h_2}{h_4} s_4 - \frac{A_3}{A_1} \frac{h_2}{h_3} s_3 \right) \frac{Q_1}{Q_2} \right] \quad \text{XIII.26}$$

Using Equation XIII.12

$$\tau_1 = \frac{M_t}{2 \left\{ A_1 h_1 + A_2 h_2 \left(\frac{Q_1}{Q_2} \right) + A_3 h_3 \left(\frac{Q'_1}{Q_6} \right) \right\}} \quad \text{XIII.27}$$

$$\tau_2 = \frac{M_c}{2 \left\{ A_1 h_1 \left(\frac{Q_2}{Q_1} \right) + A_2 h_2 + A_3 h_3 \left(\frac{Q'_1}{Q_6} \right) \left(\frac{Q_2}{Q_1} \right) \right\}} \quad \text{XIII.28}$$

$$\tau_3 = \frac{\tau_1 h_1 - \tau_2 h_2}{h_3} \quad \text{XIII.29}$$

$$\tau_6 = \left(\frac{Q'_1}{Q_6} \right) \tau_1 \quad \text{XIII.30}$$

$$\tau_4 = \frac{\tau_2 h_2 - \tau_6 h_6}{h_4} \quad \text{XIII.31}$$

$$\tau_5 = \left(\frac{h_2}{h_5} \right) \tau_2 \quad \text{XIII.32}$$

Note that the above formulas are verified in Appendix G using an independent approach.

XIII.3 Sample Calculation

$$S_1 = S_3 = S_4 = S_6 = 11.5$$

$$S_2 = S_5 = 5.875$$

$$Q_6 = S_6 + \frac{h_6}{h_4} S_4 = 11.5 + \frac{.375}{.375} \times 11.5 = 23$$

$$Q_1 = \left\{ \left(\frac{8.625 + 67.562 + 8.625}{8.625} \right) - \left(\frac{8.625 \times 11.5}{23.00 \times 8.625} \right) \right\} \left(11.5 + \frac{.375}{.375} \times 11.5 \right) - 11.5$$

$$\underline{Q_1 = 203.165}$$

$$Q_2 = \left[\left(5.875 + \frac{.5}{.5} \times 5.875 \right) + \left(\frac{8.625 + 67.562 + 8.625}{8.625} \right) \left(\frac{.5 \times 11.5}{.375} \right) \right. \\ \left. + \left(\frac{.5 \times 11.5}{.375} - \frac{8.625 \times .5}{8.625 \times .375} \times 11.5 \right) \left(\frac{11.5}{23} \right) \right]$$

$$\underline{Q_2 = 162.527}$$

$$Q_1^1 = \left(\frac{8.625}{8.625} \right) \left(11.5 + \frac{.375}{.375} \times 11.5 \right) + \left(\frac{.5 \times 11.5}{.375} - \frac{8.625 \times .5}{8.625 \times .375} \times 11.5 \right) \frac{203.165}{162.527}$$

$$\underline{Q_1^1 = 23}$$

$$f_1 = \tau_1 h_1 = \frac{M_t h_1}{2 \left\{ A_1 h_1 + A_2 h_2 \left(\frac{Q_1}{Q_2} \right) + A_3 h_3 \left(\frac{Q_1'}{Q_6} \right) \right\}} \\ = \frac{0.375 M_t}{2 \left\{ 8.625(.375) + 67.562(.5) \left(\frac{203.165}{162.527} \right) + 8.625(.375) \left(\frac{23}{23} \right) \right\}} \\ = \frac{M_t}{259.7}$$

$$f_2 = \tau_2 h_2 = \frac{M_t h_2}{2 \left\{ A_1 h_1 \left(\frac{Q_2}{Q_1} \right) + A_2 h_2 + A_3 h_3 \left(\frac{Q_1'}{Q_6} \right) \left(\frac{Q_2}{Q_1} \right) \right\}} \\ = \frac{0.5 M_t}{2 \left\{ 8.625(.375) \left(\frac{162.527}{203.165} \right) + 67.562(.5) + 8.625(.375) \left(\frac{23}{23} \right) \left(\frac{162.527}{203.165} \right) \right\}} \\ = \frac{M_t}{155.8}$$

$$f_3 = \tau_6 h_6 = \left(\frac{Q_1'}{Q_6} \right) \tau_1 h_6 = \frac{Q_1'}{Q_6} f_1 = \frac{M_t}{259.7}$$

Now using the approximate approach, the equivalent section is a single box of centerline dimensions 6.625 x 11.5. Therefore, the maximum shear flow is

$$f_{\max} = \frac{M_t}{2A} = \frac{M_t}{2(6.625 \times 11.5)} = \frac{M_t}{152.4}$$

The error resulting from the approximation is

$$\text{error} = \frac{f_{\max} - f_{\text{exact}}}{f_{\text{exact}}} \times 100 = \frac{\frac{1}{152.4} - \frac{1}{155.8}}{\frac{1}{155.8}} \times 100 = 2.23\%$$

which is certainly within acceptable tolerance.

Chapter XIV

Integrity of Critical Attachments II

XIV.1 Introduction

The integrity of critical attachments to the cradle structure is investigated in this chapter. The main concern in these critical attachments is to study the local effects of some abrupt changes in cross-section, such as notches, as well as the effect of kinks. In other words, the objective here is to evaluate the effect of stress concentration at these critical attachments. Such analysis is not warranted for the other components of the cradle structure since it was found that stresses are low compared with AISC requirements, (see Chapter X). However, due to the relative importance of the cylinder attachment with regards to the overall safety of the cradle structure, the following investigation is undertaken to ensure the safety of such attachment.

XIV.2 Adequacy of Hydraulic Cylinder Attachment

In the three dimensional finite element model of the cradle structure, given in Volume II of this report, the cylinder attachment structure is modeled as a separate beam element between cylinder end and saddle cross beam. The three components of the cylinder are applied at the end of the cylinder attachment structure. Loads at the interface between this beam element and the saddle are computed by the Sturdyne Code, and they depend upon the beam element section properties. The following is an approximate model in which the attachment plates ABC, Fig. XIV.2-1, are modeled as a planar grid. The strain energy approach is used to analyze the statically indeterminate structure.

