CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LIGO PROJECT

FINAL DESIGN REVIEW
DATA PACKAGE
BEAM TUBE MODULE
DESIGN & QUALIFICATION TEST

CONTRACT C146

CDRL #15
DRD #9 ITEM IV
DESIGN CALCULATIONS & ANALYSES

Prepared by

CBI TECHNICAL SERVICES COMPANY
PLAINFIELD, ILLINOIS
APRIL 11, 1994

CBI CONTRACT 930212

LIGO BEAM TUBE MODULES
TABLE OF CONTENTS FOR DETAILED DESIGN CALCULATIONS

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO Beam Tube Modules **Detailed Design Calculations** **Table of Contents**	MADE BY WJC	CHKD BY RJW	MADE BY	CHKD BY	SHT 1 OF 2
	DATE 4/5/94	DATE 4/5/94	DATE	DATE	

LIGO BEAM TUBE MODULES
TABLE OF CONTENTS FOR DETAILED DESIGN CALCULATIONS

SUBJECT **LIGO Beam Tube Modules** **Detailed Design Calculations** **Table of Contents**	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
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IN LIGHT OF CAUTIONARY NOTE OF ASME VIII DIV. 1 UG-29 FOR LATERAL BUCKLING OF STIFFENER RINGS, APPLY AISC TYPE CRITERIA FOR A DEPTH TO THICKNESS LIMIT:

FROM AISC 9TH EDITION OF MANUAL OF STEEL CONSTRUCTION, TABLE B5.1, LIMIT TO $95/\sqrt{F_y}$.

$$\frac{b}{t} = \frac{1.75}{.1875} = 9.3 < \frac{95}{\sqrt{F_y}} = \frac{95}{\sqrt{19.5}} = 21.5 \quad OK$$

SUBJECT LIGO BEAM TUBES STIFFENER RINGS	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY JEH	CHKD BY RJW	MADE BY	CHKD BY	SHT 1 OF 1
	DATE 11/3/93	DATE 4 NOV 93	DATE	DATE	2.1

DESIGN OF VACUUM VESSELS WITH CIRCUMFERENTIAL STIFFENERS
DAVID TAYLOR MODEL BASIN PROCEDURE & MODIFIED ASME DIVISION II

Purpose: **This calculation shows the required spacing of the 1.75" x 0.1875" beam tube vacuum stiffeners designed PER THE ASME CODE with a Factor of Safety of 3.00, in order to obtain an allowable design pressure >= 14.70 psi, with a < 1 percent permissible variation in the actual and required moments of inertia of the stiffener / shell section. The moment of inertia of the stiffener accounts for the 6 degree rotation that can be expected during construction.**

Input Variables, Cylinder

Cylinder O.D, Dc	**49.00**	**inches**
Cylinder Thickness, tc	**0.127**	**inches**
Design Pressure, p	**14.70**	**psi**
Design Temperature	**300**	**degrees F**
Safety Factor, FS	**3.00**	**ASME Safety Factor**

Input Variables, Stiffener

Stiffener Depth, dstiff	**1.750**	**inches**
Stiffener Thick, tstiff	**0.1875**	**inches**
Stiffener Spacing, L	**26.500**	**inches**

Computed Circumferential Stress in Cylinder

Sc = 2,836 psi ---> (p * Dc) / (2 * tc)

Determine Tangent Modulus of the Material, Et

Et = 27,000,000 psi ---> (For 304L @ 300F, Table TM-1, p664, ASME Section II Part D)

Determine Collapsing Pressure, Pcr

Pcr = 46.36 psi ---> (2.6 * Et * ((tc/Dc)^2.5)) / (L/Dc - 0.45 * ((tc/Dc)^0.5))

Determine Maximum Allowable Pressure, Pall = Pcr / FS

Pall = 15.45 psi ---> Pcr / FS

Determine Maximum Allowable Spacing Between Stiffeners

Lmax = 27.80 inches ---> Dc * ((tc/Dc)^0.5) * (0.45 + ((2.6 * Et)/(FS * p))*((tc/Dc)^2))

Determine Maximum Allowable Circumferential Stress, Sc_all

Sc_all = 2,981 psi ---> ((2.6/(FS * 2)) * Et * ((tc/Dc)^1.5))/((L/Dc) - 0.45 * ((tc/Dc)^0.5))

Determine Corresponding Minimum Thickness of Cylinder, tc_min

tc_min = 0.051 inches ---> 2 * (Dc/2) * ((2 * p/Et)^0.5)

Intermediate Vacuum Stiffeners

A_stiff = 0.328 in**2 ---> dstiff * tstiff
A_shell = 0.348 in**2 ---> 1.1 * tc * Sqrt(Dc * tc)
A_total = 0.677 in**2 ---> A_stiff + A_shell
ybar = 0.519 inches abv shell ---> (A_stiff * (dstiff/2 + tc) + A_shell * (tc/2)) / A_total
I_stiff = 0.083 in**4 ---> Moment of Inertia of stiffener with a 6 degree incline from the vertical.
I_shell = 0.0005 in**4 ---> (1/12) * (1.1 * Sqrt(Dc * tc)) * tc^3
I_tot = 0.232 in4** ---> I_stiff + I_shell + A_stiff * (dstiff/2 + tc - ybar)^2 + A_shell * (ybar - tc/2)^2
B_stiff = 3,876 psi ---> 0.75 * (p * Dc) / (tc + A_stiff / L)
A_value = 0.000287 ---> (2 * B_stiff) / Et
Req'd I_tot = 0.234 in4** ---> ((Dc^2 * L * (tc + A_stiff / L) * A_value) / 10.9) * (FS / 3), ASME Div 2 UG-29

Conclusion: **For a design meeting the ASME Code with a Factor of Safety of 3.00, the vacuum stiffeners must be spaced no farther than 26.50 inches apart for an allowable design pressure >= 14.70 psi, assuming a < 1 percent variation in the actual and required moments of inertia of the stiffener / shell section.**

SUBJECT	OFFICE: NOE		REVISION:		REFERENCE NO. 930212
LIGO BEAM TUBE VACUUM STIFFENERS SPACING, ALLOWABLE PRESSURE, AND SIZE WITH ASME & NON-ASME SAFETY FACTORS	MADE BY WJC	CHKD RJW	MADE BY	CHKD	SHT 1 OF 4
	DATE 3/11/94	DATE 18 MAR 94	DATE	DATE	2.2

DESIGN OF VACUUM VESSELS WITH CIRCUMFERENTIAL STIFFENERS
DAVID TAYLOR MODEL BASIN PROCEDURE & MODIFIED ASME DIVISION II

Purpose: **This calculation shows the required spacing of the 1.75" x 0.1875" beam tube vacuum stiffeners designed PER THE ASME CODE with a Factor of Safety of 3.00, in order to obtain an allowable design pressure >= 14.70 psi, with an accepted 5 percent variation in the actual and required moments of inertia of the stiffener / shell section. The moment of inertia of the stiffener accounts for the 6 degree rotation that can be expected during construction.**

Input Variables, Cylinder

Cylinder O.D, Dc	**49.00**	**inches**
Cylinder Thickness, tc	**0.127**	**inches**
Design Pressure, p	**14.70**	**psi**
Design Temperature	**300**	**degrees F**
Safety Factor, FS	**3.00**	**ASME Safety Factor**

Input Variables, Stiffener

Stiffener Depth, dstiff	**1.750**	**inches**
Stiffener Thick, tstiff	**0.1875**	**inches**
Stiffener Spacing, L	**27.750**	**inches**

Computed Circumferential Stress in Cylinder

Sc = 2,836 psi ---> (p * Dc) / (2 * tc)

Determine Tangent Modulus of the Material, Et

Et = 27,000,000 psi ---> (For 304L @ 300F, Table TM-1, p664, ASME Section II Part D)

Determine Collapsing Pressure, Pcr

Pcr = 44.18 psi ---> (2.6 * Et * ((tc/Dc)^2.5)) / (L/Dc - 0.45 * ((tc/Dc)^0.5))

Determine Maximum Allowable Pressure, Pall = Pcr / FS

Pall = 14.73 psi ---> Pcr / FS

Determine Maximum Allowable Spacing Between Stiffeners

Lmax = 27.80 inches ---> Dc * ((tc/Dc)^0.5) * (0.45 + ((2.6 * Et)/(FS * p))*((tc/Dc)^2))

Determine Maximum Allowable Circumferential Stress, Sc_all

Sc_all = 2,841 psi ---> ((2.6/(FS * 2)) * Et * ((tc/Dc)^1.5))/((L/Dc) - 0.45 * ((tc/Dc)^0.5))

Determine Corresponding Minimum Thickness of Cylinder, tc_min

tc_min = 0.051 inches ---> 2 * (Dc/2) * ((2 * p/Et)^0.5)

Intermediate Vacuum Stiffeners

A_stiff =	0.328	in**2	---> dstiff * tstiff
A_shell =	0.348	in**2	---> 1.1 * tc * Sqrt(Dc * tc)
A_total =	0.677	in**2	---> A_stiff + A_shell
ybar =	0.519	inches abv shell	---> (A_stiff * (dstiff/2 + tc) + A_shell * (tc/2)) / A_total
I_stiff =	0.083	in**4	---> Moment of Inertia of stiffener with a 6 degree incline from the vertical.
I_shell =	0.0005	in**4	---> (1/12) * (1.1 * Sqrt(Dc * tc)) * tc^3
I_tot =	**0.232**	**in**4**	---> I_stiff + I_shell + A_stiff * (dstiff/2 + tc - ybar)^2 + A_shell * (ybar - tc/2)^2
B_stiff =	3,891	psi	---> 0.75 * (p * Dc) / (tc + A_stiff / L)
A_value =	0.000288		---> (2 * B_stiff) / Et
Req'd I_tot =	**0.245**	**in**4**	---> ((Dc^2 * L * (tc + A_stiff / L) * A_value) / 10.9) * (FS / 3), ASME Div 2 UG-29

Conclusion: **For a design meeting the ASME Code with a Factor of Safety of 3.00, the vacuum stiffeners must be spaced no farther than 27.75 inches apart for an allowable design pressure of 14.70 psi, assuming an accepted 5 percent variation in the actual and required moments of inertia of the stiffener / shell section.**

SUBJECT	OFFICE: NOE		REVISION:		REFERENCE NO. 930212
LIGO BEAM TUBE VACUUM STIFFENERS SPACING, ALLOWABLE PRESSURE, AND SIZE WITH ASME & NON-ASME SAFETY FACTORS	MADE BY WJC	CHKD RJW	MADE BY	CHKD	SHT 2 OF 4
	DATE 3/11/94	DATE 14 MAR 94	DATE	DATE	2.3

DESIGN OF VACUUM VESSELS WITH CIRCUMFERENTIAL STIFFENERS
DAVID TAYLOR MODEL BASIN PROCEDURE & MODIFIED ASME DIVISION II

Purpose: This calculation shows the resulting Factor of Safety (Non-ASME) that is obtained by spacing the beam tube vacuum stiffeners (1.75" x 0.1875") at 30", yet still obtaining an allowable design pressure >= 14.70 psi, with a < 1 percent permissible variation in the actual and required moments of inertia of the stiffener / shell section.
The moment of inertia of the stiffener accounts for the 6 degree rotation that can be expected during construction.

Input Variables, Cylinder

Cylinder O.D, Dc	**49.00**	**inches**
Cylinder Thickness, tc	**0.127**	**inches**
Design Pressure, p	**14.70**	**psi**
Design Temperature	**300**	**degrees F**
Safety Factor, FS	**2.65**	**Non-ASME Safety Factor**

Input Variables, Stiffener

Stiffener Depth, dstiff	**1.750**	**inches**
Stiffener Thick, tstiff	**0.1875**	**inches**
Stiffener Spacing, L	**30.000**	**inches**

Computed Circumferential Stress in Cylinder

Sc = 2,836 psi ---> (p * Dc) / (2 * tc)

Determine Tangent Modulus of the Material, Et

Et = 27,000,000 psi ---> (For 304L @ 300F, Table TM-1, p664, ASME Section II Part D)

Determine Collapsing Pressure, Pcr

Pcr = 40.74 psi ---> (2.6 * Et * ((tc/Dc)^2.5)) / (L/Dc - 0.45 * ((tc/Dc)^0.5))

Determine Maximum Allowable Pressure, Pall = Pcr / FS

Pall = 15.37 psi ---> Pcr / FS

Determine Maximum Allowable Spacing Between Stiffeners

Lmax = 31.32 inches ---> Dc * ((tc/Dc)^0.5) * (0.45 + ((2.6 * Et)/(FS * p))*((tc/Dc)^2))

Determine Maximum Allowable Circumferential Stress, Sc_all

Sc_all = 2,966 psi ---> ((2.6/(FS * 2)) * Et * ((tc/Dc)^1.5))/((L/Dc) - 0.45 * ((tc/Dc)^0.5))

Determine Corresponding Minimum Thickness of Cylinder, tc_min

tc_min = 0.051 inches ---> 2 * (Dc/2) * ((2 * p/Et)^0.5)

Intermediate Vacuum Stiffeners

A_stiff = 0.328 in**2 ---> dstiff * tstiff
A_shell = 0.348 in**2 ---> 1.1 * tc * Sqrt(Dc * tc)
A_total = 0.677 in**2 ---> A_stiff + A_shell
ybar = 0.519 inches abv shell ---> (A_stiff * (dstiff/2 + tc) + A_shell * (tc/2)) / A_total
I_stiff = 0.083 in**4 ---> Moment of Inertia of stiffener with a 6 degree incline from the vertical.
I_shell = 0.0005 in**4 ---> (1/12) * (1.1 * Sqrt(Dc * tc)) * tc^3
I_tot = 0.232 in4** ---> I_stiff + I_shell + A_stiff * (dstiff/2 + tc - ybar)^2 + A_shell * (ybar - tc/2)^2
B_stiff = 3,916 psi ---> 0.75 * (p * Dc) / (tc + A_stiff / L)
A_value = 0.000290 ---> (2 * B_stiff) / Et
Req'd I_tot = 0.234 in4** ---> ((Dc^2 * L * (tc + A_stiff / L) * A_value) / 10.9) * (FS / 3), ASME Div 2 UG-29

Conclusion: With a 30" spacing of the beam tube vacuum stiffeners, a Factor of Safety of 2.65 will result in a design that provides both an allowable design pressure >= 14.70 psi and variation of < 1 percent in the actual and required moments of inertia of the stiffener / shell section. This design does not conform to the requirements of the ASME Code.

SUBJECT **LIGO BEAM TUBE VACUUM STIFFENERS SPACING, ALLOWABLE PRESSURE, AND SIZE WITH ASME & NON-ASME SAFETY FACTORS**	OFFICE: NOE		REVISION:		REFERENCE NO. 930212
	MADE BY WJC	CHKD RJW	MADE BY	CHKD	SHT 3 OF 4
	DATE 3/10/94	DATE 18MAR94	DATE	DATE	2.4

DESIGN OF VACUUM VESSELS WITH CIRCUMFERENTIAL STIFFENERS
DAVID TAYLOR MODEL BASIN PROCEDURE & MODIFIED ASME DIVISION II

Purpose: **This calculation shows the resulting Factor of Safety (Non-ASME) that is obtained by spacing the beam tube vacuum stiffeners (1.75" x 0.1875") at 30", yet still obtaining an allowable design pressure >= 14.70 psi, with an accepted 5 percent variation in the actual and required moments of inertia of the stiffener / shell section.**
The moment of inertia of the stiffener accounts for the 6 degree rotation that can be expected during construction.