XIV.2.1 Strain Energy due to Bending Moment and Torsion

$$W = \sum \int \frac{M^2}{2EI} ds + \sum \int \frac{T^2}{2GJ} ds$$

Fig. XIV. 2-2 Upper Cylinder Bracket

Apply Castigliano's second theorem, the deflection and rotation at point A are zero

$$\rightarrow \begin{cases} \frac{\partial W}{\partial x_a} = 0 \\ \frac{\partial W}{\partial x_b} = 0 \\ \frac{\partial W}{\partial x_c} = 0 \end{cases}$$

$$\rightarrow \begin{cases} \Sigma \int M \frac{\partial M}{\partial x_a EI} ds + \Sigma \int T \frac{\partial T}{\partial x_a GJ} ds = 0 \\ \Sigma \int M \frac{\partial M}{\partial x_b EI} ds + \Sigma \int T \frac{\partial T}{\partial x_b GJ} ds = 0 \\ \Sigma \int M \frac{\partial M}{\partial x_c EI} ds + \Sigma \int T \frac{\partial T}{\partial x_c GJ} ds = 0 \end{cases}$$

XIV.2.2 Primary Structure

Fig. XIV.2.2-1 Normal Loading on Assumed Model of Hydraulic Cylinder Attachment

$$EI_1 = 30 \times 10^3 \times 36 = 108 \times 10^4 \text{ k-in}^2$$

$$GJ_1 = 11.5 \times 10^3 \times 36 = 41.4 \times 10^4 \text{ k-in}^2$$

$$EI_2 = 30 \times 10^3 \times 180 = 540 \times 10^4 \text{ k-in}^2$$

$$GJ_2 = 11.5 \times 10^3 \times 182 = 209.3 \times 10^4 \text{ k-in}^2$$

Redundants:

$$x_a = \text{shear}$$

$$x_b = \text{bending moment}$$

$$x_c = \text{torsion moment}$$

From A to B

$$M = x_b - x_a \cdot x, \quad T = x_c$$

$$\frac{\partial M}{\partial x_a} = -x, \quad \frac{\partial M}{\partial x_b} = 1, \quad \frac{\partial M}{\partial x_c} = 0$$

$$\frac{\partial T}{\partial x_a} = 0, \quad \frac{\partial T}{\partial x_b} = 0, \quad \frac{\partial T}{\partial x_c} = 1$$

From B to C

$$M = x_c + x_a \cdot y, \quad T = x_b - 10.25 \cdot x_a$$

$$\frac{\partial M}{\partial x_a} = y, \quad \frac{\partial M}{\partial x_b} = 0, \quad \frac{\partial M}{\partial x_c} = 1$$

$$\frac{\partial T}{\partial x_a} = -10.25, \quad \frac{\partial T}{\partial x_b} = 1, \quad \frac{\partial T}{\partial x_c} = 0$$

From C to D

$$M = x_c + x_a \cdot y + 42.72 (y - 4.75), \quad T = x_b - 10.25 x_a$$

$$\frac{\partial M}{\partial x_a} = y, \quad \frac{\partial M}{\partial x_b} = 0, \quad \frac{\partial M}{\partial x_c} = 1$$

$$\frac{\partial T}{\partial x_a} = -10.25, \quad \frac{\partial T}{\partial x_b} = 1, \quad \frac{\partial T}{\partial x_c} = 0$$

$$\begin{aligned} & \int_0^{10.25} \frac{(x_b - x_a \cdot x) \cdot (-x)}{EI_1} dx + \int_0^{4.75} \frac{(x_c + x_a \cdot y) \cdot y}{EI_2} dy \\ & + \int_{4.75}^{11.25} \frac{[x_c + x_a \cdot y + 42.72(y - 4.75)]y}{EI_2} dy \\ & + 0 + \int_0^{4.75} \frac{(x_b - 10.25 x_a) \cdot (-10.25)}{GJ_2} dy + \int_{4.75}^{11.25} \frac{(x_b - 10.25 x_a)(-10.25)}{GJ_2} dy \\ & = 0 \\ & \int_0^{10.25} \frac{(x_b - x_a \cdot x) \cdot 1}{EI_1} dx + 0 + 0 + 0 + \int_0^{4.75} \frac{(x_b - 10.25 x_a) \cdot 1}{GJ_2} dy \\ & + \int_{4.75}^{11.25} \frac{(x_b - 10.25 x_a) \cdot 1}{GJ_2} dy = 0 \\ & 0 + \int_0^{4.75} \frac{(x_c + x_a \cdot y) \cdot 1}{EI_2} dy + \int_{4.75}^{11.25} \frac{[x_c + x_a \cdot y + 42.72(y - 4.75)] \cdot 1}{EI_2} dy \\ & + \int_0^{10.25} \frac{x_c \cdot 1}{GJ_1} dx + 0 + 0 = 0 \end{aligned}$$

$$\begin{aligned}
& \frac{1}{108 \times 10^4} - \left(\frac{10.25^2}{2} x_b + \frac{10.25^3}{3} x_a \right) + \frac{1}{540 \times 10^4} \left(\frac{4.75^2}{2} x_c + \frac{4.75^4}{3} x_a \right) \\
& + \frac{1}{540 \times 10^4} \left[\left(\frac{11.25^2}{2} - \frac{4.75^2}{2} \right) x_c + \left(\frac{11.25^3}{3} - \frac{4.75^3}{3} \right) x_a - 42.72 \right. \\
& \left. \left(\frac{11.25^3}{3} - \frac{4.75^3}{3} \right) + 42.72 \cdot 4.75 \cdot \left(\frac{11.25^2}{2} - \frac{4.75^2}{2} \right) \right] + \frac{.1}{209.3 \times 10^4} \\
& \left[-10.25 \cdot 11.25 \cdot x_b + 10.25^2 \cdot 11.25 \cdot x_a \right] = 0 \\
& \frac{1}{108 \times 10^4} \left(10.25 x_b - \frac{10.25^2}{2} x_a \right) + \frac{1}{209.3 \times 10^4} (11.25 x_b - 10.25 \times 11.25 x_a) \\
& = 0 \\
& \frac{1}{540 \times 10^4} \left[4.75 x_c + \frac{4.75^2}{2} x_a \right] + \frac{1}{540 \times 10^4} \left[(11.25 - 4.75) x_c \right. \\
& + \left(\frac{11.25^2}{2} - \frac{4.75^2}{2} \right) x_a + 42.72 \left(\frac{11.25^2}{2} - \frac{4.75^2}{2} \right) \\
& \left. + 42.72 \times 4.75 \times (11.25 - 4.75) \right] \frac{1}{41.4 \times 10^4} (10.25 x_c) = 0 \\
& \rightarrow \begin{cases} 9.85 x a - 1.037 x b + 0.117 x c = -15.166 \\ 1.037 x a - 0.149 x b = 0 \\ 0.117 x a + 0.269 x c = -1.671 \end{cases}
\end{aligned}$$

$$\rightarrow \begin{cases} 9.847x_a - 1.037x_b + 0.117x_c = -15.166 \\ 1.037x_a - 0.149x_b + 0 = 0 \\ 0.117x_a + 0 + 0.268x_c = -1.671 \end{cases}$$

Solve

$$\rightarrow \begin{cases} x_a = -5.598K \\ x_b = -38.96 \text{ k-in} \\ x_c = -3.78 \text{ k-in} \end{cases}$$

By equilibrium equation, reactions at D could be found as shown in the figure below.

Fig. XIV.2.2-2 Calculated Reactions on Normal Condition Model of Hydraulic Cylinder Attachment

It should be noted that this distribution of loads is only approximate, since the top and bottom plates and the reinforcements have been ignored. This analysis was intended only to gain a conservative, but more realistic distribution of vertical shear at points A and D. The bending moments at point A will be absorbed by the entire cross-section at point A and have been treated separately.

According to the current computer analysis, the load on the cylinder is found to be 82.28 k (vertical component = 69.78^k) for load case 2. By using proportions, the following are the corresponding values for the reactions at A and D.

Figure XIV.2.2-3 Reactions Due to Load Case 2 on Hydraulic Cylinder Attachment Assumed Model

XIV.2.3 Analysis of Stresses in the Cross Beam No.3 Welds

XIV.2.3.1 Section Properties

$$A = 2 \times 13\frac{3}{4} \times \frac{1}{4} + 2 \times 12 \times \frac{1}{4}$$

$$= 12.875 \text{ in}^2$$

$$I_{22} = 2 \left[13.75 \times \frac{1}{4} \times 6.125^2 + \frac{1}{4} \times \frac{12^3}{12} \right]$$

$$= 329.9 \text{ in}^4$$

$$I_{33} = 2 \left[\frac{1}{4} \frac{13.75^3}{12} + \frac{1}{4} \times 12 \times \left(\frac{12.75^2}{2} \right) \right]$$

$$= 352.2 \text{ in}^4$$

Fig. XIV.2.3.1-1 Cross Section of Cross Beam No. 3 of Fig. XIV.2-1 for Stress Calculations in this Section

XIV.2.3.2 Normal Loading Case (1)

From Equilibrium of forces at joint 125, the following forces can be obtained for Cross Beam No. 3 at the junction with the main beam at joint 125.

$$R_1 = 7.895 \text{ K}$$

$$R_2 = 11.088 \text{ K}$$

$$R_3 = .507 \text{ K}$$

$$M_1 = 19.878 \text{ K.in}$$

$$M_2 = 50.587 \text{ K.in}$$

$$M_3 = 70.335 \text{ K.in}$$

Normal Stresses in flange

$$f_1 = \frac{7.895}{12.875} = 0.61 \text{ ksi}$$

$$f_2 = \frac{50.587 \times 6.125}{329.9} = 0.94 \text{ ksi}$$

$$f_3 = \frac{70.335 \times 13.75}{(352.2)(2)} = 1.37 \text{ ksi}$$

$$\text{Total axial load on flange} = R_5 = (.61 + .94)\left(\frac{1}{4}\right)(13.75) = 5.33^k$$

$$\text{Total moment on flange} = \bar{M}_1 = \frac{1}{2} \left(\frac{13.75}{2} \right) \left(\frac{1}{4} \right) (1.37) \left(\frac{2}{3} \right) (13.75) = 10.8 \text{ k.in}$$

Total Shear in Flanges

$$\text{due to } R_2 \quad V_2 = \frac{R_2}{2} = \frac{11.088}{2} = 5.5^k$$

$$\text{due to Torsion} \quad V_1 = \frac{M_1}{2At} (12.75) = \frac{19.878(12.75)}{2(12.25)(12.75)(.25)} = 3.25^k$$

$$\text{Total Shear Force} = R_6 = 5.5 + 3.25 = 8.75^k$$

Forces on Weld E (Fig. XIV.2-1.)

$$F_1' = \frac{5.33}{2} + \frac{10.8}{5} = 4.825^k$$

$$F_2 = \frac{8.75}{2} = 4.375^k$$

XIV.2.3.3 Accidental Load Case (2)

From Equilibrium of forces at joint 125, the following forces can be obtained for the cross beam no. 3 at joint 125.

$$R_1 = 3.601 \text{ k}$$

$$R_2 = 18.252 \text{ k}$$

$$R_3 = .226 \text{ k}$$

$$M_1 = 2.628 \text{ k.in}$$

$$M_2 = 140.306 \text{ k.in}$$

$$M_3 = 17.974 \text{ k.in}$$

Normal stresses in flange

$$f_1 = \frac{3.601}{12.875} = 0.28 \text{ ksi}$$

$$f_2 = \frac{140.306 \times 6.125}{329.9} = 2.6 \text{ ksi}$$

$$f_3 = \frac{17.974 \times 13.75}{(352.2)2} = 0.35 \text{ ksi}$$

$$R_5 = \text{Total axial load on flange} = (0.28 + 2.6)\left(\frac{1}{4}\right)(13.75) = 9.9 \text{ k}$$

$$\bar{M}_1 = \text{Total moment on flange} = \frac{1}{2}\left(\frac{13.75}{2}\right)\left(\frac{1}{4}\right)(.35)\left(\frac{2}{3}\right)(13.75) = 2.76 \text{ k.in}$$

Total Shear Force in Flanges

$$\text{due to } R_2 \quad V_2 = \frac{R_2}{2} = \frac{18.252}{2} = 9.13 \text{ k}$$

$$\text{due to Torsion} \quad V_1 = \frac{M_1}{2At} (12.75) = \frac{2.628(12.75)}{2(12.25)(12.75)(.25)} = 0.43 \text{ k}$$

$$R_6 = \text{Total Shear Force} = 9.13 + 0.43 = 9.56 \text{ k}$$

Forces on weld E

$$F_1 = \left(\frac{9.9}{2} + \frac{2.76}{5}\right) = 5.5 \text{ k}$$

$$F_2 = \frac{9.56}{2} = 4.78 \text{ k}$$

XIV.2.4 Analysis of Welds in the Cylinder Attachment Forces for Load Case 1

XIV.2.4.1 For 10° - 2 cyl. Loading (see Fig. XIV.2-1)

$$V = 34,880 \text{ lbs}$$

$$H = 21,795$$

$$e = 6.375"$$

$$b = 2.6875"$$

$$d = 12"$$

$$l = 6.5"$$

$$R_1 = \frac{34680 \times 7.0}{12.5} = 19533 \text{ lbs}$$

$$R_2 = \frac{12.5 - 2.25}{12.5} \times 21795 = 17872 \text{ lbs}$$

$$R_3 = \frac{2.25}{12.5} \times 21795 = 3923 \text{ lbs}$$

$$R_4 = \frac{170,000}{12.5} = 13600 \text{ lbs}$$

XIV.2.4.2 Calculation of Vertical Shear Stresses in Weld A

$$Q = 6.25 \times 1.25 \times 3.125 = 24.41 \text{ in}^3$$

$$I = \frac{1}{12} \times 1.25 \times 12.5^3 = 203.45 \text{ in}^4$$

Fig. XIV.2.4.2-1 Detail of Weld on 1 1/4" Plate of Hydraulic Cylinder Attachment

$$\text{Vertical Shear Flow in Weld} = \frac{30100 \times 24.41}{203.45} = 3611 \text{ \#/in}$$

Shear Stress in weld A due to Vertical Load

$$\tau = \frac{3611}{0.3535} = 10217 \text{ psi} < 20000$$

XIV.2.4.3 Shear Flow in Weld B

$$Q = 6.25 \times 0.25 \times 3.125 = 4.88 \text{ in}^3$$

$$I = \frac{1}{12} \times 0.25 \times 12.5^3 = 40.69 \text{ in}^4$$

Shear Flow due to Effect of Vertical Shear Only

$$= \frac{4770 \times 4.88}{40.69} = 572 \text{ lbs/in}$$

Vertical Shear Stress in Weld B

$$= \frac{572}{0.25 \times 0.707} = 3236 \text{ psi} < 20000 \quad \text{O.K.}$$

XIV.2.4.4 Shear Stress in Weld C1

Due to the effect of $R_1 + R_2 = 37405$

$$\tau_1 = \frac{37405}{2 \times 10.25 \times 0.375} = 4866 \text{ psi}$$

Due to the effect of R_4

$$\tau_2 = \frac{13600}{2 \times 10.25 \times 0.375} = 1769 \text{ psi (in Weld C1)}$$