Input Variables, Cylinder

Cylinder O.D, Dc	**49.00**	**inches**
Cylinder Thickness, tc	**0.127**	**inches**
Design Pressure, p	**14.70**	**psi**
Design Temperature	**300**	**degrees F**
Safety Factor, FS	**2.77**	**Non-ASME Safety Factor**

Input Variables, Stiffener

Stiffener Depth, dstiff	**1.750**	**inches**
Stiffener Thick, tstiff	**0.1875**	**inches**
Stiffener Spacing, L	**30.000**	**inches**

Computed Circumferential Stress in Cylinder

Sc = 2,836 psi ---> (p * Dc) / (2 * tc)

Determine Tangent Modulus of the Material, Et

Et = 27,000,000 psi ---> (For 304L @ 300F, Table TM-1, p664, ASME Section II Part D)

Determine Collapsing Pressure, Pcr

Pcr = 40.74 psi ---> (2.6 * Et * ((tc/Dc)^2.5)) / (L/Dc - 0.45 * ((tc/Dc)^0.5))

Determine Maximum Allowable Pressure, Pall = Pcr / FS

Pall = 14.71 psi ---> Pcr / FS

Determine Maximum Allowable Spacing Between Stiffeners

Lmax = 30.01 inches ---> Dc * ((tc/Dc)^0.5) * (0.45 + ((2.6 * Et)/(FS * p))*((tc/Dc)^2))

Determine Maximum Allowable Circumferential Stress, Sc_all

Sc_all = 2,837 psi ---> ((2.6/(FS * 2)) * Et * ((tc/Dc)^1.5))/((L/Dc) - 0.45 * ((tc/Dc)^0.5))

Determine Corresponding Minimum Thickness of Cylinder, tc_min

tc_min = 0.051 inches ---> 2 * (Dc/2) * ((2 * p/Et)^0.5)

Intermediate Vacuum Stiffeners

A_stiff = 0.328 in**2 ---> dstiff * tstiff
A_shell = 0.348 in**2 ---> 1.1 * tc * Sqrt(Dc * tc)
A_total = 0.677 in**2 ---> A_stiff + A_shell
ybar = 0.519 inches abv shell ---> (A_stiff * (dstiff/2 + tc) + A_shell * (tc/2)) / A_total
I_stiff = 0.083 in**4 ---> Moment of Inertia of stiffener with a 6 degree incline from the vertical.
I_shell = 0.0005 in**4 ---> (1/12) * (1.1 * Sqrt(Dc * tc)) * tc^3
I_tot = 0.232 in4** ---> I_stiff + I_shell + A_stiff * (dstiff/2 + tc - ybar)^2 + A_shell * (ybar - tc/2)^2
B_stiff = 3,916 psi ---> 0.75 * (p * Dc) / (tc + A_stiff / L)
A_value = 0.000290 ---> (2 * B_stiff) / Et
Req'd I_tot = 0.244 in4** ---> ((Dc^2 * L * (tc + A_stiff / L) * A_value) / 10.9) * (FS / 3), ASME Div 2 UG-29

Conclusion: **With a 30" spacing of the beam tube vacuum stiffeners, a Factor of Safety of 2.77 will result in a design that provides both an allowable design pressure >= 14.70 psi and variation of < 5 percent in the actual and required moments of inertia of the stiffener / shell section. This design does not conform to the requirements of the ASME Code.**

SUBJECT	OFFICE: NOE		REVISION:		REFERENCE NO. 930212
LIGO BEAM TUBE VACUUM STIFFENERS SPACING, ALLOWABLE PRESSURE, AND SIZE WITH ASME & NON-ASME SAFETY FACTORS	MADE BY WJC	CHKD	MADE BY	CHKD	SHT 4 OF 4
	DATE 3/11/94	DATE 10 Mar 94	DATE	DATE	2.5

BEAM TUBE VACUUM STIFFENERS: ROTATION DURING WELDING

Purpose

Determine the reduction in the moment of inertia of a vacuum stiffener that rotates a maximum of 8 degrees from the vertical when welded to the beam tube. Consider the effect upon the total moment of inertia of the combined stiffener / shell section. The effect of the rotation upon the location of the C.G. of the stiffener is very minor and shall be neglected.

Stiffener Size & Area

1.75" deep x 0.1875" thick 304L bar,
==> d = 1.750 in
==> b = 0.188 in
==> As = 0.328 in^2
==> alpha = angle of rotation of stiffener from vertical

Moment of Inertia of Rotated Stiffener, Ist

Ist = b * d * ((b^2 * sin(alpha)^2) + (d^2 * cos(alpha)^2)) / 12
(AISC Manual, "Properties of Geometric Sections")

Effective Width and Area of Beam Tube Shell

Shell Thickness, t ==================>	0.127 in
Shell Outside Diameter, Do ============>	49.00 in
Effect Width, Le = 1.10 * [(Do * t)^0.5] ====>	2.744 in
Effective Area, Ae = Le * t ==============>	0.348 in^2
Moment of Inertia, Ish = Le * t^3 / 12 =====>	0.0005 in^4

For the Combined Stiffener / Shell Section

Area, At = 0.677 in^2
ybar = 0.519 in above bottom of shell
Moment of Inertia, Icomb = Ist + Ish + [As * (d/2 + t - ybar)^2] + [Ae * (ybar - t/2)^2]

Stiffener Rotation, alpha	0 deg	2 deg	4 deg	6 deg	8 deg	
Stiffener Inertia, Is (in^4)	0.0837	0.0836	0.0833	0.0828	0.0821	<==== For the stiffener only
Combined Inertia, Icomb (in^4)	0.2331	0.2325	0.2322	0.2317	0.2310	<==== For the stiffener / shell section
Change from alpha = 0 deg	0.00 %	-0.24 %	-0.37 %	-0.59 %	-0.89 %	

===> 0.90 % maximum reduction in moment of inertia of combined section, NEGLIGIBLE

SUBJECT LIGO BEAM TUBE VACUUM STIFFENERS REDUCTION IN INERTIA DUE TO ROTATION	OFFICE: NOE		REVISION		REFERENCE NO. 930212
	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 1
	DATE 3/10/94	DATE 19MAR94	DATE	DATE	2.6

ATTACHMENT OF STIFFENER RINGS TO TUBE PER UG-30.

USE 1/8" FILLET WELD LEGS (MINIMUM PER UG-30(f))

ALLOWABLE FOR FILLET WELD PER UW-18(d):

$0.55 \times \text{AREA} \times S$

FOR A 1" LONG, 1/8" FILLET, AREA = $1/8$ in^2

$$\text{ALLOWABLE} = 0.55 \times \frac{1}{8} \frac{\text{in}^2}{\text{in}} \times 15{,}400 \text{ psi} = 1059 \ \#/\text{in.}$$

ATTACHMENT WELDS ARE SIZED PER UG-30(e) TO RESIST:

- FULL RADIAL PRESSURE LOAD FROM SHELL BETWEEN STIFFENERS, PL_s
- RADIAL SHEAR COMPUTED AS 2% OF RING COMPRESSIVE LOAD, $0.02 PL_s R_o$
- SHEAR LOADS ACTING RADIALLY ACROSS STIFFENER (NOT APPLICABLE)

ASSUME A MAXIMUM VALUE OF $L_s = 28''$

$$PL_s = 14.7 \text{ psi} (28 \text{ in}) = 412 \ \#/\text{in} \quad \text{RADIAL}$$

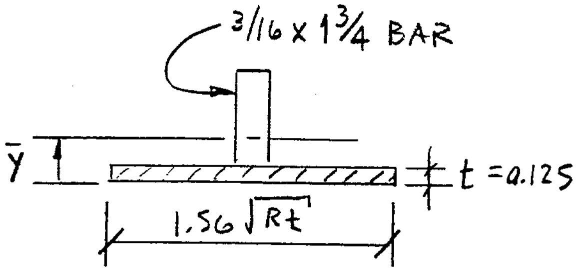
$$0.02 PL_s R_o = 0.02 (14.7 \text{ psi})(28 \text{ in})(24.125 \text{ in}) = 199 \ \# \quad \text{RADIAL}$$

SUBJECT	CBI OFFICE NoE		REVISION		REFERENCE NO. 930212
LIGO BEAM TUBES STIFFENER RINGS	MADE BY JEH	CHKD BY [illegible]	MADE BY	CHKD BY	SHT 1 OF 3
	DATE 11/3/93	DATE [illegible]	DATE	DATE	2.7

PARTICIPATING WIDTH OF TUBE:

$$1.56\sqrt{Rt} = 1.56\sqrt{24(.125)} = 2.702 \text{ in}$$

DETERMINE Q, FIRST MOMENT OF AREA:



$$Q = A_{TUBE}\left(\bar{y} - \frac{t}{2}\right)$$

$\bar{y} = 0.5246$ in (COMBINED SECTION)

$$Q = 2.702 \times 0.125\left(0.5246 - \frac{0.125}{2}\right) = 0.156 \text{ in}^3$$

$$\frac{VQ}{I} = \frac{199\#(0.156 \text{ in}^3)}{0.230 \text{ in}^4} = 135 \text{ \#/in. TANGENTIAL}$$

COMBINED LOAD ON WELD:

$$\sqrt{412^2 + 135^2} = 434 \text{ \#/in}$$

% OF CIRCUMFERENCE WELDED REQ'D FOR ONE-SIDED:

$$\frac{434}{1059} \times 100 = 41\%$$

∴ CONTINUOUS 1/8" FILLET ON ONE SIDE ONLY IS ACCEPTABLE (SOME SMALL LENGTH WILL REMAIN UNWELDED WHERE JOINT IN STIFFENER CROSSES TUBE SEAM)

SUBJECT
LIGO BEAM TUBES
STIFFENER RINGS

CBI OFFICE NOE

REVISION

REFERENCE NO. 930212

MADE BY JEH
CHKD BY RJW
MADE BY
CHKD BY

SHT 2 OF 3

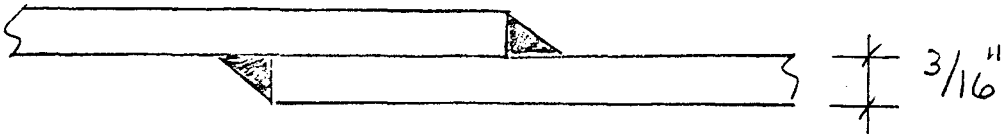
DATE 11/3/93
DATE 6 NOV 93
DATE
DATE

2.8

Printed In USA

GO 64 REV SEP 84

EVALUATE LAPPED ATTACHMENT OF STIFFENER ENDS:



ASSUME LOAD TO BE TRANSMITTED ACROSS JOINT IS 15,400 psi MULTIPLIED BY THE FULL STIFFENER AREA

LOAD = $15{,}400 \text{ psi} \times 3/16 \times 1.75 = 5053\#$

ASSUME FULL THICKNESS FILLETS, $1\frac{1}{2}$" LONG ARE USED:

ALLOWABLE LOAD = $0.55 \times 15{,}400 \text{ psi} \times 2(1.5) \times .1875 = 4764\#$

$4764 < 5053\#$ REQ'D ∴ ADD'L WELD IS REQ'D.

DETERMINE LENGTH OF GROOVE WELD ACROSS TOP WHICH WILL SUPPLY THE NECESSARY ADD'L STRENGTH

USE BUTT GROOVE W/O EDGE PREPARATION. ASSUME 1/16" PENETRATION. USE A 60% GROOVE WELD EFFICIENCY FOR SHEAR IN ACCORDANCE WITH UW-15(c). IF LAP OF STIFFENERS IS SPECIFIED AS A NOMINAL 1", ± 1/2", THE SHORTEST LENGTH IS 1/2":

$.60 \times 15{,}400 \text{psi} \times \frac{1}{16} \times \frac{1}{2} = 289\#$

$4764 + 289 = 5053\# \leq 5053\#$ REQ'D OK

SUBJECT LIGO BEAM TUBES STIFFENER RINGS	CBI OFFICE NOE		REVISION	REFERENCE NO. 930212
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	DATE 11/3/93	DATE 8 [illegible]	DATE	DATE	2.9

Printed In USA

GO 64 REV SEP 84

MAXIMUM UNSUPPORTED GAP

$D_o = 49.004$

$t = 0.127$

$L = 28.35$

$$D_o/t = \frac{49.004}{0.127} = 385.9$$

$$L/D_o = \frac{28.35}{49.004} = 0.578$$

FIG UG 29.2

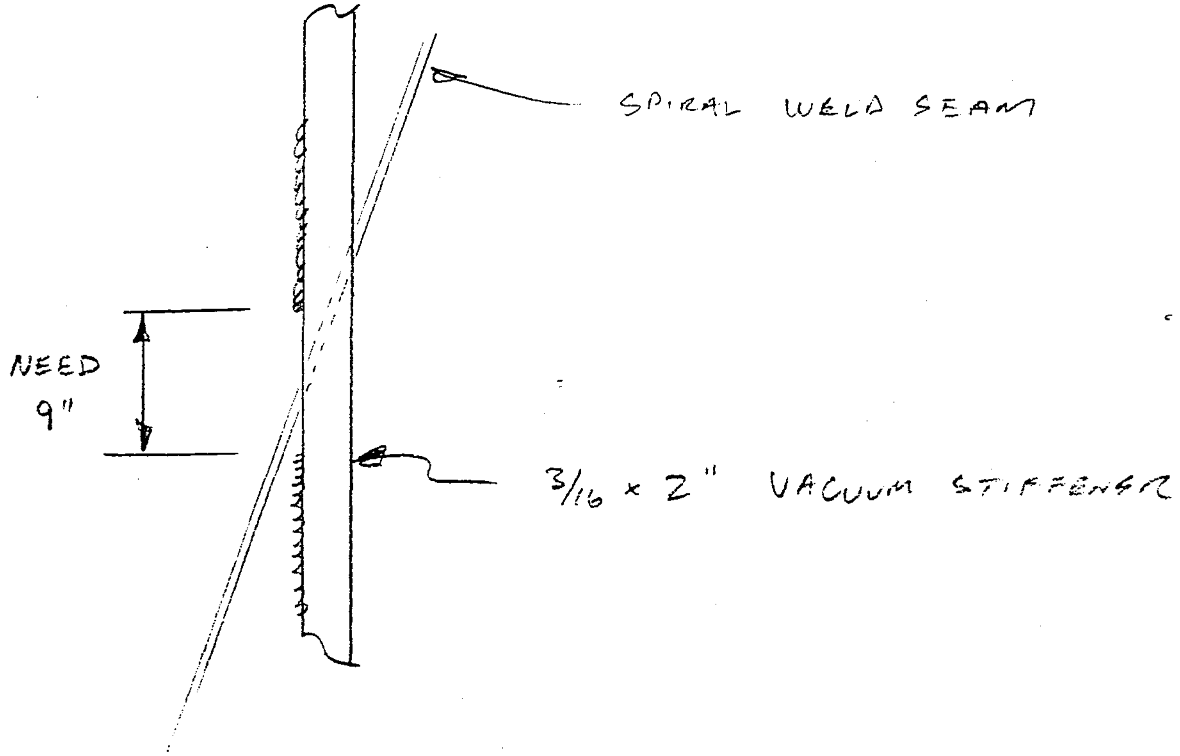
$$ARC = 0.085\,D_o = 0.085(49.004) = 4.165 \rightarrow 4\ 3/16''$$

9" IS PREFERRED

SUBJECT LIGO BEAM TUBE MAX GAP OF STIFFENER RING	CBI OFFICE NOF-C		REVISION		REFERENCE NO. 930212
	MADE BY RIL	CHKD BY WJC	MADE BY	CHKD BY	SHT 1 OF 3
	DATE 3 FEB 93	DATE 4-3-94	DATE	DATE	2.10

Printed In USA

GO 64 REV SEP 84



- PER UG-29 / FIGURE UG 29.2

MAX UNSUPPORTED LENGTH $4\frac{3}{16}$

- LOOK @ TRUE BUCKLING STRENGTH

$$1.56(49.077/2 \times .127)^{.5} = 2.748''$$

$$E = 27100000 \text{ psi}$$

$$I = \frac{2.478(.127)^3}{12} = 0.000469$$

$$N = \frac{49.0077\pi}{4.165} = 36.96 \Rightarrow 37$$

TO COMPARE TO ASME

$$P_{CR}\ \#/in = \frac{EI(N^2-1)}{R^3}$$

$$= \frac{27.1\times10^6(.000469)(37^2-1)}{(49.077/2)^3}$$

$$= 1191\ \#/in$$

$$\text{PRESSURE} = \frac{1191}{28.35''} = 42.02\text{ psi}$$

$$\frac{42.02}{14.7} = FS = 2.86 \approx 3.0$$

SUBJECT	CBI OFFICE NOE-C	REVISION		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 2 OF 3
	DATE 3Feb93	DATE 4-3-94	DATE	DATE	2.11

- TRY 9"

$$N = \frac{49.004\pi}{9} = 17.1 \Rightarrow 17$$

$$P_{CR} = \frac{27.1\times10^{6}(.000469)(17^{2}-1)}{(48.877/2)^{3}} = 251 \text{ \#/IN}$$

$$\text{PRESSURE} = \frac{251}{28.35 \text{ STIFF SPA}} = 8.85 \text{ psi} < 14.7 \quad \text{N.G.}$$

- DETERMINE MAXIMUM UNWELDED LENGTH W/ FS=2.5

$$P_{CR} = 2.5(14.7)(28.35'') = 1042$$

$$N = \sqrt{1+\frac{R^{3}P_{CR}}{EI}} = \sqrt{1+\frac{(48.877/2)^{3}(1042)}{27.1\times10^{6}(.000469)}}$$

$$N = 34.6 \Rightarrow 34$$

$$S = \frac{49.004\pi}{N} = 4.5''$$

- MAXIMUM UNWELDED LENGTH W/ FS = 1.5

$$P_{CR} = 1.5(14.7)(28.35) = 625$$

$$N = \sqrt{1+\frac{(48.877/2)^{3}(625)}{27.1\times10^{6}(.000469)}} = 26.8 \Rightarrow 27$$

$$S = \frac{49.004\pi}{27} = 5.70''$$

SUBJECT	CBI OFFICE NOFC		REVISION		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 3 OF 3
	DATE 3FEB93	DATE 4-3-94	DATE	DATE	2.12

INERTIA OF EXPANSION JOINT

- ONE CONVOLUTE   C-5 EJMA

$$I_{1-1} = N\left[\frac{nt(2w-q)^3}{48} + 0.4qnt(w-0.2q)^2\right] \quad (C-49)$$

$N = 1$
$n = 1$
$t = 0.105$
$w = 2.5 - 0.105 = 2.395$
$q = 1''$

$$I = 1\left[\frac{(1)(.105)(2(2.395)-1)^3}{48} + 0.4(1)(1)(.105)(2.395-0.2(1))^2\right]$$

$$I_{11} = 1\left[0.119 + 0.202\right] = .321 \text{ in}^4 > I_{REQ'D} \text{ PER ASME}$$