Resultant Shear Stress in Weld C1

$$\tau_{R1} = \sqrt{\tau_1^2 + \tau_2^2} = 5178 \text{ psi} < 20000 \text{ psi} \quad \text{O.K.}$$

XIV.2.4.5 Shear Stresses in Weld D

Due to $R_1 + R_2$

$$\tau_3 = \frac{37405}{11.25 \times 0.375} = 8866 \text{ psi}$$

Due to R_4

$$\tau_4 = \frac{13600}{11.25 \times 0.375} = 3224 \text{ psi}$$

$$\tau_{R2} = \sqrt{\tau_3^2 + \tau_4^2} = 9434 \text{ psi} < 20000 \text{ psi} \quad \text{O.K.}$$

XIV.2.4.6 Effect of External Bending Moment on 1 1/4" Plate

$$\begin{aligned}
 M &= (R_1 + R_2)(2.25) \\
 &= (37405)(2.25) \\
 &= 84161 \text{ lb.in}
 \end{aligned}$$

Fig. XIV.2.4.6-1 Cross-section through 1 1/4" Back-up Plate of Figure XIV.2.4.2-1

$$\begin{aligned}
 \bar{y} &= \frac{12.5 \times 1.25 \times 0.625 + 10 \times 2.5 \times 2.5}{12.5 \times 1.25 + 10 \times 2.5} = 1.778 \text{ in} \\
 I &= \frac{12.5}{12} \times 1.25^3 + 12.5 \times 1.25 \times 1.15^2 + \frac{10 \times 2.5^3}{12} + 10 \times 2.5 \\
 &\quad \times 0.7222^2 \\
 &= 45.37 \text{ in}^4
 \end{aligned}$$

Bending Stress in 1 1/4" Plate

$$\sigma = \frac{84161 \times 1.972}{45.37} = 3658 < .6(50000) = 30000 \text{ psi O.K.}$$

XIV.2.4.7 Shearing Stresses in Bolts

$$\text{Stress area per bolt} = 0.462 \text{ in}^2$$

Number of bolts considered = 8

$$\text{Vertical Shear of Bolts} = \frac{34880}{8 \times 0.462} = 9437 \text{ psi}$$

$$\begin{aligned}\text{Moment about the center of bolts} &= (34,880)(5 \frac{3}{4}) + (21,795)(4 \frac{1}{4}) \\ &= 293.20 \text{ k.in}\end{aligned}$$

$$I \text{ for bolts} = 4(4.875)^2 + 4(1.625)^2 = 105.625$$

$$\text{Max Force} = \frac{293.2}{105.625} (4.875) - \frac{21.795}{8} = 10.8 \text{ k}$$

$$\text{Tensile Stress} = \frac{10.8}{.462} = 23.4 \text{ ksi}$$

Assume A490 bolts, allowable tensile is given according to AISC Section 1.6.3

$$f_t = 70.0 - 1.6 f_v = 70 - 1.6 (9.437) = 54.9 \text{ ksi} \quad \text{O.K.}$$

XIV.2.4.8 Shear Stress in Pin

Vertical load on pin = 34880 lbs

Horizontal load on pin = 21795 lbs

$$\text{Area of pin} = \frac{\pi}{4} \times (2.247)^2 = 3.965 \text{ in}^2$$

$$\tau_7 = \frac{34880}{3.965} = 8797 \text{ psi}$$

$$\tau_8 = \frac{21795}{3.965} = 5497 \text{ psi}$$

$$\tau_{R4} = \sqrt{\tau_7^2 + \tau_8^2} = 10373 \text{ psi} < 20000 \text{ psi}$$

XIV.2.4.9 Shear Stresses in Weld E

From section XIV.2.3 the forces are given

$$\tau_9 = \frac{4.825}{2 \times 0.1875 \times 0.707} = 18200 \text{ psi}$$

$$\tau_{10} = \frac{4.375}{2 \times 0.1875 \times 0.707} = 16500 \text{ psi}$$

$$\tau_{R5} = \sqrt{\tau_9^2 + \tau_{10}^2} = 24600 \text{ psi} > 20000 \text{ psi}$$

This weld analysis is based on size of welds as shown on the drawings which indicate two intermittent welds of 3/16 inch fillets. However, some photographs of these welds indicate three intermittent welds instead of two. (see photographs ANL-NEG 113-5693 k) If this is verified by on the site inspection of welds then the stress will be reduced by 2/3, i.e.

$$\frac{2}{3} \times 24600 = 16400 < 20000 \text{ psi}$$

XIV.2.4.10 Analysis of Weld C2

Figure XIV.2.4.10-1 Geometry of Weld C2

C.G. of weld

$$\bar{x} = \frac{3 \times .3125 \times 3 \times 3}{3 \times .3125 \times 3 + 2 \times 1/4 \times 6} = 1.45 \text{ in}$$

$$\text{Area of weld} = 5.813 \text{ in}^2$$

$$I_{xx} = 2 \times 1/4 \times 6 \times (12.25)^2 + 2 \times 3 \times .3125 \times (8)^2 + 3 \left(\frac{.3125 (3)^3}{12} \right)$$

$$= 572.3 \text{ in}^4$$

$$I_{yy} = 3 \times .3125 \times 3 \times (1.55)^2 + 2 \left[1/4 \frac{(6)^3}{12} + 1/4 (6)(1.45)^2 \right]$$

$$= 22.1 \text{ in}^4$$

$$J = I_{xx} + I_{yy} = 594.4 \text{ in}^4$$

$$R_1 + R_2 = 37.405 \text{ k}$$

$$R_4 = 13.600 \text{ k}$$

$$R_5 = 5.33 \text{ k}$$

$$\bar{M}_1 = 10.8 \text{ k.in}$$

$$R_6 = 8.75 \text{ k}$$

$$F_x = 42.735 \text{ k}$$

$$F_y = 22.35 \text{ k}$$

In order to obtain a resultant moment on the weld group, the moments due to $R_1 + R_2$ and R_4 are assumed to be taken by the cross-beam directly, which is much stiffer than the plate.

$$\therefore M = 42.735(4.5) + 22.35(1.45) + 10.8 = 235.5 \text{ k.in}$$

Maximum stresses in the weld are at the tip of the weld point A*. This is given as follows:

$$f_x' = \frac{42.735}{5.813} = 7.35 \text{ ksi}$$

$$f_y' = \frac{22.35}{5.813} = 3.84 \text{ ksi}$$

$$f_y'' = \frac{235.5 \times 4.45}{594.4} = 1.76 \text{ ksi}$$

$$f_x'' = \frac{235.5 \times 12.25}{594.4} = 4.85 \text{ ksi}$$

$$f_R = \sqrt{(f_x' + f_x'')^2 + (f_y' + f_y'')^2} = 13.4 < 20 \text{ ksi}$$

XIV.2.5 Analysis of Welds in the Cylinder Attachment Forces for Load Case 2

XIV.2.5.1 For 10° - 1 cyl. loading (Accidental-most critical) (see Figure XIV.2-2)

$$V = 69,780 \text{ lbs}$$

$$H = 43,602 \text{ lbs}$$

$$e = 6.375''$$

$$b = 2.6875''$$

$$d = 12''$$

$$l = 6.5''$$

$$R_1 = \frac{69,780 \times 7.0}{12.5} = 39077 \text{ lbs}$$

$$R_2 = \frac{12.5 - 2.25}{12.5} \times 43,602 = 34881 \text{ lbs}$$

$$R_3 = \frac{2.25}{12.5} \times 43,602 = 28,721 \text{ lbs}$$

$$R_4 = \frac{339,700}{12.5} = 27176 \text{ lbs}$$

XIV.2.5.2 Calculation of Vertical Shear Stresses in Weld A

$$Q = 6.25 \times 1.25 \times 3.125 = 24.41 \text{ in}^3$$

$$I = \frac{1}{12} \times 1.25 \times 12.5^3 = 203.45 \text{ in}^4$$

$$\text{Vertical Shear Flow in Weld} = \frac{60240 \times 24.41}{203.45} = 7227.6 \text{ \#/in}$$

Shear Stress in Weld A due to Vertical Load

$$\tau = \frac{7227.6}{0.3535} = 20446 \text{ psi} < 26600$$

XIV.2.5.3 Shear Flow in Weld B

$$Q = 6.25 \times 0.25 \times 3.125 = 4.88 \text{ in}^3$$

$$I = \frac{1}{12} \times 0.25 \times 12.5^3 = 40.69 \text{ in}^4$$

Shear flow due to effect of vertical shear only

$$= \frac{9540 \times 4.88}{40.69} = 1144 \text{ lbs/in}$$

Vertical shear stress in Weld B

$$= \frac{1144}{0.25 \times 0.707} = 6473 \text{ psi}$$

XIV.2.5.4 Shear stress in Welds C1

Due to the effect of $R_1 + R_2 = 73958 \text{ lbs}$

$$\tau_1 = \frac{73958}{2 \times 10.25 \times 0.375} = 9621 \text{ psi (in Weld C1)}$$

Due to the effect of R_4

$$\tau_2 = \frac{27176}{2 \times 10.25 \times 0.375} = 3535 \text{ psi (in Weld C1)}$$

Resultant shear stress in Weld C1

$$\tau_{R1} = \sqrt{\tau_1^2 + \tau_2^2} = 4296 \text{ psi (in Weld C1)}$$

XIV.2.5.5 Shear Stress in Weld D

Due to $R_1 + R_2$

$$\tau_3 = \frac{73958}{11.25 \times 0.375} = 17530 \text{ psi}$$

Due to R_4

$$\tau_4 = \frac{27176}{11.25 \times 0.375} = 6442 \text{ psi}$$

$$\tau_{R2} = \sqrt{\tau_3^2 + \tau_4^2} = 18676 \text{ psi}$$

XIV.2.5.6 Effect of External Bending Moment on 1 1/4" Plate (Fig. XIV.2.4) 6-

Bending Moment

$$\begin{aligned} M &= (R_1 + R_2)(2.25) \\ &= (73958)(2.25) \\ &= 166406 \text{ lb.in} \end{aligned}$$

Section properties are given in Section XIV.2.4.6

Bending Stress in 1 1/4" Plate

$$\sigma = \frac{166406 \times 1.972}{45.37} = 7233 \text{ psi}$$

XIV.2.5.7 Shearing Stresses in Bolts

Stress area per bolt = 0.462 in^2

Number of bolts considered = 8

$$\text{Vertical shear of bolts} = \frac{69,780}{8 \times .462} = 18880 \text{ psi}$$

$$\begin{aligned} \text{Moment about the center of bolts} &= (69,780)(5 \frac{3}{4}) + (43,602)(4 \frac{1}{4}) \\ &= 586,543 \text{ k.in} \end{aligned}$$

$$I \text{ for bolts} = 4(4.875)^2 + 4(1.625)^2 = 105.625$$

$$\text{Max force} = \frac{586.543}{105.625} (4.875) - \frac{43.602}{8} = 21.6 \text{ k}$$

$$\text{Tensile Stress} = \frac{21.6}{.462} = 46.8 \text{ ksi}$$

Assume A490 bolts, allowable tensile is given according to AISC section 1.6.3

$$f_t = 70.0 - 1.6 f_v = 70 - 1.6(18.88) = 39.8 \text{ ksi}$$

For accidental condition $f_t = 1.33(39.8) = 52.9 \text{ ksi}$ O.K.

XIV.2.5.8 Shear Stress in Pin

Vertical load on pin = 69780 lbs

Horizontal load on pin = 43602 lbs

$$\text{Area of pin} = \frac{\pi}{4} \times (2.247)^2 = 3.965 \text{ in}^2$$

$$\tau_7 = \frac{69730}{3.965} = 17599 \text{ psi}$$

$$\tau_8 = \frac{43602}{3.965} = 10997 \text{ psi}$$

$$\tau_{R4} = \sqrt{\tau_7^2 + \tau_8^2} = 20752 \text{ psi} < 26600 \text{ psi}$$

XIV.2.5.9 Shear Stresses in Weld E

From Section XIV.2.3 the forces are given

$$\tau_9 = \frac{5500}{2 \times 0.1875 \times 0.707} = 20745 \text{ psi}$$

$$\tau_{10} = \frac{4780}{2 \times 0.1875 \times 0.707} = 18029 \text{ psi}$$

$$\tau_{R5} = \sqrt{\tau_9^2 + \tau_{10}^2} = 27484 \text{ psi} > 26600 \text{ psi}$$

As noted at the end of analysis of this weld under normal loading condition in preceding sections, if the photographs verify three intermittent welds instead of two, (see photographs ANL-NEG 113-5693 k) then the above stress is reduced by 2/3, i.e.

$$\frac{2}{3} \times 27484 = 18322 \text{ psi} < 26600 \text{ psi allowable}$$

XIV.2.5.10 Analysis of Weld C₂

$$R_1 + R_2 = 73.958 \text{ k}$$

$$R_4 = 27.176 \text{ k}$$

$$R_5 = 9.9 \text{ k}$$

$$\bar{M}_1 = 2.76 \text{ k.in}$$

$$R_6 = 9.56 \text{ k}$$

$$F_x = 83.858 \text{ k}$$

$$F_y = 36.736 \text{ k}$$

At this point, assume conservatively that $R_1 + R_2$ and R_4 are transferred to the center of the cross-beam. The resulting bending moment is a moment about 3-3 axis which is handled by the box section and the connection of cross-beam to main beam.