FOR 9 CONVOLUTES

$$I_{11} = 9(.321) = 2.89 \text{ in}^4$$

CONCLUSION

THE CONVOLUTION OF THE EXPANSION JOINT WILL ACT AS A VACUUM STIFFENER. THE MAXIMUM SPACING CAN BE BASED ON A 0.105 THICKNESS

SUBJECT MOMENT OF INERTIA - EXP'N JT. CONVOLUTE	CBI OFFICE NCG-L	REVISION		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 1 OF 1
	DATE 1-20-94	DATE 4-4-94	DATE	DATE	2.13

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GO 64 REV SEP 84

PUMP PORT NECK THICKNESS

ASME VIII DIV 1
UG-28

ASSUME:

$t = 0.025$
$l = 3"$ (MAXIMUM NECK LENGTH)
$\phi = 10"$

$$D/t = 10"/0.025 = 400$$

$$L/D = \frac{3}{10} = 0.3$$

$A = 0.0006$ FIG G PART D SUBPART 3

$B = 5000$ FIG HA-3

$$P = \frac{4B}{3(D/t)} = \frac{4(5000)}{3(400)} = 16.7 \text{ psi} > 14.7$$

MAXIMUM OD

FOR EFFECTIVE LIMITS (UG-40) d FROM ℄ OF NOZZLE ∴ OD = 20"

SPACING FROM STIFFENERS 6" OR 8t STD 9301-2

STIFFENER SPACING = 27.7" SAY 27.5"

$$\text{MAX OD} = 27.5 - 3/16 \text{ THICK} - 2(1/3 \text{ FILLETS}) - 2(6" \text{ SPACING}) = 15.0625"$$

THICKNESS REQUIRED

$$t_{REQ'D} = \frac{0.500 \text{ IN}^2 \text{ (AREA REQ'D)}}{15" - (10 + 2 \times 1.5)} = 0.25"$$

SUBJECT	OFFICE		REVISION		REFERENCE NO.
10" φ PUMP PORT LIGO BEAM TUBE	CBI NOB-C				930212
	MADE BY RJH	CHKD BY BTS	MADE BY	CHKD BY	SHT 1 OF 11
	DATE 1 NOV 93	DATE 10 NOV 93	DATE	DATE	3.1

CHECK WELD SIZE BETWEEN NECK & SHELL

- LOAD ON NOZZLE

DUE TO EXTERNAL PRESSURE = $14.7 \times \pi (5)^2 = 1154$ #

$$f = \frac{1134^{\#}}{\pi(10)} = 367 \ \#/_{in}$$

DUE TO NOZZLE END LOADS 150# SAY 4" FROM SHELL

$$f = \frac{M}{S} = \frac{4(150^{\#})}{\frac{\pi(10)^2}{4}} = 7.64 \ \#/_{in} \qquad S = \frac{\pi d^2}{4}$$

Pg 510 DESIGN OF ℄ STRUCTURES

DUE TO SHEAR

$$f = \frac{150^{\#}}{\pi 10} = 4.77$$

TOTAL STRESS

$$f = \sqrt{(4.77)^2 + (36.7+7.64)^2} = 44.6 \ \#/_{in}$$

- CAPACITY OF WELD

$$\text{FILLET} = (1/3)(0.49)(13000)(1\tfrac{1}{2}, \text{FULL 1 SIDE STITCH OTHER SIDE})$$
$$= 1194 \ \#/_{in}$$

WELD IS ADEQUATE

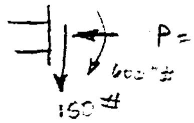
SUBJECT 10" ϕ PUMP PORT LIGO BEAM TUBE	CBI OFFICE LGB C	REVISION		REFERENCE NO. 930212
	MADE BY RJ	CHKD BY BTS	MADE BY	CHKD BY	SHT 2 OF 11
	DATE 7NOV93	DATE 10NOV93	DATE	DATE	3.2

Printed In USA

GO 64 REV SEP 84

CHECK SHELL FOR NOZZLE LOADS SEE STD 9107-3.6

LOAD ON NOZZLE



$P = 1154$

$V_L = 0$

$V_C = 150$

$M_C = -600"\#$

INITIAL STRESS

$$\sigma_\phi = \frac{PR_m}{T} = \frac{14.7(24)}{.125} = 2822 \text{ psi}$$

$$\sigma_x = \frac{PR}{2T} = \frac{\sigma_\theta}{2} = 1411.2$$

$$\sigma_x (A_m \rightarrow D_m) = 1411 \text{ psi}$$

$$\sigma_\phi (A_m \rightarrow D_m) = 2822$$

ASSUME SURFACE STRESSES = 1 1/2 × MEMBRANE

$$\sigma_x (A_u \rightarrow D_u) = 1.5(1411.2) = 2117$$

$$\sigma_\phi (A_u \rightarrow D_u) = 1.5(2822) = 4234$$

PUNCHING SHEAR

$$\tau_{x\phi} = \frac{1.5P}{2\pi r_o T} = \frac{1.5(1154)}{2\pi(5)(.125)} = 441 \text{ psi}$$

@ $.5\sqrt{Rt}$

$$\tau_{x\phi} = \frac{1.5(1154)}{2\pi(5+\underbrace{.5\sqrt{24(.125)}}_{.866''}).125} = 376 \text{ psi}$$

SUBJECT	OFFICE HOU	REVISION		REFERENCE NO. 9301C
10" ∅ PUMP PORT LIGO BEAM TUBE	MADE BY Bill / CHKD BY BTS	MADE BY	CHKD BY	SHT 3 OF 11
	DATE 2NOV93 / DATE 10NOV93	DATE	DATE	3.3

Printed In USA

GC 64 REV SEP 84

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OGRAM E1027A STD 9107- 3- 6 [ IBM RS/6000 ]
VISION 14 - 04/22/93 (WRC-107 REV MAR 79)
RESS INTENSITIES AT LOADED ATTACHMENTS IN CYLINDERS AND SPHERES
E CBI STANDARD 9107-3-6 FOR INSTRUCTIONS ON USING THIS PROGRAM.

   INPUT
          ATTCHMTS     VESSEL      LOADING      ANALYSIS
              1        1=CYL      -1=FIXED         3D

            KN           KB           RM            T          LOC          C
           1.00         1.00        24.000         .125       .5000        .00

            RO           TI           TP            W
           5.000         .000         .000         .000

            P            VL           VC            MC          ML          MT
          1154.00         .00       -150.00       -600.00       .00         .00

  INITIAL STRESSES NEXT TO ATTCHMNT
     SX(AU)   SO(AU)   SX(CU)   SO(CU)   SX(AM)   SO(AM)   SX(CM)   SO(CM)
      2117.    4234.    2117.    4234.    1411.    2822.    1411.    2822.
  INITIAL STRESSES AT LOC*SQRT(R*T)
     SX(AU)   SO(AU)   SX(CU)   SO(CU)   SX(AM)   SO(AM)   SX(CM)   SO(CM)
      2117.    4234.    2117.    4234.    1411.    2822.    1411.    2822.
  INITIAL STRESSES AT EDGE OF REINF
     SX(AU)   SO(AU)   SX(CU)   SO(CU)   SX(AM)   SO(AM)   SX(CM)   SO(CM)
         0.       0.       0.       0.       0.       0.       0.       0.

   INT                RADIAL PUNNCHING SHEAR STRESSES
  PRESS       NEXT TO ATTCHMNT       AT LOC*SQRT(R*T)         AT EDGE OF REINF
               AT A,B,C, AND D        AT A,B,C, AND D          AT A,B,C, AND D
   -15.                    441.                   376.                      0.




 10" DIAMETER PUMP PORT
 930212
 ROUND  ATTCHMT 10" DIA NOZZLE                          ON A CYLINDRICAL  VESSEL
```

SUBJECT	MADE BY	CHKD BY	REV.	BY		CHARGE NO.
	BTS	EJW	0			930212
	DATE	DATE		CHKD		
	10NOV93	10NOV93		DATE		SHT 4 OF 11

3.4

```
OUTPUT
BIJLAARD COEFICIENTS
         NEXT TO ATTCHMNT         AT LOC*SQRT(R*T)
          A & B      C & D          A & B      C & D
NX/P     6.727     18.388          5.151     16.181
MX/P      .032       .013*          .025       .009*
NX/MC          16.360                   16.360
MX/MC            .022                     .020
NX/ML           5.532                    4.626
MX/ML            .014                     .012
NO/P    18.388      6.727         16.181      5.151
MO/P      .013       .032*          .009       .025*
NO/MC           5.573                    4.670
MO/MC            .054                     .051
NO/ML          11.680                    9.832
MO/ML            .010                     .008

*  MX/P FROM FIG 2C-1 INSTEAD OF 2C &/OR MO/P FROM 1C-1 INSTEAD OF 1C
```

```
10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                    ON A CYLINDRICAL  VESSEL
```

SUBJECT	MADE BY BTS	CHKD BY RJN	0	BY		CHARGE NO. 930212
	DATE 10NOV93	DATE 10NOV93	REV	CHKD		
				DATE		SHT 5 OF 11

```
SURFACE STRESS INTENSITIES NEXT TO ATTCHMNT (U=OUTS);(L=INS)
RO=  5.000;
        (AU)      (AL)     (BU)      (BL)      (CU)      (CL)     (DU)      (DL)
SX  -16840.   11665.  -16840.   11665.  -10841.   -1810.  -14626.   -1017.
SO  -12733.   -1414.  -12733.   -1414.  -13731.    9066.  -19949.   14265.
TAU    -76.     -76.      76.      76.       0.       0.       0.       0.
SI   16827.   13080.   16827.   13080.   13716.   10876.   19934.   15282.

SURFACE STRESS INTENSITIES AT LOC*SQRT(R*T) (U=OUTS);(L=INS)
RO=  5.866;
        (AU)      (AL)     (BU)      (BL)      (CU)      (CL)     (DU)      (DL)
SX  -13278.    9315.  -13278.    9315.   -8830.   -2343.  -11879.   -1844.
SO  -10355.   -2094.  -10355.   -2094.  -10786.    7187.  -15770.   11444.
TAU    -65.     -65.      65.      65.       0.       0.       0.       0.
SI   13265.   11410.   13265.   11410.   10771.    9531.   15755.   13287.

OUTPUT INCLUDING INITIAL STRESSES
SURFACE STRESS INTENSITIES NEXT TO ATTCHMNT (U=OUTS);(L=INS)
RO=  5.000;
        (AU)      (AL)     (BU)      (BL)      (CU)      (CL)     (DU)      (DL)
SX  -14723.   12370.  -14723.   12370.   -8724.   -1105.  -12509.    -312.
SO   -8499.      -4.   -8499.      -4.   -9497.   10476.  -15715.   15675.
TAU    -76.     -76.      76.      76.       0.       0.       0.       0.
SI   14709.   12375.   14709.   12375.    9482.   11581.   15700.   15987.

SURFACE STRESS INTENSITIES AT LOC*SQRT(R*T) (U=OUTS);(L=INS)
RO=  5.866;
        (AU)      (AL)     (BU)      (BL)      (CU)      (CL)     (DU)      (DL)
SX  -11161.   10020.  -11161.   10020.   -6713.   -1638.   -9762.   -1139.
SO   -6121.    -684.   -6121.    -684.   -6552.    8597.  -11536.   12854.
TAU    -65.     -65.      65.      65.       0.       0.       0.       0.
SI   11147.   10705.   11147.   10705.    6698.   10236.   11521.   13992.
```

```
10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                          ON A CYLINDRICAL  VESSEL
```

SUBJECT	MADE BY BTS	CHKD BY RAH	REV 0	BY		CHARGE NO. 930212
	DATE 10NOV93	DATE 10/10/93		CHKD		
				DATE		SHT 6 OF 11

3.6

```
CTRLINE STRESS INTENSITIES NEXT TO ATTCHMNT (M=CTRL)
RO=  5.000;
                (AM)             (BM)             (CM)             (DM)
SX            -2588.           -2588.           -6326.           -7821.
SO            -7073.           -7073.           -2333.           -2842.
TAU             -76.              76.              0.               0.
SI             7155.            7155.            6413.            7896.

CTRLINE STRESS INTENSITIES AT LOC*SQRT(R*T) (M=CTRL)
RO=  5.866;
                (AM)             (BM)             (CM)             (DM)
SX            -1981.           -1981.           -5587.           -6862.
SO            -6224.           -6224.           -1799.           -2163.
TAU             -65.              65.              0.               0.
SI             6301.            6301.            5669.            6932.

OUTPUT INCLUDING INITIAL STRESSES
CTRLINE STRESS INTENSITIES NEXT TO ATTCHMNT (M=CTRL)
RO=  5.000;
                (AM)             (BM)             (CM)             (DM)
SX            -1177.           -1177.           -4915.           -6410.
SO            -4251.           -4251.             489.             -20.
TAU             -76.              76.              0.               0.
SI             4407.            4407.            5665.            6845.

CTRLINE STRESS INTENSITIES AT LOC*SQRT(R*T) (M=CTRL)
RO=  5.866;
                (AM)             (BM)             (CM)             (DM)
SX             -570.            -570.           -4176.           -5451.
SO            -3402.           -3402.            1023.             659.
TAU             -65.              65.              0.               0.
SI             3597.            3597.            5322.            6281.




10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                    ON A CYLINDRICAL  VESSEL
 SYSIN]
```

SUBJECT

BTS RJW

DATE 10NOV93 DATE 10NOV93

REV 0

BY

CHKD

DATE

CHARGE NO. 930212

SHT 7 OF 11

```
OGRAM E1027A STD 9107- 3- 6 [ IBM RS/6000 ]
EVISION 14 - 04/22/93 (WRC-107 REV MAR 79)
RESS INTENSITIES AT LOADED ATTACHMENTS IN CYLINDERS AND SPHERES
E CBI STANDARD 9107-3-6 FOR INSTRUCTIONS ON USING THIS PROGRAM.

     INPUT
            ATTCHMTS     VESSEL     LOADING      ANALYSIS
               1          1=CYL     -1=FIXED        3D

              KN          KB          RM           T          LOC           C
             1.00        1.00       24.000        .125       .5000         .00

              RO          TI          TP           W
            5.000        .000        .000        .000

               P          VL          VC          MC          ML           MT
           1154.00        .00      150.00      600.00         .00          .00

    INITIAL STRESSES NEXT TO ATTCHMNT
       SX(AU)   SO(AU)   SX(CU)   SO(CU)   SX(AM)   SO(AM)   SX(CM)   SO(CM)
        2117.    4234.    2117.    4234.    1411.    2822.    1411.    2822.

    INITIAL STRESSES AT LOC*SQRT(R*T)
       SX(AU)   SO(AU)   SX(CU)   SO(CU)   SX(AM)   SO(AM)   SX(CM)   SO(CM)
        2117.    4234.    2117.    4234.    1411.    2822.    1411.    2822.

    INITIAL STRESSES AT EDGE OF REINF
       SX(AU)   SO(AU)   SX(CU)   SO(CU)   SX(AM)   SO(AM)   SX(CM)   SO(CM)
           0.       0.       0.       0.       0.       0.       0.       0.

     INT              RADIAL PUNNCHING SHEAR STRESSES
    PRESS      NEXT TO ATTCHMNT      AT LOC*SQRT(R*T)      AT EDGE OF REINF
                AT A,B,C, AND D       AT A,B,C, AND D       AT A,B,C, AND D
     -15.                  441.                  376.
                                                                         0.




    10" DIAMETER PUMP PORT
    930212
    ROUND  ATTCHMT 10" DIA NOZZLE                       ON A CYLINDRICAL  VESSEL
```

SUBJECT						CHARGE NO. 930212
	BTS	RJW	0	BY		
	DATE	DATE		CHKD		
	10NOV93	10NOV93		DATE		SHT OF

```
OUTPUT
BIJLAARD COEFICIENTS
        NEXT TO ATTCHMNT        AT LOC*SQRT(R*T)
          A & B     C & D        A & B     C & D
NX/P      6.727    18.388        5.151    16.181
MX/P       .032      .013*        .025      .009*
NX/MC         16.360                 16.360
MX/MC           .022                   .020
NX/ML          5.532                  4.626
MX/ML           .014                   .012
NO/P     18.388     6.727       16.181     5.151
MO/P       .013      .032*        .009      .025*
NO/MC          5.573                  4.670
MO/MC           .054                   .051
NO/ML         11.680                  9.832
MO/ML           .010                   .008

*  MX/P FROM FIG 2C-1 INSTEAD OF 2C &/OR MO/P FROM 1C-1 INSTEAD OF 1C
```

```
10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                    ON A CYLINDRICAL  VESSEL
```

SUBJECT	MADE BY	CHKD BY	REVISION	BY		CHARGE NO.
	BTS	RJW				930212
	DATE	DATE		CHKD		
	10 NOV 93	10/10/93		DATE		SHT 9 OF 11

3.9

```
SURFACE STRESS INTENSITIES NEXT TO ATTCHMNT (U=OUTS);(L=INS)
RO=  5.000;
          (AU)      (AL)      (BU)      (BL)      (CU)      (CL)      (DU)      (DL)
SX   -16840.   11665.  -16840.   11665.  -14626.   -1017.  -10841.   -1810.
SO   -12733.   -1414.  -12733.   -1414.  -19949.   14265.  -13731.    9066.
TAU      76.      76.     -76.     -76.       0.       0.       0.       0.
SI    16827.   13080.   16827.   13080.   19934.   15282.   13716.   10876.