$$M = 83.858 (4.5) + (36.736)(1.45) + 2.76 = 433.39 \text{ k.in}$$

Maximum stresses in weld are at the tip A* which is given by;

$$f_x' = \frac{83.858}{5.813} = 14.43 \text{ ksi}$$

$$f_y' = \frac{36.726}{5.813} = 6.32 \text{ ksi}$$

$$f_y'' = \frac{433.39 \times 4.45}{594.4} = 3.24 \text{ ksi}$$

$$f_x'' = \frac{433.39 \times 12.25}{594.4} = 8.93 \text{ ksi}$$

$$f_R = \sqrt{(f_x' + f_x'')^2 + (f_y' + f_y'')^2} = 25.24 \text{ ksi} < 26.60 \text{ ksi} \quad \text{O.K.}$$

XIV. 3 Local Buckling of Cross Beams

The results of Chapter X indicate that the cradle structure is adequate against buckling. However, there are areas such as cross beam no.3, shown in Fig. XIV.3-1, that require special attention. Accordingly, it was decided to perform a comprehensive plate buckling analysis, along with the thickness criteria, to demonstrate compliance. The computer program provided directly the transverse components of the loading which were then resolved in the direction postulated for buckling. The analysis is performed herein for the saddle no.3 (or cross beam no.3) as a bench mark case for determining the integrity of the structure against buckling. Due to the complexity of the cradle structure, and limited available time, a detailed buckling analysis was not feasible. Hence, a very conservative approach had to be taken in buckling analysis. As it follows, only a portion of the continuous plate is considered to show compliance to buckling criteria. Refer to computer model of cradle assembly in volume II of the report. Take node 129 (member 45) to represent part of beam shown in Fig. XIV.3-1. Comparing all load cases, the most critical for node 129 is load case 2, single cylinder at 10° incline: internal forces and moments at node 129 are:

Axial	= 0.2225 k	Torsion M_1	= 161.7 k.in
Shear (Vert.) R_3	= 7.661 k	Bending M_2	= 284.5 k.in
Shear (Horiz.) R_2	= 41.95 k	Bending M_3	= 149.5 k.in

Figure XIV.3-1 Side View of Cross Beam of Figure XIV.2-1

Figure XIV.3-2 Assumed Beam Section

Take an element of the saddle plate approximately at mid-depth:

	DIRECT STRESS	SHEAR STRESS
Due to $R_1 = 0.225$		
$S_x = \frac{225}{4 \times 13'' \times 0.25''} =$	17	
Due to $R_3 = 7.661 \text{ k}$		
$S_s = \frac{7,661}{2 \times 13'' \times 0.25''} =$		1,178
Due to $R_2 = 41.95 \text{ k}$		
Due to $M_1 = 161.7 \text{ k in}$		
$I_x = I_y = 2 \left[\frac{0.25 (13)^3}{12} + 0.25 (13) (6.5)^2 \right]$		
$= 366 \text{ in}^4$		
$J = I_x + I_y = 732 \text{ in}^4$		
$S_s = \frac{161,700 \times 6.5}{732} =$		1,436
Due to $M_3 = 149.5 \text{ k in}$		
$S_x = \frac{149,500 \times 6.5}{366} =$	2,655	
Due to $M_2 = 284.5 \text{ k in}$		
$F_c = 8210 \left[\frac{(1-0.707)^2}{0.707^2} \right]^{1/2} = 6284 \text{ lbs}$		
$S_y = \frac{6284 \cos 27.5^\circ}{3'' \times 0.25''} =$	7432	
$S_x = \frac{6284 \sin 27.5^\circ}{13'' \times 0.25''} =$	893	
Total =	$S_x = 3565$ $S_y = 7432$	2,614

Figure XIV.3-3 Resolved forces on inclined plate

Figure XIV.3-4 Resolved forces on inclined plate

F_1 and F_2 - due to stresses on the beam flange due to bending M_3 .

$$S = \frac{284,500 \times 6.5}{366} = 5053 \text{ psi}$$

$$F_1 = 5053 \frac{\text{lbs}}{\text{in}^2} \times 6.5'' \times 0.25'' = 8210 \text{ lbs}$$

$$F_2 = 8210 \text{ lbs}$$

Principal stress:

Assumed all direct stresses in compression:

$$\text{Max. Shear} = \frac{(7432 - 3565)^2}{2} = 2734 \text{ psi}$$

$$\text{Max. compression} = \frac{7432 + 3565}{2} + 2734 = 8232 \text{ psi}$$

(only hypothetical, since all forces are conservatively considered compressive Buckling stress of plate: Refer to "Formulas for Stress and Strain" by Roark,

Table XVI, Case A-4.

Critical compressive stress

$$S' = K \times \frac{E}{1 - \nu^2} \times \frac{t^2}{b^2}, \quad \frac{a}{b} = \frac{13''}{3''} = 4.33$$

Use a factor of safety of 2.0

$$K = 0.42$$

$$E = 30 \times 10^6$$

$$\nu = 0.3$$

$$t = 0.25''$$

$$S' = \frac{96,153}{2} = 48,000 \text{ psi}$$

Referring to "Design of Welded Structures" by Blodgett, p. 2.12-7, Buckling of Plates, for case considered with one edge free:

$$\frac{b}{t} = \frac{3}{0.25} = 12$$

$$K = 0.425$$

$$\text{Buckling stress} = 45,000 \text{ psi}$$

Actual stress is much less than the critical buckling stress. The computed stress of the vertical plate in question, as given in Chapter X, has much lower compressive stresses than those calculated here, mainly because of overconservative assumptions here. Compliance to AISC Code Criteria for buckling is given on following page.

From AISC Code (Equation 1.5-2 of Reference 6)

$$\text{Web Plate Thickness} > \frac{R}{5kF_y}$$

$$t < \frac{R}{5kF_y}$$

K = flange thickness + weld

$$= 0.25" + 0.25" = 0.5"$$

$$\text{Web Plate Thickness} > \frac{7.454 \times \frac{8}{3}}{5 \times 0.5 \times 50} = 0.06"$$

Actual web plate $t = 0.25"$

Note that the AISC buckling formula $t \leq \frac{d_c \sqrt{F_y}}{120}$ is not applicable for this web analysis due to differences between the boundary conditions of the web under consideration and the underlined assumptions on which the code equation was based. In lieu of using the code equation, a more accurate analysis was presented in the previous page which has shown that the buckling requirements of the web are satisfied, therefore, stiffeners are not needed.

XIV.3.2 Conclusions of Buckling Analysis

Allowable buckling stress using Roark method (Case A - page 348) is calculated on previous page as 43,000 psi. The calculated compressive stresses given in the previous pages are much less than this value. Further, another calculation of stress based on very limited effective cross section (of the cross section under consideration) using a very conservative assumption that all available forces are compressive shows a stress of 10,353 psi. It is obvious that a margin of safety of greater than 4 against buckling exists. On the previous page, a further check against buckling was made using methods of Page 2.12-7 of

Blodget's "Design of Welded Structures". Further, a check against the AISC code crippling criteria was also made and demonstrated integrity.

CHAPTER XV

CONCLUSIONS AND RECOMMENDATIONS

XV.1 Summary

A stress analysis has been performed on the SLSF loop handling system to determine the adequacy of the design under various postulated normal and off-normal operating conditions. The part of the loop handling system that is of interest in these analyses consists of two major components (1) The Loop Handling Machine (LHM) that contains the SLSF loop and, (2) the transporter that moves the LHM between the various facilities of interest at INEL.

Stresses at various points in these components were determined for a total of nine different operating conditions. These conditions are described in Chapters II and III of the report.

The report contains 15 chapters and 8 appendices. The analytical criteria, methods, and results are contained in chapters 1 through 14. Chapter 15 contain the conclusions and recommendations. Some additional details on methods of analysis are presented in the appendices.

The analysis indicates that the loop handling system will operate safely under all of the different normal or off-normal conditions that were investigated in this report.

A summary of the analyses of each component and its critical attachment is presented in the following:

XV.2 SLSF Loop Handling Machine

The results of the stress analysis of the LHM and hoist system are presented in Chapters VI and VII of Volume I of this report. The results of Chapter VI are summarized in Table XV.4-1 of this chapter. The analysis of the hoist system presented in sections VI.1.2 and VI.1.3 of the report proves that the system is quite capable of withstanding normal as well as emergency

hoist loading. This analysis is not extended to the analysis of the ETR crane, which is the responsibility of EG&G Co., or the analysis of the spreader bar, used in the Hot Fuel Examination Facility (HFEF) in conjunction with HFEF cranes, documented separately by HFEF engineers and analysts.

The analysis of the lifting lugs and their effect on the LHM cask due to normal and emergency hoist conditions is investigated in sections VI.2.2 and VI.2.6.

The design analysis of the Grapple Drive Assembly is given in sections VI.2.3 to VI.2.4. This analysis was performed under the guidelines of American Gear Manufacturers Association (AGMA) standards. The results show that the design is adequate by a large margin. An extensive analysis of the grapple drive bracket mounting was also performed and the results indicate a high margin of safety. Under erection loadings, the counter-balance, Tie-Down Straps, T-Slot Welds and T-Bar bolts were analyzed in sections VI.2.7 and VI.2.8. All factors of safety in these regions are high. The lowest factor of safety (1.38) was for the tie-down strap under off-normal dynamic erection. These straps are inspected frequently, especially if an off-normal erection of the LHM should occur.

LHM welds at the lower end were analyzed under a 10G postulated horizontal loading under which the factor of safety in welds is 1.62, and in bolts is 1.02. It is obvious that such a loading is a conservative assumption. Adequate administrative procedures are being taken against extremely severe dynamic horizontal loading. Loop supports were analyzed for a 2G postulated loading in section VI.2.10 under which the factor of safety is 1.26. Inspection of loop support bolts is suggested at least once a year.

XV.3 Critical Attachments I

The critical attachments of the LHM to the cradle structure are analyzed in Chapter VIII in Volume I of this report. A summary of results is

given in Table XV.5-1 of this chapter. Cylinder mounting pins were analyzed in section VIII.2.1 and cradle trunnion pins were analyzed in section VIII.3.1 for normal as well as emergency loading conditions. The cylinder mounting pin has a factor of safety in shear of 1.96 under emergency hoist conditions.

The T-Bar, T-Slot, and bolts were analyzed for the 5g lateral acceleration postulated loading, and are reported in section VIII.4. Inspection of these bolts is required, should there be a significant lateral dynamic loading. Toe welds of the cradle base plate to the toe were analyzed and reported in section VIII.5.1. Factors of safety on all these welds are >2.0 , except the vertical welds which have a factor of safety of 1.8. An extensive finite element analysis of the cradle base plate was performed and reported in section VIII.5.2. The factor of safety calculated for the cradle base plate is 1.2. Hence, administrative procedures are being used to prevent dynamic impact loading of the LHM on the cradle base plate.

Further analysis of tie-down mechanisms, such as tie-down straps, tie-down clamps, and the associated welds, bolts, and other accessories, were analyzed for 1.62G postulated loading and are reported in section VIII.6. As shown in Table XV.4-1, the factors of safety calculated for these critical attachments are very close to 1.0. It is therefore recommended that administrative procedures be implemented to protect tie-down mechanisms against occurrence of a severe lateral loading. These welds must be inspected once every year. Hold-down clamps were analyzed in section VIII.7 under a 2G postulated loading and the factors of safety are uniformly high.

XV.4 Cradle Structures

The cradle structure has a complex box-beam configuration that required an extensive analysis. A complex computer model of the entire loop handling system was developed to investigate the behavior of this structure

under various postulated LHM erection loadings. This model incorporated very small finite difference elements of the loop handling system in order to more accurately represent the system. The model is considered a unique application of finite element technique. Since an exact representation of the system by finite element technique is difficult, a number of conservative approximations had to be made in the computer model.

A detailed description of this model is given in Chapter IX in Volume II of this report, which also included the resulting flexibility analysis load distributions in the entire system.

XV.5 Design Conformance of Cradle Structure

Procedures described in the AISC code were used in demonstrating the integrity of the cradle structure and these results are reported in Chapter X in Volume III of this report. The cradle welds were analyzed in accordance with AISC code and are reported in Chapter IX in Volume III of this report. All cradle beams and all connecting and local welds conform to AISC code design criteria for normal and emergency loadings, and hence are structurally adequate.

Trunnion structures were also analyzed for all normal and emergency load cases, and are reported in Chapter X in Volume III of this report.

In order to investigate the effect of the cross beam (saddle no. 4) connecting weld on the adjoining side plate that is a part of the longitudinal beam in that region, a detailed stress analysis was carried out using plate theory. The results of the analysis (Chapter XII, Volume III) indicate for all normal and accidental loading cases a large margin of safety.

The cradle and trunnion structures in most regions are composed of closed box-beam members with only few members of open plate construction. The treatment of torsion was done in a manner that is consistent with the

membrane analogy. Chapter XIII provides a derivation of torsion stress behavior in multicell regions. It also verifies calculations of Chapter X using this derivation.

XV.6 Critical Attachments II

Critical attachments II are those attachments of the SLSF loop handling system cradle structure that are critical during the erection of the loop handling system by hydraulic cylinders. Analysis of these critical attachments is given in Chapter XIV, Volume III, of this report. The most critically stressed weld in this region is in the vicinity of the hydraulic cylinder attachment with the cross beam (saddle no. 3) of the cradle structure. It is the weld with the top plate of the cross beam (saddle no. 3) that overlaps with the top plate of the adjoining longitudinal cylinder attachment. The factor of safety in these welds is 1.1. These welds should be inspected in the event of any off-normal loading conditions.

XV.7 LHS Trailer

SLSF - LHS Trailer was designed for the required capacity and manufactured by an outside vendor. Hence, this report did not go into the task of proving the structural integrity of the trailer on assurance from the SLSF project that the vendor's qualifications of the design were adequate for the project. However, in the analysis of the SLSF loop handling system, cradle structure, and critical attachments, the system structure finite element computer models included the trailer details in order to take the trailer stiffness into consideration.

XV.80 Recommendations

The stress analysis of the SLSF loop handling system, as described in this report, satisfies the requirements of the SLSF project. No further analyses are considered necessary to insure the safe operation of this system.