SURFACE STRESS INTENSITIES AT LOC*SQRT(R*T) (U=OUTS);(L=INS)
RO=  5.866;
          (AU)      (AL)      (BU)      (BL)      (CU)      (CL)      (DU)      (DL)
SX   -13278.    9315.  -13278.    9315.  -11879.   -1844.   -8830.   -2343.
SO   -10355.   -2094.  -10355.   -2094.  -15770.   11444.  -10786.    7187.
TAU      65.      65.     -65.     -65.       0.       0.       0.       0.
SI    13265.   11410.   13265.   11410.   15755.   13287.   10771.    9531.

OUTPUT INCLUDING INITIAL STRESSES
SURFACE STRESS INTENSITIES NEXT TO ATTCHMNT (U=OUTS);(L=INS)
RO=  5.000;
          (AU)      (AL)      (BU)      (BL)      (CU)      (CL)      (DU)      (DL)
SX   -14723.   12370.  -14723.   12370.  -12509.    -312.   -8724.   -1105.
SO    -8499.      -4.   -8499.      -4.  -15715.   15675.   -9497.   10476.
TAU      76.      76.     -76.     -76.       0.       0.       0.       0.
SI    14709.   12375.   14709.   12375.   15700.   15987.    9482.   11581.

SURFACE STRESS INTENSITIES AT LOC*SQRT(R*T) (U=OUTS);(L=INS)
RO=  5.866;
          (AU)      (AL)      (BU)      (BL)      (CU)      (CL)      (DU)      (DL)
SX   -11161.   10020.  -11161.   10020.   -9762.   -1139.   -6713.   -1638.
SO    -6121.    -684.   -6121.    -684.  -11536.   12854.   -6552.    8597.
TAU      65.      65.     -65.     -65.       0.       0.       0.       0.
SI    11147.   10705.   11147.   10705.   11521.   13992.    6698.   10236.
```

```
10" DIAMETER PUMP PORT
930212
ROUND  ATTCHMT 10" DIA NOZZLE                        ON A CYLINDRICAL  VESSEL
```

SUBJECT
BTS | RJW | BY
DATE 10NOV93 | DATE 10NOV93 | CHKD | DATE
CHARGE NO. 930212
SHT 10 OF 11

```
CTRLINE STRESS INTENSITIES NEXT TO ATTCHMNT (M=CTRL)
RO=  5.000;
               (AM)              (BM)             (CM)             (DM)
SX            -2588.            -2588.           -7821.           -6326.
SO            -7073.            -7073.           -2842.           -2333.
TAU              76.              -76.              0.               0.
SI             7155.             7155.            7896.            6413.

CTRLINE STRESS INTENSITIES AT LOC*SQRT(R*T) (M=CTRL)
RO=  5.866;
               (AM)              (BM)             (CM)             (DM)
SX            -1981.            -1981.           -6862.           -5587.
SO            -6224.            -6224.           -2163.           -1799.
TAU              65.              -65.              0.               0.
SI             6301.             6301.            6932.            5669.

OUTPUT INCLUDING INITIAL STRESSES
CTRLINE STRESS INTENSITIES NEXT TO ATTCHMNT (M=CTRL)
RO=  5.000;
               (AM)              (BM)             (CM)             (DM)
SX            -1177.            -1177.           -6410.           -4915.
SO            -4251.            -4251.             -20.             489.
TAU              76.              -76.              0.               0.
SI             4407.             4407.            6845.            5665.

CTRLINE STRESS INTENSITIES AT LOC*SQRT(R*T) (M=CTRL)
RO=  5.866;
               (AM)              (BM)             (CM)             (DM)
SX             -570.             -570.           -5451.           -4176.
SO            -3402.            -3402.             659.            1023.
TAU              65.              -65.              0.               0.
SI             3597.             3597.            6281.            5322.
```

```
  10" DIAMETER PUMP PORT
  930212
  ROUND  ATTCHMT 10" DIA NOZZLE                          ON A CYLINDRICAL  VESSEL
P  SYSIN]
```

SUBJECT

MADE BY BTS
DATE 10NOV93

CHKD BY Rirl
DATE 10NOV93

0 BY

CHKD

DATE

CHARGE NO. 930212

SHT 11 OF 11

PATHWAY

ENGINEERING CALCULATIONS	DRAW.	REV.	SHEET 1 of 4
CUSTOMER CB&I	BY RKB	QUOTE JOB NO	DATE 1/7/94

ENGINEERING CALCULATIONS

BELLOWS TORSION

$$S_s = \frac{2M_t}{n t \pi D_b^2} \quad \text{(EJMA EQ \# C-47)}$$

OR

$$M_t = \frac{n t \pi D_b^2 S_s}{2}$$

WHERE $n = 1$

$t = 0.11''$

$D_b = 48.5''$

$S_s = 2000$ Psi. FROM TESTING

$$M_t = \frac{1(.11)\pi(48.5)^2\,2000}{2}$$

$$= 812,819 \text{ IN-LBS (MAX)}$$

PATHWAY "CAN-DO" IT

PATHWAY

ENGINEERING CALCULATIONS

DRAWN

REV

SHEET 2 OF 4

CUSTOMER CB&I

BY RKB

QUOTE/JOB NO.

DATE 1/7

TORSIONAL SPRING RATE PER CAN $\left(\frac{Kt(B)}{N}\right)$ $= \dfrac{\pi G n t D_o^3}{229.2\ Ld}$

WHERE $G = 10.8 \times 10^6$ PSI

$n = 1$

$t = .11''$

$D_o = 48.5''$

$Ld = .571B + 2W$

$= .571(2) + 2(2.39)$

$= 5.922''$

TORSIONAL SPRING RATE PER CAN $= \dfrac{\pi(10.8 \times 10^6)(1)(.11)(48.5)^3}{229.2(5.922)}$

$\dfrac{Kt(B)}{N} = 3.14 \times 10^8$ in-Lbs/Deg

ENGINEERING CALCULATIONS

PATHWAY "CAN-DO" IT

PATHWAY

ENGINEERING CALCULATIONS

DRAW		REV	SHEET 3 of 4
CUSTOMER CB4I	BY RKB	QUOTE JOB NO	DATE 1/7

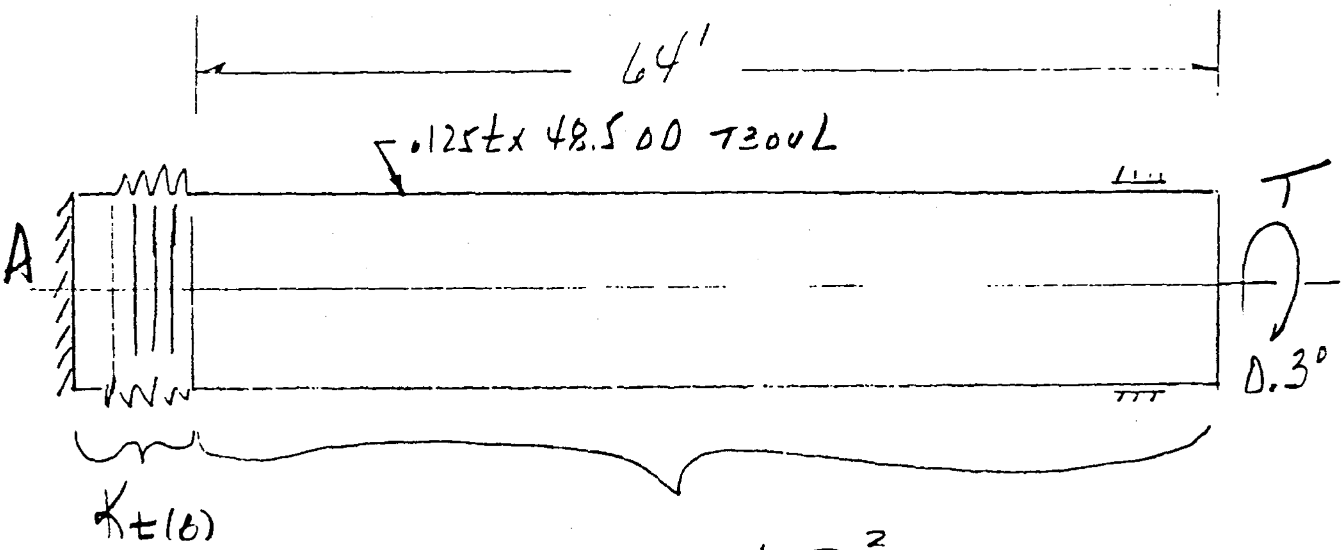
N No. Cons	Mt Max Moment	$K_{t(B)}$ Torsional Spring Rate	$\theta_{B(max)}$ Max. Torsional Rotation
2	812,819	1.57×10^8	0.0052°
4	↓	7.85×10^7	0.0104°
6		5.23×10^7	0.0155°
8		3.93×10^7	0.0207°
10		3.14×10^7	0.0259°

PATHWAY

ENGINEERING CALCULATIONS

DRAWING NO | REV | SHEET 4 OF 4

CUSTOMER CB&I | BY RLB | QUOTE JOB NO | DATE 1/7



$$K_{t(P)} = \frac{\pi G t D^3}{229.2\ L}$$

$$\theta_B = \frac{K_{t(P)}\,\theta_P}{K_{t(P)}}$$

$$= \frac{\pi (10.8\times10^6)(.125)(48.5)^3}{229.2\ (64)(12)}$$

$$= 2.75\times10^6 \text{ in-lbs/deg}$$

No Convs	Bellows Kt(B)	θB	Torque on Anchor (T)
2	1.57×10^8	.0053°	8.3×10^5 in-lbs
4	7.85×10^7	.0105°	↓
6	5.23×10^7	.0158°	
8	3.93×10^7	.0210°	
10	3.14×10^7	.0263°	

BEAM TUBE & EXPANSION JOINT PROPERTIES - BEAM ELEMENT EQUIVALENTS <u>FOR INCLUSION IN RISA-2D BEAM TUBE MODEL</u>

PURPOSE

CONVERT THE AXIAL AND ANGULAR SPRING RATES OF THE EXPANSION JOINT BELLOWS INTO EQUIVALENT AXIAL AND ROTATIONAL STIFFNESSES FOR A BEAM ELEMENT FOR INCLUSION IN A RISA-2D MODEL OF A PORTION OF THE BEAM TUBE MODULE. CONVERT INTO EQUIVALENT AREA AND MOMENT OF INERTIA. ADDITIONALLY, DETERMINE THE AREA AND MOMENT OF INERTIA OF THE BEAM TUBE FOR INCLUSION IN THE RISA-2D MODEL.

EXPANSION JOINT PROPERTIES

AXIAL SPRING RATE	8,316	LB / IN	(PATHWAY)
ANGULAR SPRING RATE	47,191	IN-LB / DEG	(PATHWAY)
ANGULAR SPRING RATE	2,703,845	IN-LB / RAD	
ELASTIC MODULUS AT 70F	28,300	KSI	
ELASTIC MODULUS AT 300F	27,000	KSI	
BELLOWS LENGTH	18	IN	
BELLOWS THICKNESS	0.105	IN	
BELLOWS O.D.	49.00	IN	

BEAM TUBE PROPERTIES

BEAM TUBE O.D	49.00	IN
BEAM TUBE THICKNESS	0.127	IN

FOR THE RISA BEAM ELEMENT REPRESENTING THE BELLOWS:

AXIAL STIFFNESS = AREA * ELASTIC MODULUS / LENGTH

===> AREA = AXIAL STIFFNESS * LENGTH / ELASTIC MODULUS

ROTATIONAL STIFFNESS = ELASTIC MODULUS * MOMENT OF INERTIA / LENGTH

===> MOMENT OF INERTIA = (ROTATIONAL STIFFNESS * LENGTH) / (ELASTIC MODULUS)

RISA BEAM ELEMENT PROPERTIES @ 70F (FOR BELLOWS)

AREA ==========> 0.0053 IN**2
INERTIA ========> 1.7198 IN**4

RISA BEAM ELEMENT PROPERTIES @ 300F (FOR BELLOWS)

AREA ==========> 0.0055 IN**2
INERTIA ========> 1.8026 IN**4

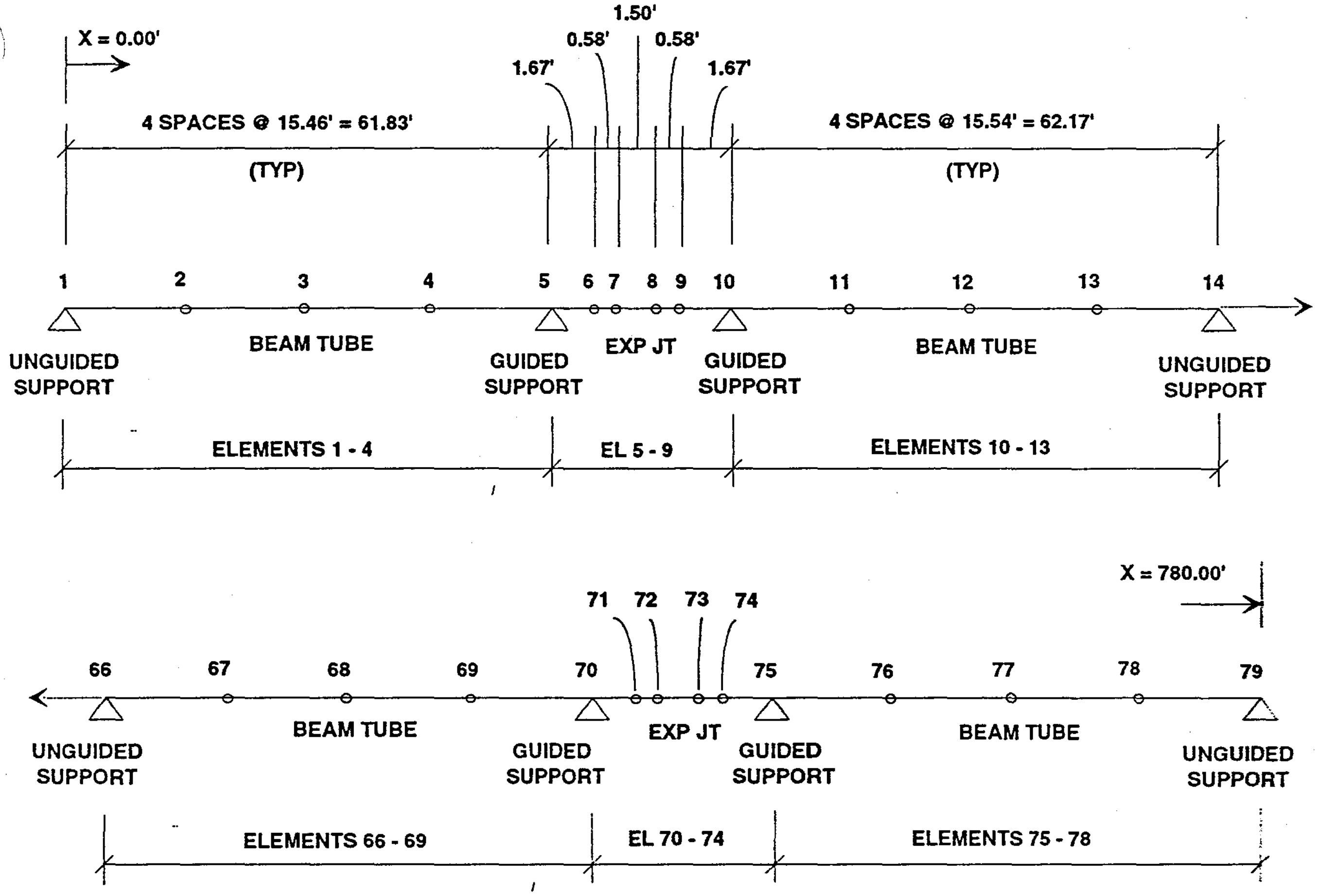
RISA BEAM ELEMENT PROPERTIES (FOR NONCONVOLUTED EXPANSION JOINT END)

AREA ==========> 16.13 IN**2
INERTIA ========> 4819.97 IN**4

RISA BEAM ELEMENT PROPERTIES (FOR BEAM TUBE)

AREA ==========> 19.50 IN**2
INERTIA ========> 5823.45 IN**4 NOTE: 5731 IN**4 USED IN MODEL ====> NEGLIGIBLE DIFFERENCE

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
RISA-2D BEAM ELEMENT SECTION PROPERTIES BELLOWS, EXPANSION JOINT END & BEAM TUBE	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 1
	DATE 2/28/94	DATE 4 MAR94	DATE	DATE	5.1



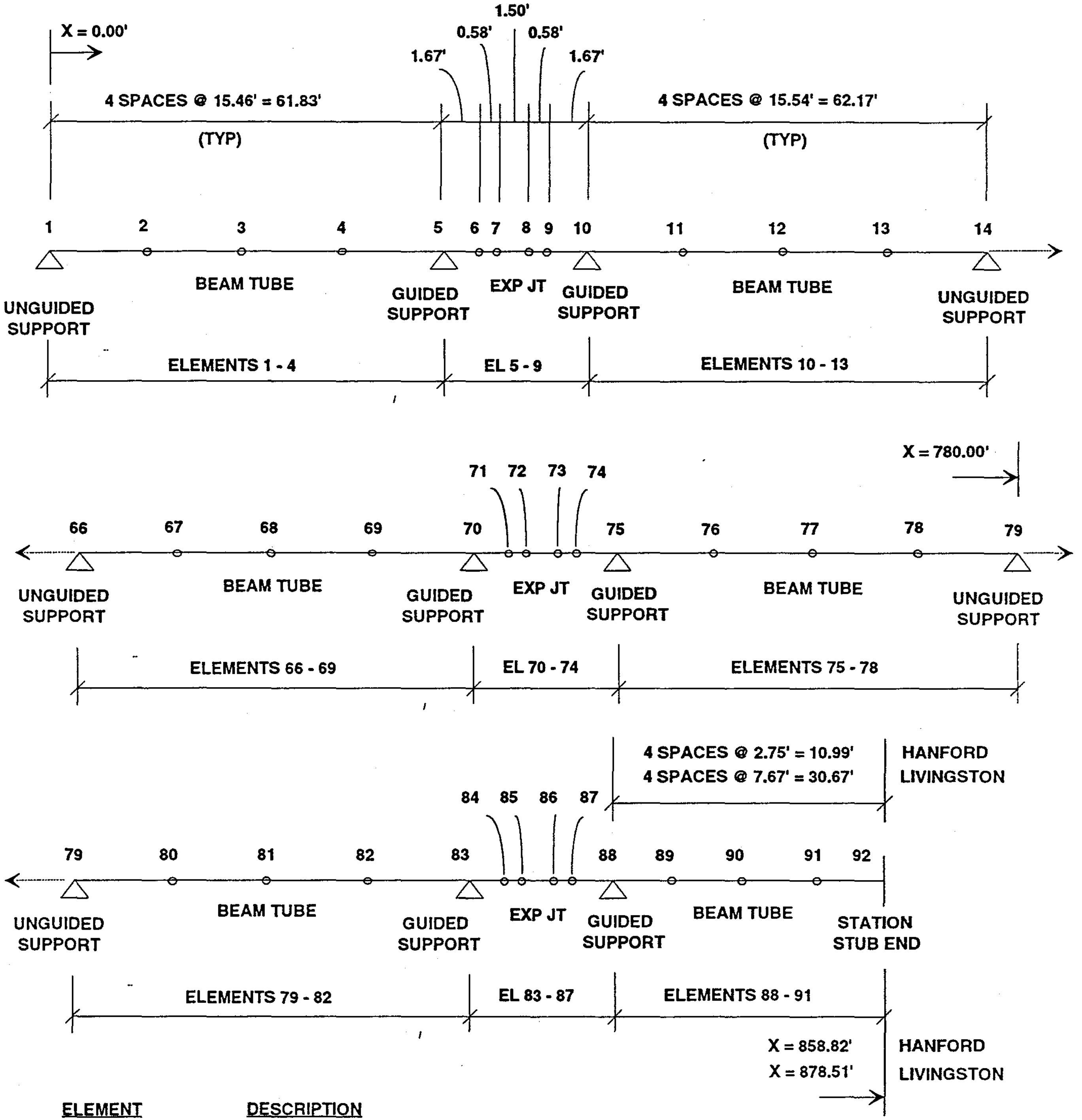
<u>ELEMENT</u>	<u>DESCRIPTION</u>
1 - 5, 9 - 13, 66 - 70, 74 - 78	BEAM TUBE
6, 8, 71, 73	EXP JT STUB END
7, 72	EXP JT BELLOWS

NOT TO SCALE

SUBJECT

RISA-2D MODEL OF LIGO BEAM TUBE
CASE #1, #1A & #1B
NODES AND ELEMENTS

CBI OFFICE NOE C		REVISION		REFERENCE NO. 930212
MADE BY WJC	CHKD BY RW	MADE BY	CHKD BY	SHT 1 OF 2
DATE 2-25-94	DATE 18MAR94	DATE	DATE	5.2



ELEMENT	DESCRIPTION
1 - 5, 9 - 13, 66 - 70, 74 - 78, 79 - 83, 87 - 91	BEAM TUBE
6, 8, 71, 73, 84, 86	EXP JT STUB END
7, 72, 85	EXP JT BELLOWS

NOT TO SCALE

SUBJECT

RISA-2D MODEL OF LIGO BEAM TUBE
CASE #2 -- HANFORD, WA SITE
CASE #3 -- LIVINGSTON, LA SITE
NODES AND ELEMENTS

CBI OFFICE NOE C		REVISION		REFERENCE NO. 930212
MADE BY WJC	CHKD BY RJW	MADE BY	CHKD BY	SHT 2 OF 2
DATE 2-26-94	DATE 16 MAR 94	DATE	DATE	5.3

RISA-2D MODEL OF LIGO BEAM TUBE MODULE: CASE #1 NODE NUMBERS
CASE #1: SIMPLE SUPPORTS AT BOTH ENDS, TOTAL LENGTH = 780'

NODE	X (FT)	DESCRIPTION
1	0.000	FIXED SUPP'T, ROTATION FREE
2	15.458	
3	30.917	
4	46.375	
5	61.833	GUIDED SUPP'T
6	63.500	END TUBE / START EJ STUB
7	64.083	END EJ STUB / START BELLOWS
8	65.583	END BELLOWS / START EJ STUB
9	66.167	END EJ STUB / START TUBE
10	67.833	GUIDED SUPP'T
11	83.375	
12	98.917	
13	114.458	
14	130.000	FIXED SUPP'T, ROTATION FREE
15	145.458	
16	160.917	
17	176.375	
18	191.833	GUIDED SUPP'T
19	193.500	END TUBE / START EJ STUB
20	194.083	END EJ STUB / START BELLOWS
21	195.583	END BELLOWS / START EJ STUB
22	196.167	END EJ STUB / START TUBE
23	197.833	GUIDED SUPP'T
24	213.375	
25	228.917	
26	244.458	
27	260.000	FIXED SUPP'T, ROTATION FREE
28	275.458	
29	290.917	
30	306.375	
31	321.833	GUIDED SUPP'T
32	323.500	END TUBE / START EJ STUB
33	324.083	END EJ STUB / START BELLOWS
34	325.583	END BELLOWS / START EJ STUB
35	326.167	END EJ STUB / START TUBE
36	327.833	GUIDED SUPP'T
37	343.375	
38	358.917	
39	374.458	
40	390.000	FIXED SUPP'T, ROTATION FREE
41	405.458	
42	420.917	
43	436.375	
44	451.833	GUIDED SUPP'T
45	453.500	END TUBE / START EJ STUB
46	454.083	END EJ STUB / START BELLOWS
47	455.583	END BELLOWS / START EJ STUB
48	456.167	END EJ STUB / START TUBE
49	457.833	GUIDED SUPP'T

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
RISA-2D MODEL OF BEAM TUBE MODULE, CASE #1 NODE NUMBERS, COORDINATES & DESCRIPTION	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 2
	DATE 2/28/94	DATE 15 MAR 94	DATE	DATE	5.4

RISA-2D MODEL OF LIGO BEAM TUBE MODULE: CASE #1 NODE NUMBERS

CASE #1: SIMPLE SUPPORTS AT BOTH ENDS, TOTAL LENGTH = 780'

NODE	X (FT)	DESCRIPTION
50	473.375	
51	488.917	
52	504.458	
53	520.000	FIXED SUPP'T, ROTATION FREE
54	535.458	
55	550.917	
56	566.375	
57	581.833	GUIDED SUPP'T
58	583.500	END TUBE / START EJ STUB
59	584.083	END EJ STUB / START BELLOWS
60	585.583	END BELLOWS / START EJ STUB
61	586.167	END EJ STUB / START TUBE
62	587.833	GUIDED SUPP'T
63	603.375	
64	618.917	
65	634.458	
66	650.000	FIXED SUPP'T, ROTATION FREE
67	665.458	
68	680.917	
69	696.375	
70	711.833	GUIDED SUPP'T
71	713.500	END TUBE / START EJ STUB
72	714.083	END EJ STUB / START BELLOWS
73	715.583	END BELLOWS / START EJ STUB
74	716.167	END EJ STUB / START TUBE
75	717.833	GUIDED SUPP'T
76	733.375	
77	748.917	
78	764.458	
79	780.000	FIXED SUPP'T, ROTATION FREE

<table>
<tr><td rowspan="3">SUBJECT
RISA-2D MODEL OF BEAM TUBE MODULE, CASE #1
NODE NUMBERS, COORDINATES & DESCRIPTION</td><td colspan="2">OFFICE: NOE</td><td colspan="2">REVISION</td><td>REFERENCE NO.
930212</td></tr>
<tr><td>MADE BY
WJC</td><td>CHKD
RJW</td><td>MADE BY</td><td>CHKD BY</td><td>SHT 2 OF 2</td></tr>
<tr><td>DATE
2/28/94</td><td>DATE
18MAR94</td><td>DATE</td><td>DATE</td><td>5.5</td></tr>
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```
                                                           3/09/94

LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================

Units Option      : US Standard

AISC Code Checks  : 9th Edition ASD

Shear Deformation: No

P-Delta Effects   : No

Redesign          : No

Edge Forces       : No

A.S.I.F.          : 1.333
```

SUBJECT	CBI NOE C OFFICE		REVISION		REFERENCE NO.
	MADE BY WJC	CHKD BY RJW	MADE BY	CHKD BY	SHT__ OF__
	DATE 3-18-94	DATE 18 MAR 94	DATE	DATE	

5.6

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
Node                                   Boundary Conditions
 No      X-Coord     Y-Coord      X-dof        Y-dof      Rotation    Temp.
-----------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
  1        0.00        0.00           R            R                   0.00
  2       15.46        0.00                                            0.00
  3       30.92        0.00                                            0.00
  4       46.37        0.00                                            0.00
  5       61.83        0.00                        R                   0.00
  6       62.92        0.00                                            0.00
  7       63.50        0.00                                            0.00
  8       66.17        0.00                                            0.00
  9       66.75        0.00                                            0.00
 10       67.83        0.00                        R                   0.00
 11       83.37        0.00                                            0.00
 12       98.92        0.00                                            0.00
 13      114.46        0.00                                            0.00
 14      130.00        0.00           R            R                   0.00
 15      145.46        0.00                                            0.00
 16      160.92        0.00                                            0.00
 17      176.37        0.00                                            0.00
 18      191.83        0.00                        R                   0.00
 19      192.92        0.00                                            0.00
 20      193.50        0.00                                            0.00
 21      196.17        0.00                                            0.00
 22      196.75        0.00                                            0.00
 23      197.83        0.00                        R                   0.00
 24      213.37        0.00                                            0.00
 25      228.92        0.00                                            0.00
 26      244.46        0.00                                            0.00
 27      260.00        0.00           R            R                   0.00
 28      275.46        0.00                                            0.00
 29      290.92        0.00                                            0.00
 30      306.37        0.00                                            0.00
 31      321.83        0.00                        R                   0.00
 32      322.92        0.00                                            0.00
 33      323.50        0.00                                            0.00
 34      326.17        0.00                                            0.00
 35      326.75        0.00                                            0.00
 36      327.83        0.00                        R                   0.00
 37      343.37        0.00                                            0.00
 38      358.92        0.00                                            0.00
 39      374.46        0.00                                            0.00
 40      390.00        0.00           R            R                   0.00
 41      405.46        0.00                                            0.00
 42      420.92        0.00                                            0.00
 43      436.37        0.00                                            0.00
 44      451.83        0.00                        R                   0.00
 45      452.92        0.00                                            0.00
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------
Node                                   Boundary Conditions
 No      X-Coord     Y-Coord      X-dof        Y-dof     Rotation     Temp.
-----------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
 46      453.50        0.00                                            0.00
 47      456.17        0.00                                            0.00
 48      456.75        0.00                                            0.00
 49      457.83        0.00                        R                   0.00
 50      473.37        0.00                                            0.00
 51      488.92        0.00                                            0.00
 52      504.46        0.00                                            0.00
 53      520.00        0.00            R           R                   0.00
 54      535.46        0.00                                            0.00
 55      550.92        0.00                                            0.00
 56      566.37        0.00                                            0.00
 57      581.83        0.00                        R                   0.00
 58      582.92        0.00                                            0.00
 59      583.50        0.00                                            0.00
 60      586.17        0.00                                            0.00
 61      586.75        0.00                                            0.00
 62      587.83        0.00                        R                   0.00
 63      603.37        0.00                                            0.00
 64      618.92        0.00                                            0.00
 65      634.46        0.00                                            0.00
 66      650.00        0.00            R           R                   0.00
 67      665.46        0.00                                            0.00
 68      680.92        0.00                                            0.00
 69      696.37        0.00                                            0.00
 70      711.83        0.00                        R                   0.00
 71      712.92        0.00                                            0.00
 72      713.50        0.00                                            0.00
 73      716.17        0.00                                            0.00
 74      716.75        0.00                                            0.00
 75      717.83        0.00                        R                   0.00
 76      733.37        0.00                                            0.00
 77      748.92        0.00                                            0.00
 78      764.46        0.00                                            0.00
 79      780.00        0.00            R           R                   0.00
```

```
                                                                3/09/94

LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=========================================================================