It is recommended that inspections be performed at the following locations, before, during, and after operation of the system, as required. These inspections must especially be performed in the event of one of the off-normal conditions described in this report.

- a. The LHM lifting lugs.
- b. The loop tie-down straps and loop support bolts.
- c. The cradle-lifting hydraulic cylinder mounting pins.
- d. The welds with the top plate of the cross beam (saddle no. 3) that overlaps with the top plate of the adjoining longitudinal hydraulic cylinder attachment. (See chapter XIV of Volume III for details).

It is further recommended that administrative procedures be employed that will reduce, or eliminate, the possibility of occurrence of the off-normal conditions described in this report.*

*The authors have received assurance from the SLSF project that these recommendations have been included in the administrative and operating procedures.

XV.4-1 Summary of Stresses in SLSF Loop Handling System

Chapter	Component	Loading Conditions	σ	τ	FSY*	FSS*	Report Page	Remarks
VI.1.2	Crane Cables	Sudden stoppage of hoist Cable breakage on one side	Load capacities specified			2.37 2.25	112 116	
VI.1.3	Lifting Links	Emergency hoist	31,608		4.27		122	
VI.2.2.1	Lifting Lug - LHM Cask Interface	Weld stresses in loaded lug	1,562	2,538	19.2 7.9		132 132	
VI.2.2.2	LHM Cask - Lifting Load Stresses	Emergency hoist	5,033		5.9		147	
VI.2.2.3	LHM Cask	Stresses due to loop supports All loads assumed on one support	18,597		1.6		148	Method used is conservative O.K.
VI.2.3	Grapple Shackle Pin Finger Finger Pin Bolts	Normal condition	1,133 18,957	11,696 33,919	8.0 102.0 2.1 2.6		154 154 156 158	
VI.2.4.1	Gear Drive Assembly Shaft 11 Shaft 11 Shaft from 11 to Formsprag Clutch Pinion Shaft 14 Pinion Shaft 14 Gear Shaft 22 Gear Shaft 22 Pinion 15 and Gear 29	Normal condition	26,458 28,216 30,685	18,132 15,612 21,136 18,714	5.2 4.34 5.03 4.89 3.72 4.49 4.42		162 162 164 166 166 171 171 173	
VI.2.5	Grapple Drive Mounting Bolt Stresses Weld Stresses	Normal condition	20,247	426	4.49 47.0		182 184	

*FSY - Factor of Safety with tensile yield

FSS - Factor of Safety with shear yield

Table XV.4-1 (cont'd)

Chapter	Component	Loading Conditions	σ	τ	FSY*	FSS*	Report Page	Remarks
VI.2.6	<u>Lifting Lug Stresses</u>						190	
	Lug Cross-Section	Normal hoist	282		106.0		203	
	Lug Plates	Normal hoist	10,572		2.83		203	
	Lug Plates	Normal hoist		5,965	3.6		203	
VI.2.7	Counterbalance	Normal condition					259	
	Hollow ARM Section		4,831		7.4		258	
	Hollow ARM Section			1,397	15.7		258	
VI.2.8.5	Tie-Down Strap	During erection of LHM Due to dynamic effects	21,713		1.38		278	
VI.2.8.6	T-Slot Welds	During erection of LHM Due to dynamic effects		1,015	19.7		279	
VI.2.8.7	T-Bar Bolts	During erection of LHM Due to dynamic effects	8,957		11.2		281	
VI.2.9	<u>LHM Welds and Connections</u>	10G horizontal loading						
	Welds at Lower End		18,536		1.62		285	Administrative procedures and inspection suggested
	Bolts		122,496		1.02		287	
VI.2.10	<u>Loop Supports</u>	2G loading	79,656		1.26		288	
	Bolts							

Table XV.4-1 (cont'd)

Chapter	Component	Loading Conditions	σ	τ	FSY*	FSS*	Report Page	Remarks
VIII.2.1	Cylinder Mounting Pins	Emergency hoist	70,326	16,767	1.96		327	Suggest higher strength pin material as a spare for replacement - should dynamic loading or accident occur
		Emergency hoist			5.48		332	
VIII.3.1	Cradle Trunnion Pins	Emergency hoist	15,603	3,537	5.77		337	
		Emergency hoist			16.96		337	
VIII.4	<u>T-Bar Analysis</u>	5G lateral acceleration						
	T-Bar		2,653		13.6		345	
	T-Slot (Channel)		17,600		1.7		345	
	Bolts		70,200		1.4		345	
VIII.5.1	<u>Toe Weld of Cradle Base Plate</u>	Normal loading						
	Horizontal Welds		6,907		4.34		349	
	Vertical Welds		10,235		2.93		350	
	Vertical Welds			11,092	1.8		356	
	Bolts		41,021		4.19		357	
VIII.5.2	Cradle Base Plate	Finite element analysis		16,600	1.2		396	Administrative procedure required for non-occurrence of dynamic impact
VIII.6	<u>Tie-Down Mechanisms</u>	1.62 G loading				2.4		
	Strap		37,012		1.00		397	
	Strap Welds			13,295	1.85		397	
	Clamp Bending		32,612		1.38		398	
	Connecting Rod Thds		52,336				398	
	Eccentric Shaft Ends		102,420				399	
	Bolts		52,703		1.32		400	
VIII.7	<u>Hold-Down Clamps</u>	2G loading			2.34			
	Bolts		57,524		1.83		403	
	Slide		12,499		4.0		404	
	Slide			13,205	2.5		405	
	Body		18,495		2.7		406	

TABLE XV.4-1 (Cont'd)

CHAPTER	COMPONENT	LOADING	STRESSES IN PSI σ τ	FACTOR PER SHEAR	OF SAFETY AISC SHEAR	REPORT PAGE	REMARKS
X.4.7	Cradle Structure Member No. 58 Node 144	Load Case 2	36510	1.0		848	This factor of safety is an indication to the ratio of AISC allowable to max. actual stresses. Thus a value of 1.0 means that the max. actual stresses are within the allowable limits specified by AISC. It should be noted that the AISC allowable stresses already have taken into account proper material and load factors to ensure the safety of the structure.
X.5.7	Trunion Block Member No. 150 & 151 Node No. 210	Load Case 5	14350 ^(a)	2.07		897	
XI.4.5	Cradle Structure Connecting Weld Beam No. 553 Node No. 50i	Load Case 12	18991 ^(b)		1.1	933	
XI.5.2	Cradle Structure Local Weld Beams 71 & 72	Load Case 2	16226 ^(c)		1.64	957	It should be noted that Load Case No. 10 has been discarded in the report with the assumption that all reverse travel of transporter will occur at lowest possible speed under administrative control. (a) $f_a + f_{bx} + f_{by}$ (b) $13429 \times \sqrt{2}$ (c) $1183.8 \times 1.33 \times \sqrt{2} / (5 \times \frac{3}{7})$
XII.4	Cradle Structure Side Plate of Cross Beam No. 4	Load Case 4	25915	1.54		978	
XIV.2.5	Cradle Structure Cross Beam No. 3 Junction with Cylinder Attachment	Load Case 2	25240		1.05	1010	

PAGES 1029 TO 1100 ARE LEFT OPEN