-------------------------------------------------------------------------
Material      Elastic       Poisson's     Thermal      Weight  Yield Stress
 Label        Modulus        Ratio      Coefficient   Density      (Fy)
--------------(Ksi)----------------------(F)--------(K/ft3)------(Ksi)----
 1             27000.00      0.30000       0.65000      0.000      19.200
```

5.9

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------
  Section      Database       Matl.     Area        Moment of     As     y/y
   Label        Shape         Set                    Inertia     Coef
------------------------------------(in^2)---------(in^4)-------------------
BEAMTUBE                       1        19.19        5731.030    1.20
STUBEND                        1        16.13        4820.000    1.20
EXPJOINT                       1         0.01           1.803    1.20
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------
     I     J                     I  Releases  J            End Offsets
 No Node  Node   Section        x y z     x y z  Sec   Sway  I       J      Length
-------------------------------------------------------------(in)----(in)------(ft)
  1    1 -   2  BEAMTUBE                                                    15.46
  2    2 -   3  BEAMTUBE                                                    15.46
  3    3 -   4  BEAMTUBE                                                    15.45
  4    4 -   5  BEAMTUBE                                                    15.46
  5    5 -   6  BEAMTUBE                                                     1.09
  6    6 -   7  STUBEND                                                      0.58
  7    7 -   8  EXPJOINT                                                     2.67
  8    8 -   9  STUBEND                                                      0.58
  9    9 -  10  BEAMTUBE                                                     1.08
 10   10 -  11  BEAMTUBE                                                    15.54
 11   11 -  12  BEAMTUBE                                                    15.55
 12   12 -  13  BEAMTUBE                                                    15.54
 13   13 -  14  BEAMTUBE                                                    15.54
 14   14 -  15  BEAMTUBE                                                    15.46
 15   15 -  16  BEAMTUBE                                                    15.46
 16   16 -  17  BEAMTUBE                                                    15.45
 17   17 -  18  BEAMTUBE                                                    15.46
 18   18 -  19  BEAMTUBE                                                     1.09
 19   19 -  20  STUBEND                                                      0.58
 20   20 -  21  EXPJOINT                                                     2.67
 21   21 -  22  STUBEND                                                      0.58
 22   22 -  23  BEAMTUBE                                                     1.08
 23   23 -  24  BEAMTUBE                                                    15.54
 24   24 -  25  BEAMTUBE                                                    15.55
 25   25 -  26  BEAMTUBE                                                    15.54
 26   26 -  27  BEAMTUBE                                                    15.54
 27   27 -  28  BEAMTUBE                                                    15.46
 28   28 -  29  BEAMTUBE                                                    15.46
 29   29 -  30  BEAMTUBE                                                    15.45
 30   30 -  31  BEAMTUBE                                                    15.46
 31   31 -  32  BEAMTUBE                                                     1.09
 32   32 -  33  STUBEND                                                      0.58
 33   33 -  34  EXPJOINT                                                     2.67
 34   34 -  35  STUBEND                                                      0.58
 35   35 -  36  BEAMTUBE                                                     1.08
 36   36 -  37  BEAMTUBE                                                    15.54
 37   37 -  38  BEAMTUBE                                                    15.55
 38   38 -  39  BEAMTUBE                                                    15.54
 39   39 -  40  BEAMTUBE                                                    15.54
 40   40 -  41  BEAMTUBE                                                    15.46
 41   41 -  42  BEAMTUBE                                                    15.46
 42   42 -  43  BEAMTUBE                                                    15.45
 43   43 -  44  BEAMTUBE                                                    15.46
 44   44 -  45  BEAMTUBE                                                     1.09
 45   45 -  46  STUBEND                                                      0.58
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------
     I      J                 I  Releases  J           End Offsets
 No Node   Node   Section     x y z    x y z  Sec  Sway  I       J      Length
-----------------------------------------------------(in)----(in)------(ft)
 46    46 -  47  EXPJOINT                                                 2.67
 47    47 -  48  STUBEND                                                  0.58
 48    48 -  49  BEAMTUBE                                                 1.08
 49    49 -  50  BEAMTUBE                                                15.54
 50    50 -  51  BEAMTUBE                                                15.55
 51    51 -  52  BEAMTUBE                                                15.54
 52    52 -  53  BEAMTUBE                                                15.54
 53    53 -  54  BEAMTUBE                                                15.46
 54    54 -  55  BEAMTUBE                                                15.46
 55    55 -  56  BEAMTUBE                                                15.45
 56    56 -  57  BEAMTUBE                                                15.46
 57    57 -  58  BEAMTUBE                                                 1.09
 58    58 -  59  STUBEND                                                  0.58
 59    59 -  60  EXPJOINT                                                 2.67
 60    60 -  61  STUBEND                                                  0.58
 61    61 -  62  BEAMTUBE                                                 1.08
 62    62 -  63  BEAMTUBE                                                15.54
 63    63 -  64  BEAMTUBE                                                15.55
 64    64 -  65  BEAMTUBE                                                15.54
 65    65 -  66  BEAMTUBE                                                15.54
 66    66 -  67  BEAMTUBE                                                15.46
 67    67 -  68  BEAMTUBE                                                15.46
 68    68 -  69  BEAMTUBE                                                15.45
 69    69 -  70  BEAMTUBE                                                15.46
 70    70 -  71  BEAMTUBE                                                 1.09
 71    71 -  72  STUBEND                                                  0.58
 72    72 -  73  EXPJOINT                                                 2.67
 73    73 -  74  STUBEND                                                  0.58
 74    74 -  75  BEAMTUBE                                                 1.08
 75    75 -  76  BEAMTUBE                                                15.54
 76    76 -  77  BEAMTUBE                                                15.55
 77    77 -  78  BEAMTUBE                                                15.54
 78    78 -  79  BEAMTUBE                                                15.54
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=========================================================================

-------------------------------------------------------------------------
      I     J          Unbraced Lengths          K Factors    Bending Coefs
 No Node  Node     Lb-in    Lb-out      Lc        In    Out      Cm     Cb
-------------------(ft)-----(ft)-----(ft)-------------------------------
  1    1 -   2
  2    2 -   3
  3    3 -   4
  4    4 -   5
  5    5 -   6
  6    6 -   7
  7    7 -   8
  8    8 -   9
  9    9 -  10
 10   10 -  11
 11   11 -  12
 12   12 -  13
 13   13 -  14
 14   14 -  15
 15   15 -  16
 16   16 -  17
 17   17 -  18
 18   18 -  19
 19   19 -  20
 20   20 -  21
 21   21 -  22
 22   22 -  23
 23   23 -  24
 24   24 -  25
 25   25 -  26
 26   26 -  27
 27   27 -  28
 28   28 -  29
 29   29 -  30
 30   30 -  31
 31   31 -  32
 32   32 -  33
 33   33 -  34
 34   34 -  35
 35   35 -  36
 36   36 -  37
 37   37 -  38
 38   38 -  39
 39   39 -  40
 40   40 -  41
 41   41 -  42
 42   42 -  43
 43   43 -  44
 44   44 -  45
 45   45 -  46
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
     I      J          Unbraced Lengths           K Factors    Bending Coefs
 No Node  Node     Lb-in    Lb-out      Lc        In     Out     Cm      Cb
-------------------(ft)-----(ft)-----(ft)----------------------------------
 46   46 -  47
 47   47 -  48
 48   48 -  49
 49   49 -  50
 50   50 -  51
 51   51 -  52
 52   52 -  53
 53   53 -  54
 54   54 -  55
 55   55 -  56
 56   56 -  57
 57   57 -  58
 58   58 -  59
 59   59 -  60
 60   60 -  61
 61   61 -  62
 62   62 -  63
 63   63 -  64
 64   64 -  65
 65   65 -  66
 66   66 -  67
 67   67 -  68
 68   68 -  69
 69   69 -  70
 70   70 -  71
 71   71 -  72
 72   72 -  73
 73   73 -  74
 74   74 -  75
 75   75 -  76
 76   76 -  77
 77   77 -  78
 78   78 -  79
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------
        BLC          Basic Load Case                     Load Totals
        No.            Description                 Nodal    Point   Dist.
----------------------------------------------------------------------------
          1   SELF WEIGHT + INSULATION                                 78
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=============================================================================

Member Distributed Loads,BLC 1: SELF WEIGHT + INSULATION
-----------------------------------------------------------------------------
 Memb  I     J            Start         End            Start        End
  No  Node  Node  Dir   Magnitude    Magnitude        Location     Location
------------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
   1     1 -   2   Y      -0.091       -0.091          0.000       15.460
   2     2 -   3   Y      -0.091       -0.091          0.000       15.460
   3     3 -   4   Y      -0.091       -0.091          0.000       15.449
   4     4 -   5   Y      -0.091       -0.091          0.000       15.460
   5     5 -   6   Y      -0.091       -0.091          0.000        1.089
   6     6 -   7   Y      -0.091       -0.091          0.000        0.580
   7     7 -   8   Y      -0.091       -0.091          0.000        2.669
   8     8 -   9   Y      -0.091       -0.091          0.000        0.580
   9     9 -  10   Y      -0.091       -0.091          0.000        1.080
  10    10 -  11   Y      -0.091       -0.091          0.000       15.540
  11    11 -  12   Y      -0.091       -0.091          0.000       15.550
  12    12 -  13   Y      -0.091       -0.091          0.000       15.539
  13    13 -  14   Y      -0.091       -0.091          0.000       15.540
  14    14 -  15   Y      -0.091       -0.091          0.000       15.460
  15    15 -  16   Y      -0.091       -0.091          0.000       15.459
  16    16 -  17   Y      -0.091       -0.091          0.000       15.449
  17    17 -  18   Y      -0.091       -0.091          0.000       15.460
  18    18 -  19   Y      -0.091       -0.091          0.000        1.089
  19    19 -  20   Y      -0.091       -0.091          0.000        0.580
  20    20 -  21   Y      -0.091       -0.091          0.000        2.669
  21    21 -  22   Y      -0.091       -0.091          0.000        0.580
  22    22 -  23   Y      -0.091       -0.091          0.000        1.080
  23    23 -  24   Y      -0.091       -0.091          0.000       15.539
  24    24 -  25   Y      -0.091       -0.091          0.000       15.550
  25    25 -  26   Y      -0.091       -0.091          0.000       15.540
  26    26 -  27   Y      -0.091       -0.091          0.000       15.539
  27    27 -  28   Y      -0.091       -0.091          0.000       15.459
  28    28 -  29   Y      -0.091       -0.091          0.000       15.460
  29    29 -  30   Y      -0.091       -0.091          0.000       15.449
  30    30 -  31   Y      -0.091       -0.091          0.000       15.459
  31    31 -  32   Y      -0.091       -0.091          0.000        1.090
  32    32 -  33   Y      -0.091       -0.091          0.000        0.579
  33    33 -  34   Y      -0.091       -0.091          0.000        2.670
  34    34 -  35   Y      -0.091       -0.091          0.000        0.579
  35    35 -  36   Y      -0.091       -0.091          0.000        1.079
  36    36 -  37   Y      -0.091       -0.091          0.000       15.540
  37    37 -  38   Y      -0.091       -0.091          0.000       15.550
  38    38 -  39   Y      -0.091       -0.091          0.000       15.539
  39    39 -  40   Y      -0.091       -0.091          0.000       15.540
  40    40 -  41   Y      -0.091       -0.091          0.000       15.459
  41    41 -  42   Y      -0.091       -0.091          0.000       15.460
  42    42 -  43   Y      -0.091       -0.091          0.000       15.449
  43    43 -  44   Y      -0.091       -0.091          0.000       15.459
  44    44 -  45   Y      -0.091       -0.091          0.000        1.090
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=======================================================================

-----------------------------------------------------------------------
 Memb  I      J          Start       End           Start      End
  No  Node  Node  Dir  Magnitude   Magnitude      Location   Location
-----------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
  45    45 -  46   Y     -0.091      -0.091         0.000      0.579
  46    46 -  47   Y     -0.091      -0.091         0.000      2.670
  47    47 -  48   Y     -0.091      -0.091         0.000      0.579
  48    48 -  49   Y     -0.091      -0.091         0.000      1.079
  49    49 -  50   Y     -0.091      -0.091         0.000     15.540
  50    50 -  51   Y     -0.091      -0.091         0.000     15.550
  51    51 -  52   Y     -0.091      -0.091         0.000     15.539
  52    52 -  53   Y     -0.091      -0.091         0.000     15.540
  53    53 -  54   Y     -0.091      -0.091         0.000     15.460
  54    54 -  55   Y     -0.091      -0.091         0.000     15.459
  55    55 -  56   Y     -0.091      -0.091         0.000     15.450
  56    56 -  57   Y     -0.091      -0.091         0.000     15.460
  57    57 -  58   Y     -0.091      -0.091         0.000      1.089
  58    58 -  59   Y     -0.091      -0.091         0.000      0.580
  59    59 -  60   Y     -0.091      -0.091         0.000      2.669
  60    60 -  61   Y     -0.091      -0.091         0.000      0.580
  61    61 -  62   Y     -0.091      -0.091         0.000      1.080
  62    62 -  63   Y     -0.091      -0.091         0.000     15.539
  63    63 -  64   Y     -0.091      -0.091         0.000     15.549
  64    64 -  65   Y     -0.091      -0.091         0.000     15.540
  65    65 -  66   Y     -0.091      -0.091         0.000     15.539
  66    66 -  67   Y     -0.091      -0.091         0.000     15.460
  67    67 -  68   Y     -0.091      -0.091         0.000     15.459
  68    68 -  69   Y     -0.091      -0.091         0.000     15.449
  69    69 -  70   Y     -0.091      -0.091         0.000     15.460
  70    70 -  71   Y     -0.091      -0.091         0.000      1.089
  71    71 -  72   Y     -0.091      -0.091         0.000      0.580
  72    72 -  73   Y     -0.091      -0.091         0.000      2.669
  73    73 -  74   Y     -0.091      -0.091         0.000      0.580
  74    74 -  75   Y     -0.091      -0.091         0.000      1.080
  75    75 -  76   Y     -0.091      -0.091         0.000     15.539
  76    76 -  77   Y     -0.091      -0.091         0.000     15.550
  77    77 -  78   Y     -0.091      -0.091         0.000     15.540
  78    78 -  79   Y     -0.091      -0.091         0.000     15.539
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
Load Combination    Self Wt  BLC    BLC    BLC    BLC    BLC          W  E
No. Description     Dir Fac    Fac    Fac    Fac    Fac    Fac  DYNA  S  V
---------------------------------------------------------------------------
 1 DEAD LD + INSUL'N         1 1
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

Dynamic Analysis Data

Number of modes (frequencies)  :   15
Basic Load Case for masses     :   1
BLC mass direction of action   :   Y only
Acceleration of Gravity        :   32.20 ft/sec**2

 Load Combination is 1 :   DEAD LD + INSUL'N
 Nodal Displacements
----------------------------------------------------------------------------

     Node          Global X             Global Y             Rotation
---------------------(in)-----------------(in)-----------------(rad)---------
        1          0.00000             -0.00000             -0.00082
        2          0.00000             -0.13569             -0.00056
        3          0.00000             -0.19000              0.00000
        4          0.00000             -0.13484              0.00056
        5          0.00000             -0.00000              0.00081
        6          0.00000              0.01058              0.00081
        7          0.00000              0.01621              0.00081
        8          0.00000              0.00858             -0.00043
        9          0.00000              0.00558             -0.00043
       10          0.00000             -0.00000             -0.00043
       11          0.00000             -0.06767             -0.00024
       12          0.00000             -0.08041              0.00011
       13          0.00000             -0.03810              0.00029
       14          0.00000             -0.00000              0.00001
       15          0.00000             -0.03509             -0.00028
       16          0.00000             -0.07566             -0.00010
       17          0.00000             -0.06390              0.00023
       18          0.00000             -0.00000              0.00041
       19          0.00000              0.00531              0.00041
       20          0.00000              0.00814              0.00041
       21          0.00000              0.00834             -0.00042
       22          0.00000              0.00543             -0.00042
       23          0.00000             -0.00000             -0.00042
       24          0.00000             -0.06633             -0.00024
       25          0.00000             -0.07900              0.00010
       26          0.00000             -0.03734              0.00029
       27          0.00000             -0.00000              0.00000
       28          0.00000             -0.03549             -0.00028
       29          0.00000             -0.07612             -0.00010
       30          0.00000             -0.06418              0.00023
       31          0.00000             -0.00000              0.00041
       32          0.00000              0.00533              0.00041
       33          0.00000              0.00817              0.00041
       34          0.00000              0.00834             -0.00042
       35          0.00000              0.00543             -0.00042
       36          0.00000             -0.00000             -0.00042
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------

     Node          Global X             Global Y             Rotation
---------------------(in)-----------------(in)----------------(rad)---------
      37           0.00000             -0.06633             -0.00024
      38           0.00000             -0.07901              0.00010
      39           0.00000             -0.03735              0.00029
      40           0.00000             -0.00000              0.00000
      41           0.00000             -0.03549             -0.00028
      42           0.00000             -0.07611             -0.00010
      43           0.00000             -0.06418              0.00023
      44           0.00000             -0.00000              0.00041
      45           0.00000              0.00533              0.00041
      46           0.00000              0.00817              0.00041
      47           0.00000              0.00834             -0.00042
      48           0.00000              0.00543             -0.00042
      49           0.00000             -0.00000             -0.00042
      50           0.00000             -0.06633             -0.00024
      51           0.00000             -0.07901              0.00010
      52           0.00000             -0.03735              0.00029
      53           0.00000             -0.00000              0.00000
      54           0.00000             -0.03549             -0.00028
      55           0.00000             -0.07611             -0.00010
      56           0.00000             -0.06418              0.00023
      57           0.00000             -0.00000              0.00041
      58           0.00000              0.00533              0.00041
      59           0.00000              0.00817              0.00041
      60           0.00000              0.00831             -0.00042
      61           0.00000              0.00541             -0.00042
      62           0.00000             -0.00000             -0.00042
      63           0.00000             -0.06605             -0.00024
      64           0.00000             -0.07854              0.00010
      65           0.00000             -0.03694              0.00029
      66           0.00000             -0.00000              0.00000
      67           0.00000             -0.03625             -0.00029
      68           0.00000             -0.07751             -0.00011
      69           0.00000             -0.06552              0.00023
      70           0.00000             -0.00000              0.00042
      71           0.00000              0.00549              0.00042
      72           0.00000              0.00841              0.00042
      73           0.00000              0.01637             -0.00082
      74           0.00000              0.01066             -0.00082
      75           0.00000             -0.00000             -0.00082
      76           0.00000             -0.13775             -0.00057
      77           0.00000             -0.19416             -0.00000
      78           0.00000             -0.13863              0.00057
      79           0.00000             -0.00000              0.00084
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 Spring Reactions
----------------------------------------------------------------------------

     Node            Global X             Global Y              Moment
---------------------(K)------------------(K)---------------(K-ft)---------
        1             0.00000             2.79271             0.00000
        5             0.00000             3.35017             0.00000
       10             0.00000             2.15310             0.00000
       14             0.00000             7.04581             0.00000
       18             0.00000             2.38115             0.00000
       23             0.00000             2.41705             0.00000
       27             0.00000             7.02891             0.00000
       31             0.00000             2.38504             0.00000
       36             0.00000             2.41599             0.00000
       40             0.00000             7.02898             0.00000
       44             0.00000             2.38502             0.00000
       49             0.00000             2.41601             0.00000
       53             0.00000             7.02891             0.00000
       57             0.00000             2.38608             0.00000
       62             0.00000             2.41214             0.00000
       66             0.00000             7.04593             0.00000
       70             0.00000             2.12146             0.00000
       75             0.00000             3.37775             0.00000
       79             0.00000             2.80777             0.00000
   Totals             0.00000            70.98000             0.00000
```

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                                                               3/09/94

LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 Member End Forces
---------------------------------------------------------------------------
    Nodes     ========== I-End ==========      ========== J-End =========
No  I   J     Axial      Shear     Moment      Axial     Shear     Moment
-------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
 1   1-  2     0.00       2.79      -0.00       0.00     -1.39      32.30
 2   2-  3     0.00       1.39     -32.30       0.00      0.02      42.85
 3   3-  4     0.00      -0.02     -42.85       0.00      1.43      31.67
 4   4-  5     0.00      -1.43     -31.67       0.00      2.83      -1.27
 5   5-  6     0.00       0.52       1.27       0.00     -0.42      -0.76
 6   6-  7     0.00       0.42       0.76       0.00     -0.36      -0.54
 7   7-  8     0.00       0.36       0.54       0.00     -0.12       0.11
 8   8-  9     0.00       0.12      -0.11       0.00     -0.07       0.17
 9   9- 10     0.00       0.07      -0.17       0.00      0.03       0.19
10  10- 11     0.00       2.12      -0.19       0.00     -0.71      22.20
11  11- 12     0.00       0.71     -22.20       0.00      0.71      22.23
12  12- 13     0.00      -0.71     -22.23       0.00      2.12       0.27
13  13- 14     0.00      -2.12      -0.27       0.00      3.53     -43.66
14  14- 15     0.00       3.51      43.66       0.00     -2.10      -0.24
15  15- 16     0.00       2.10       0.24       0.00     -0.70      21.43
16  16- 17     0.00       0.70     -21.43       0.00      0.71      21.35
17  17- 18     0.00      -0.71     -21.35       0.00      2.11      -0.47
18  18- 19     0.00       0.27       0.47       0.00     -0.17      -0.23
19  19- 20     0.00       0.17       0.23       0.00     -0.11      -0.15
20  20- 21     0.00       0.11       0.15       0.00      0.13      -0.17
21  21- 22     0.00      -0.13       0.17       0.00      0.18      -0.26
22  22- 23     0.00      -0.18       0.26       0.00      0.28      -0.51
23  23- 24     0.00       2.14       0.51       0.00     -0.72      21.72
24  24- 25     0.00       0.72     -21.72       0.00      0.69      21.97
25  25- 26     0.00      -0.69     -21.97       0.00      2.11       0.23
26  26- 27     0.00      -2.11      -0.23       0.00      3.52     -43.48
27  27- 28     0.00       3.51      43.48       0.00     -2.10      -0.11
28  28- 29     0.00       2.10       0.11       0.00     -0.70      21.51
29  29- 30     0.00       0.70     -21.51       0.00      0.71      21.39
30  30- 31     0.00      -0.71     -21.39       0.00      2.12      -0.47
31  31- 32     0.00       0.27       0.47       0.00     -0.17      -0.23
32  32- 33     0.00       0.17       0.23       0.00     -0.12      -0.15
33  33- 34     0.00       0.12       0.15       0.00      0.13      -0.17
34  34- 35     0.00      -0.13       0.17       0.00      0.18      -0.26
35  35- 36     0.00      -0.18       0.26       0.00      0.28      -0.50
36  36- 37     0.00       2.14       0.50       0.00     -0.72      21.72
37  37- 38     0.00       0.72     -21.72       0.00      0.69      21.97
38  38- 39     0.00      -0.69     -21.97       0.00      2.11       0.23
39  39- 40     0.00      -2.11      -0.23       0.00      3.52     -43.48
40  40- 41     0.00       3.51      43.48       0.00     -2.10      -0.11
41  41- 42     0.00       2.10       0.11       0.00     -0.70      21.51
42  42- 43     0.00       0.70     -21.51       0.00      0.71      21.39
43  43- 44     0.00      -0.71     -21.39       0.00      2.12      -0.47
```

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```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------
    Nodes     ========== I-End ==========      ========== J-End ==========
No  I   J     Axial       Shear     Moment     Axial       Shear     Moment
---------------(K)---------(K)------(K-ft)--------(K)---------(K)------(K-ft)--
44  44- 45     0.00        0.27       0.47      0.00       -0.17      -0.23
45  45- 46     0.00        0.17       0.23      0.00       -0.12      -0.15
46  46- 47     0.00        0.12       0.15      0.00        0.13      -0.17
47  47- 48     0.00       -0.13       0.17      0.00        0.18      -0.26
48  48- 49     0.00       -0.18       0.26      0.00        0.28      -0.50
49  49- 50     0.00        2.14       0.50      0.00       -0.72      21.72
50  50- 51     0.00        0.72     -21.72      0.00        0.69      21.97
51  51- 52     0.00       -0.69     -21.97      0.00        2.11       0.23
52  52- 53     0.00       -2.11      -0.23      0.00        3.52     -43.48
53  53- 54     0.00        3.51      43.48      0.00       -2.10      -0.11
54  54- 55     0.00        2.10       0.11      0.00       -0.70      21.51
55  55- 56     0.00        0.70     -21.51      0.00        0.71      21.39
56  56- 57     0.00       -0.71     -21.39      0.00        2.12      -0.47
57  57- 58     0.00        0.27       0.47      0.00       -0.17      -0.23
58  58- 59     0.00        0.17       0.23      0.00       -0.12      -0.15
59  59- 60     0.00        0.12       0.15      0.00        0.13      -0.17
60  60- 61     0.00       -0.13       0.17      0.00        0.18      -0.25
61  61- 62     0.00       -0.18       0.25      0.00        0.28      -0.50
62  62- 63     0.00        2.13       0.50      0.00       -0.72      21.68
63  63- 64     0.00        0.72     -21.68      0.00        0.69      21.88
64  64- 65     0.00       -0.69     -21.88      0.00        2.11       0.10
65  65- 66     0.00       -2.11      -0.10      0.00        3.52     -43.66
66  66- 67     0.00        3.52      43.66      0.00       -2.12      -0.07
67  67- 68     0.00        2.12       0.07      0.00       -0.71      21.77
68  68- 69     0.00        0.71     -21.77      0.00        0.70      21.87
69  69- 70     0.00       -0.70     -21.87      0.00        2.10       0.23
70  70- 71     0.00        0.02      -0.23      0.00        0.08       0.19
71  71- 72     0.00       -0.08      -0.19      0.00        0.13       0.13
72  72- 73     0.00       -0.13      -0.13      0.00        0.38      -0.55
73  73- 74     0.00       -0.38       0.55      0.00        0.43      -0.79
74  74- 75     0.00       -0.43       0.79      0.00        0.53      -1.30
75  75- 76     0.00        2.85       1.30      0.00       -1.44      31.99
76  76- 77     0.00        1.44     -31.99      0.00       -0.02      43.31
77  77- 78     0.00        0.02     -43.31      0.00        1.39      32.64
78  78- 79     0.00       -1.39     -32.64      0.00        2.81      -0.00
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=============================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 AISC Code Checks
-----------------------------------------------------------------------------
      Nodes                       Member Quarter Points
 No   I   J   Maximum     0      1/4     1/2       3/4         L        Shear
-----------------------------------------------------------------------------
  1   1-  2                        - Not Calculated -
  2   2-  3                        - Not Calculated -
  3   3-  4                        - Not Calculated -
  4   4-  5                        - Not Calculated -
  5   5-  6                        - Not Calculated -
  6   6-  7                        - Not Calculated -
  7   7-  8                        - Not Calculated -
  8   8-  9                        - Not Calculated -
  9   9- 10                        - Not Calculated -
 10  10- 11                        - Not Calculated -
 11  11- 12                        - Not Calculated -
 12  12- 13                        - Not Calculated -
 13  13- 14                        - Not Calculated -
 14  14- 15                        - Not Calculated -
 15  15- 16                        - Not Calculated -
 16  16- 17                        - Not Calculated -
 17  17- 18                        - Not Calculated -
 18  18- 19                        - Not Calculated -
 19  19- 20                        - Not Calculated -
 20  20- 21                        - Not Calculated -
 21  21- 22                        - Not Calculated -
 22  22- 23                        - Not Calculated -
 23  23- 24                        - Not Calculated -
 24  24- 25                        - Not Calculated -
 25  25- 26                        - Not Calculated -
 26  26- 27                        - Not Calculated -
 27  27- 28                        - Not Calculated -
 28  28- 29                        - Not Calculated -
 29  29- 30                        - Not Calculated -
 30  30- 31                        - Not Calculated -
 31  31- 32                        - Not Calculated -
 32  32- 33                        - Not Calculated -
 33  33- 34                        - Not Calculated -
 34  34- 35                        - Not Calculated -
 35  35- 36                        - Not Calculated -
 36  36- 37                        - Not Calculated -
 37  37- 38                        - Not Calculated -
 38  38- 39                        - Not Calculated -
 39  39- 40                        - Not Calculated -
 40  40- 41                        - Not Calculated -
 41  41- 42                        - Not Calculated -
 42  42- 43                        - Not Calculated -
 43  43- 44                        - Not Calculated -
```

```
LIGO BEAM TUBE -- BAKEOUT + SELF WT
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==============================================================================

------------------------------------------------------------------------------
      Nodes                            Member Quarter Points
 No   I   J   Maximum      0         1/4     1/2       3/4        L        Shear
------------------------------------------------------------------------------
 44  44- 45                           - Not Calculated -
 45  45- 46                           - Not Calculated -
 46  46- 47                           - Not Calculated -
 47  47- 48                           - Not Calculated -
 48  48- 49                           - Not Calculated -
 49  49- 50                           - Not Calculated -
 50  50- 51                           - Not Calculated -
 51  51- 52                           - Not Calculated -
 52  52- 53                           - Not Calculated -
 53  53- 54                           - Not Calculated -
 54  54- 55                           - Not Calculated -
 55  55- 56                           - Not Calculated -
 56  56- 57                           - Not Calculated -
 57  57- 58                           - Not Calculated -
 58  58- 59                           - Not Calculated -
 59  59- 60                           - Not Calculated -
 60  60- 61                           - Not Calculated -
 61  61- 62                           - Not Calculated -
 62  62- 63                           - Not Calculated -
 63  63- 64                           - Not Calculated -
 64  64- 65                           - Not Calculated -
 65  65- 66                           - Not Calculated -
 66  66- 67                           - Not Calculated -
 67  67- 68                           - Not Calculated -
 68  68- 69                           - Not Calculated -
 69  69- 70                           - Not Calculated -
 70  70- 71                           - Not Calculated -
 71  71- 72                           - Not Calculated -
 72  72- 73                           - Not Calculated -
 73  73- 74                           - Not Calculated -
 74  74- 75                           - Not Calculated -
 75  75- 76                           - Not Calculated -
 76  76- 77                           - Not Calculated -
 77  77- 78                           - Not Calculated -
 78  78- 79                           - Not Calculated -
```

RISA-2D MODEL OF LIGO BEAM TUBE MODULE: CASE #1A NODE NUMBERS
CASE #1A: SIMPLE SUPPORTS AT BOTH ENDS, TOTAL LENGTH = 780'
1" SUPPORT SETTLEMENT @ INTERIOR FIXED (I.E., UNGUIDED) SUPPORT

NODE	X (FT)	DESCRIPTION
1	0.000	FIXED SUPP'T, ROTATION FREE
2	15.458	
3	30.917	
4	46.375	
5	61.833	GUIDED SUPP'T
6	63.500	END TUBE / START EJ STUB
7	64.083	END EJ STUB / START BELLOWS
8	65.583	END BELLOWS / START EJ STUB
9	66.167	END EJ STUB / START TUBE
10	67.833	GUIDED SUPP'T
11	83.375	
12	98.917	
13	114.458	
14	130.000	FIXED SUPP'T, ROTATION FREE
15	145.458	
16	160.917	
17	176.375	
18	191.833	GUIDED SUPP'T
19	193.500	END TUBE / START EJ STUB
20	194.083	END EJ STUB / START BELLOWS
21	195.583	END BELLOWS / START EJ STUB
22	196.167	END EJ STUB / START TUBE
23	197.833	GUIDED SUPP'T
24	213.375	
25	228.917	
26	244.458	
27	260.000	FIXED SUPP'T, ROTATION FREE
28	275.458	
29	290.917	
30	306.375	
31	321.833	GUIDED SUPP'T
32	323.500	END TUBE / START EJ STUB
33	324.083	END EJ STUB / START BELLOWS
34	325.583	END BELLOWS / START EJ STUB
35	326.167	END EJ STUB / START TUBE
36	327.833	GUIDED SUPP'T
37	343.375	
38	358.917	
39	374.458	
40	390.000	FIXED SUPP'T, ROTATION FREE =====> 1" SUPPORT SETTLEMENT IMPOSED
41	405.458	
42	420.917	
43	436.375	
44	451.833	GUIDED SUPP'T
45	453.500	END TUBE / START EJ STUB
46	454.083	END EJ STUB / START BELLOWS
47	455.583	END BELLOWS / START EJ STUB
48	456.167	END EJ STUB / START TUBE
49	457.833	GUIDED SUPP'T

SUBJECT **RISA-2D MODEL OF BEAM TUBE MODULE, CASE #1A** **NODE NUMBERS, COORDINATES & DESCRIPTION**	OFFICE: NOE		REVISION		REFERENCE NO. 930212
	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 2
	DATE 2/28/94	DATE 10MAR94	DATE	DATE	5.26

RISA-2D MODEL OF LIGO BEAM TUBE MODULE: CASE #1A NODE NUMBERS
CASE #1A: SIMPLE SUPPORTS AT BOTH ENDS, TOTAL LENGTH = 780'
1" SUPPORT SETTLEMENT @ INTERIOR FIXED (I.E., UNGUIDED) SUPPORT

NODE	X (FT)	DESCRIPTION
50	473.375	
51	488.917	
52	504.458	
53	520.000	FIXED SUPP'T, ROTATION FREE
54	535.458	
55	550.917	
56	566.375	
57	581.833	GUIDED SUPP'T
58	583.500	END TUBE / START EJ STUB
59	584.083	END EJ STUB / START BELLOWS
60	585.583	END BELLOWS / START EJ STUB
61	586.167	END EJ STUB / START TUBE
62	587.833	GUIDED SUPP'T
63	603.375	
64	618.917	
65	634.458	
66	650.000	FIXED SUPP'T, ROTATION FREE
67	665.458	
68	680.917	
69	696.375	
70	711.833	GUIDED SUPP'T
71	713.500	END TUBE / START EJ STUB
72	714.083	END EJ STUB / START BELLOWS
73	715.583	END BELLOWS / START EJ STUB
74	716.167	END EJ STUB / START TUBE
75	717.833	GUIDED SUPP'T
76	733.375	
77	748.917	
78	764.458	
79	780.000	FIXED SUPP'T, ROTATION FREE

SUBJECT

RISA-2D MODEL OF BEAM TUBE MODULE, CASE #1A
NODE NUMBERS, COORDINATES & DESCRIPTION

OFFICE: NOE
REVISION
REFERENCE NO. 930212

MADE BY	CHKD	MADE BY	CHKD BY	
WJC	RW			SHT 2 OF 2
DATE 2/28/94	DATE 19MAR94	DATE	DATE	5.27

LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS

Units Option : US Standard

AISC Code Checks : 9th Edition ASD

Shear Deformation: No

P-Delta Effects : No

Redesign : No

Edge Forces : No

A.S.I.F. : 1.333

SUBJECT	CBI OFFICE NoE C		REVISION		REFERENCE NO.
	MADE BY WJC	CHKD BY RJW	MADE BY	CHKD BY	SHT__ OF __
	DATE 3-18-94	DATE 10MAR94	DATE	DATE	

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------
Node                                   Boundary Conditions
 No      X-Coord     Y-Coord      X-dof        Y-dof      Rotation     Temp.
-----------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
   1       0.00        0.00            R            R                   0.00
   2      15.46        0.00                                             0.00
   3      30.92        0.00                                             0.00
   4      46.37        0.00                                             0.00
   5      61.83        0.00                         R                   0.00
   6      62.92        0.00                                             0.00
   7      63.50        0.00                                             0.00
   8      66.17        0.00                                             0.00
   9      66.75        0.00                                             0.00
  10      67.83        0.00                         R                   0.00
  11      83.37        0.00                                             0.00
  12      98.92        0.00                                             0.00
  13     114.46        0.00                                             0.00
  14     130.00        0.00            R            R                   0.00
  15     145.46        0.00                                             0.00
  16     160.92        0.00                                             0.00
  17     176.37        0.00                                             0.00
  18     191.83        0.00                         R                   0.00
  19     192.92        0.00                                             0.00
  20     193.50        0.00                                             0.00
  21     196.17        0.00                                             0.00
  22     196.75        0.00                                             0.00
  23     197.83        0.00                         R                   0.00
  24     213.37        0.00                                             0.00
  25     228.92        0.00                                             0.00
  26     244.46        0.00                                             0.00
  27     260.00        0.00            R            R                   0.00
  28     275.46        0.00                                             0.00
  29     290.92        0.00                                             0.00
  30     306.37        0.00                                             0.00
  31     321.83        0.00                         R                   0.00
  32     322.92        0.00                                             0.00
  33     323.50        0.00                                             0.00
  34     326.17        0.00                                             0.00
  35     326.75        0.00                                             0.00
  36     327.83        0.00                         R                   0.00
  37     343.37        0.00                                             0.00
  38     358.92        0.00                                             0.00
  39     374.46        0.00                                             0.00
  40     390.00        0.00            R   D -1.00000                   0.00
  41     405.46        0.00                                             0.00
  42     420.92        0.00                                             0.00
  43     436.37        0.00                                             0.00
  44     451.83        0.00                         R                   0.00
  45     452.92        0.00                                             0.00
```

5.29

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==============================================================================

------------------------------------------------------------------------------
Node                                    Boundary Conditions
 No      X-Coord      Y-Coord      X-dof        Y-dof       Rotation     Temp.
-----------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
 46      453.50         0.00                                              0.00
 47      456.17         0.00                                              0.00
 48      456.75         0.00                                              0.00
 49      457.83         0.00                         R                    0.00
 50      473.37         0.00                                              0.00
 51      488.92         0.00                                              0.00
 52      504.46         0.00                                              0.00
 53      520.00         0.00            R            R                    0.00
 54      535.46         0.00                                              0.00
 55      550.92         0.00                                              0.00
 56      566.37         0.00                                              0.00
 57      581.83         0.00                         R                    0.00
 58      582.92         0.00                                              0.00
 59      583.50         0.00                                              0.00
 60      586.17         0.00                                              0.00
 61      586.75         0.00                                              0.00
 62      587.83         0.00                         R                    0.00
 63      603.37         0.00                                              0.00
 64      618.92         0.00                                              0.00
 65      634.46         0.00                                              0.00
 66      650.00         0.00            R            R                    0.00
 67      665.46         0.00                                              0.00
 68      680.92         0.00                                              0.00
 69      696.37         0.00                                              0.00
 70      711.83         0.00                         R                    0.00
 71      712.92         0.00                                              0.00
 72      713.50         0.00                                              0.00
 73      716.17         0.00                                              0.00
 74      716.75         0.00                                              0.00
 75      717.83         0.00                         R                    0.00
 76      733.37         0.00                                              0.00
 77      748.92         0.00                                              0.00
 78      764.46         0.00                                              0.00
 79      780.00         0.00            R            R                    0.00
```

5.30

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------
Material      Elastic       Poisson's     Thermal        Weight  Yield Stress
 Label        Modulus         Ratio     Coefficient     Density     (Fy)
--------------(Ksi)---------------------(F)--------(K/ft3)------(Ksi)----
 1            27000.00      0.30000       0.65000        0.000     19.200
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
  Section     Database      Matl.     Area        Moment of     As     y/y
   Label       Shape        Set                    Inertia     Coef
--------------------------------------(in^2)---------(in^4)----------------
BEAMTUBE                    1          19.19       5731.030    1.20
STUBEND                     1          16.13       4820.000    1.20
EXPJOINT                    1           0.01          1.803    1.20
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------
      I     J                 I  Releases  J              End Offsets
 No Node  Node   Section     x y z     x y z  Sec  Sway  I       J      Length
------------------------------------------------------(in)----(in)------(ft)
  1    1 -   2  BEAMTUBE                                                15.46
  2    2 -   3  BEAMTUBE                                                15.46
  3    3 -   4  BEAMTUBE                                                15.45
  4    4 -   5  BEAMTUBE                                                15.46
  5    5 -   6  BEAMTUBE                                                 1.09
  6    6 -   7  STUBEND                                                  0.58
  7    7 -   8  EXPJOINT                                                 2.67
  8    8 -   9  STUBEND                                                  0.58
  9    9 -  10  BEAMTUBE                                                 1.08
 10   10 -  11  BEAMTUBE                                                15.54
 11   11 -  12  BEAMTUBE                                                15.55
 12   12 -  13  BEAMTUBE                                                15.54
 13   13 -  14  BEAMTUBE                                                15.54
 14   14 -  15  BEAMTUBE                                                15.46
 15   15 -  16  BEAMTUBE                                                15.46
 16   16 -  17  BEAMTUBE                                                15.45
 17   17 -  18  BEAMTUBE                                                15.46
 18   18 -  19  BEAMTUBE                                                 1.09
 19   19 -  20  STUBEND                                                  0.58
 20   20 -  21  EXPJOINT                                                 2.67
 21   21 -  22  STUBEND                                                  0.58
 22   22 -  23  BEAMTUBE                                                 1.08
 23   23 -  24  BEAMTUBE                                                15.54
 24   24 -  25  BEAMTUBE                                                15.55
 25   25 -  26  BEAMTUBE                                                15.54
 26   26 -  27  BEAMTUBE                                                15.54
 27   27 -  28  BEAMTUBE                                                15.46
 28   28 -  29  BEAMTUBE                                                15.46
 29   29 -  30  BEAMTUBE                                                15.45
 30   30 -  31  BEAMTUBE                                                15.46
 31   31 -  32  BEAMTUBE                                                 1.09
 32   32 -  33  STUBEND                                                  0.58
 33   33 -  34  EXPJOINT                                                 2.67
 34   34 -  35  STUBEND                                                  0.58
 35   35 -  36  BEAMTUBE                                                 1.08
 36   36 -  37  BEAMTUBE                                                15.54
 37   37 -  38  BEAMTUBE                                                15.55
 38   38 -  39  BEAMTUBE                                                15.54
 39   39 -  40  BEAMTUBE                                                15.54
 40   40 -  41  BEAMTUBE                                                15.46
 41   41 -  42  BEAMTUBE                                                15.46
 42   42 -  43  BEAMTUBE                                                15.45
 43   43 -  44  BEAMTUBE                                                15.46
 44   44 -  45  BEAMTUBE                                                 1.09
 45   45 -  46  STUBEND                                                  0.58
```

5.33

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------
       I      J                   I  Releases  J            End Offsets
 No Node   Node   Section        x y z     x y z  Sec  Sway  I       J        Length
--------------------------------------------------------------(in)----(in)------(ft)
 46   46 -  47  EXPJOINT                                                    2.67
 47   47 -  48  STUBEND                                                     0.58
 48   48 -  49  BEAMTUBE                                                    1.08
 49   49 -  50  BEAMTUBE                                                   15.54
 50   50 -  51  BEAMTUBE                                                   15.55
 51   51 -  52  BEAMTUBE                                                   15.54
 52   52 -  53  BEAMTUBE                                                   15.54
 53   53 -  54  BEAMTUBE                                                   15.46
 54   54 -  55  BEAMTUBE                                                   15.46
 55   55 -  56  BEAMTUBE                                                   15.45
 56   56 -  57  BEAMTUBE                                                   15.46
 57   57 -  58  BEAMTUBE                                                    1.09
 58   58 -  59  STUBEND                                                     0.58
 59   59 -  60  EXPJOINT                                                    2.67
 60   60 -  61  STUBEND                                                     0.58
 61   61 -  62  BEAMTUBE                                                    1.08
 62   62 -  63  BEAMTUBE                                                   15.54
 63   63 -  64  BEAMTUBE                                                   15.55
 64   64 -  65  BEAMTUBE                                                   15.54
 65   65 -  66  BEAMTUBE                                                   15.54
 66   66 -  67  BEAMTUBE                                                   15.46
 67   67 -  68  BEAMTUBE                                                   15.46
 68   68 -  69  BEAMTUBE                                                   15.45
 69   69 -  70  BEAMTUBE                                                   15.46
 70   70 -  71  BEAMTUBE                                                    1.09
 71   71 -  72  STUBEND                                                     0.58
 72   72 -  73  EXPJOINT                                                    2.67
 73   73 -  74  STUBEND                                                     0.58
 74   74 -  75  BEAMTUBE                                                    1.08
 75   75 -  76  BEAMTUBE                                                   15.54
 76   76 -  77  BEAMTUBE                                                   15.55
 77   77 -  78  BEAMTUBE                                                   15.54
 78   78 -  79  BEAMTUBE                                                   15.54
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
     Nodes                          Member Quarter Points
 No    I   J   Maximum       0        1/4     1/2        3/4       L        Shear
---------------------------------------------------------------------------
 44   44- 45                           - Not Calculated -
 45   45- 46                           - Not Calculated -
 46   46- 47                           - Not Calculated -
 47   47- 48                           - Not Calculated -
 48   48- 49                           - Not Calculated -
 49   49- 50                           - Not Calculated -
 50   50- 51                           - Not Calculated -
 51   51- 52                           - Not Calculated -
 52   52- 53                           - Not Calculated -
 53   53- 54                           - Not Calculated -
 54   54- 55                           - Not Calculated -
 55   55- 56                           - Not Calculated -
 56   56- 57                           - Not Calculated -
 57   57- 58                           - Not Calculated -
 58   58- 59                           - Not Calculated -
 59   59- 60                           - Not Calculated -
 60   60- 61                           - Not Calculated -
 61   61- 62                           - Not Calculated -
 62   62- 63                           - Not Calculated -
 63   63- 64                           - Not Calculated -
 64   64- 65                           - Not Calculated -
 65   65- 66                           - Not Calculated -
 66   66- 67                           - Not Calculated -
 67   67- 68                           - Not Calculated -
 68   68- 69                           - Not Calculated -
 69   69- 70                           - Not Calculated -
 70   70- 71                           - Not Calculated -
 71   71- 72                           - Not Calculated -
 72   72- 73                           - Not Calculated -
 73   73- 74                           - Not Calculated -
 74   74- 75                           - Not Calculated -
 75   75- 76                           - Not Calculated -
 76   76- 77                           - Not Calculated -
 77   77- 78                           - Not Calculated -
 78   78- 79                           - Not Calculated -
```

5.47

RISA-2D MODEL OF LIGO BEAM TUBE MODULE: CASE #1B NODE NUMBERS
CASE #1B: SIMPLE SUPPORTS AT BOTH ENDS, TOTAL LENGTH = 780'
1" SUPPORT SETTLEMENT @ INTERIOR GUIDED SUPPORT

NODE	X (FT)	DESCRIPTION	
1	0.000	FIXED SUPP'T, ROTATION FREE	
2	15.458		
3	30.917		
4	46.375		
5	61.833	GUIDED SUPP'T	
6	63.500	END TUBE / START EJ STUB	
7	64.083	END EJ STUB / START BELLOWS	
8	65.583	END BELLOWS / START EJ STUB	
9	66.167	END EJ STUB / START TUBE	
10	67.833	GUIDED SUPP'T	
11	83.375		
12	98.917		
13	114.458		
14	130.000	FIXED SUPP'T, ROTATION FREE	
15	145.458		
16	160.917		
17	176.375		
18	191.833	GUIDED SUPP'T	
19	193.500	END TUBE / START EJ STUB	
20	194.083	END EJ STUB / START BELLOWS	
21	195.583	END BELLOWS / START EJ STUB	
22	196.167	END EJ STUB / START TUBE	
23	197.833	GUIDED SUPP'T	
24	213.375		
25	228.917		
26	244.458		
27	260.000	FIXED SUPP'T, ROTATION FREE	
28	275.458		
29	290.917		
30	306.375		
31	321.833	GUIDED SUPP'T	=====> 1" SUPPORT SETTLEMENT IMPOSED
32	323.500	END TUBE / START EJ STUB	
33	324.083	END EJ STUB / START BELLOWS	
34	325.583	END BELLOWS / START EJ STUB	
35	326.167	END EJ STUB / START TUBE	
36	327.833	GUIDED SUPP'T	=====> 1" SUPPORT SETTLEMENT IMPOSED
37	343.375		
38	358.917		
39	374.458		
40	390.000	FIXED SUPP'T, ROTATION FREE	
41	405.458		
42	420.917		
43	436.375		
44	451.833	GUIDED SUPP'T	
45	453.500	END TUBE / START EJ STUB	
46	454.083	END EJ STUB / START BELLOWS	
47	455.583	END BELLOWS / START EJ STUB	
48	456.167	END EJ STUB / START TUBE	
49	457.833	GUIDED SUPP'T	

SUBJECT RISA-2D MODEL OF BEAM TUBE MODULE, CASE #1B NODE NUMBERS, COORDINATES & DESCRIPTION	OFFICE: NOE		REVISION		REFERENCE NO. 930212
	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 2
	DATE 2/28/94	DATE 18 MAR 94	DATE	DATE	5.48.

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==================================================================

------------------------------------------------------------------
       I     J         Unbraced Lengths        K Factors   Bending Coefs
 No  Node  Node    Lb-in    Lb-out     Lc      In    Out     Cm     Cb
-------------------(ft)-----(ft)-----(ft)--------------------------------
  1    1 -   2
  2    2 -   3
  3    3 -   4
  4    4 -   5
  5    5 -   6
  6    6 -   7
  7    7 -   8
  8    8 -   9
  9    9 -  10
 10   10 -  11
 11   11 -  12
 12   12 -  13
 13   13 -  14
 14   14 -  15
 15   15 -  16
 16   16 -  17
 17   17 -  18
 18   18 -  19
 19   19 -  20
 20   20 -  21
 21   21 -  22
 22   22 -  23
 23   23 -  24
 24   24 -  25
 25   25 -  26
 26   26 -  27
 27   27 -  28
 28   28 -  29
 29   29 -  30
 30   30 -  31
 31   31 -  32
 32   32 -  33
 33   33 -  34
 34   34 -  35
 35   35 -  36
 36   36 -  37
 37   37 -  38
 38   38 -  39
 39   39 -  40
 40   40 -  41
 41   41 -  42
 42   42 -  43
 43   43 -  44
 44   44 -  45
 45   45 -  46
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------
      I     J        Unbraced Lengths           K Factors    Bending Coefs
 No Node  Node    Lb-in    Lb-out     Lc        In    Out       Cm     Cb
-------------------(ft)-----(ft)-----(ft)----------------------------------
 46   46 -  47
 47   47 -  48
 48   48 -  49
 49   49 -  50
 50   50 -  51
 51   51 -  52
 52   52 -  53
 53   53 -  54
 54   54 -  55
 55   55 -  56
 56   56 -  57
 57   57 -  58
 58   58 -  59
 59   59 -  60
 60   60 -  61
 61   61 -  62
 62   62 -  63
 63   63 -  64
 64   64 -  65
 65   65 -  66
 66   66 -  67
 67   67 -  68
 68   68 -  69
 69   69 -  70
 70   70 -  71
 71   71 -  72
 72   72 -  73
 73   73 -  74
 74   74 -  75
 75   75 -  76
 76   76 -  77
 77   77 -  78
 78   78 -  79
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------
       BLC          Basic Load Case                        Load Totals
       No.            Description                    Nodal   Point   Dist.
----------------------------------------------------------------------------
         1  1" FIXED SUPPORT SETTLEMENT                                78
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

Member Distributed Loads,BLC 1: 1" FIXED SUPPORT SETTLEMENT
----------------------------------------------------------------------------
 Memb  I      J             Start          End           Start        End
  No  Node  Node  Dir    Magnitude     Magnitude       Location     Location
-------------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
   1     1 -   2   Y        -0.001        -0.001          0.000       15.460
   2     2 -   3   Y        -0.001        -0.001          0.000       15.460
   3     3 -   4   Y        -0.001        -0.001          0.000       15.449
   4     4 -   5   Y        -0.001        -0.001          0.000       15.460
   5     5 -   6   Y        -0.001        -0.001          0.000        1.089
   6     6 -   7   Y        -0.001        -0.001          0.000        0.580
   7     7 -   8   Y        -0.001        -0.001          0.000        2.669
   8     8 -   9   Y        -0.001        -0.001          0.000        0.580
   9     9 -  10   Y        -0.001        -0.001          0.000        1.080
  10    10 -  11   Y        -0.001        -0.001          0.000       15.540
  11    11 -  12   Y        -0.001        -0.001          0.000       15.550
  12    12 -  13   Y        -0.001        -0.001          0.000       15.539
  13    13 -  14   Y        -0.001        -0.001          0.000       15.540
  14    14 -  15   Y        -0.001        -0.001          0.000       15.460
  15    15 -  16   Y        -0.001        -0.001          0.000       15.459
  16    16 -  17   Y        -0.001        -0.001          0.000       15.449
  17    17 -  18   Y        -0.001        -0.001          0.000       15.460
  18    18 -  19   Y        -0.001        -0.001          0.000        1.089
  19    19 -  20   Y        -0.001        -0.001          0.000        0.580
  20    20 -  21   Y        -0.001        -0.001          0.000        2.669
  21    21 -  22   Y        -0.001        -0.001          0.000        0.580
  22    22 -  23   Y        -0.001        -0.001          0.000        1.080
  23    23 -  24   Y        -0.001        -0.001          0.000       15.539
  24    24 -  25   Y        -0.001        -0.001          0.000       15.550
  25    25 -  26   Y        -0.001        -0.001          0.000       15.540
  26    26 -  27   Y        -0.001        -0.001          0.000       15.539
  27    27 -  28   Y        -0.001        -0.001          0.000       15.459
  28    28 -  29   Y        -0.001        -0.001          0.000       15.460
  29    29 -  30   Y        -0.001        -0.001          0.000       15.449
  30    30 -  31   Y        -0.001        -0.001          0.000       15.459
  31    31 -  32   Y        -0.001        -0.001          0.000        1.090
  32    32 -  33   Y        -0.001        -0.001          0.000        0.579
  33    33 -  34   Y        -0.001        -0.001          0.000        2.670
  34    34 -  35   Y        -0.001        -0.001          0.000        0.579
  35    35 -  36   Y        -0.001        -0.001          0.000        1.079
  36    36 -  37   Y        -0.001        -0.001          0.000       15.540
  37    37 -  38   Y        -0.001        -0.001          0.000       15.550
  38    38 -  39   Y        -0.001        -0.001          0.000       15.539
  39    39 -  40   Y        -0.001        -0.001          0.000       15.540
  40    40 -  41   Y        -0.001        -0.001          0.000       15.459
  41    41 -  42   Y        -0.001        -0.001          0.000       15.460
  42    42 -  43   Y        -0.001        -0.001          0.000       15.449
  43    43 -  44   Y        -0.001        -0.001          0.000       15.459
  44    44 -  45   Y        -0.001        -0.001          0.000        1.090
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
========================================================================

------------------------------------------------------------------------
 Memb   I     J             Start         End           Start        End
  No  Node  Node  Dir   Magnitude   Magnitude       Location   Location
----------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
  45    45 -  46   Y      -0.001      -0.001          0.000      0.579
  46    46 -  47   Y      -0.001      -0.001          0.000      2.670
  47    47 -  48   Y      -0.001      -0.001          0.000      0.579
  48    48 -  49   Y      -0.001      -0.001          0.000      1.079
  49    49 -  50   Y      -0.001      -0.001          0.000     15.540
  50    50 -  51   Y      -0.001      -0.001          0.000     15.550
  51    51 -  52   Y      -0.001      -0.001          0.000     15.539
  52    52 -  53   Y      -0.001      -0.001          0.000     15.540
  53    53 -  54   Y      -0.001      -0.001          0.000     15.460
  54    54 -  55   Y      -0.001      -0.001          0.000     15.459
  55    55 -  56   Y      -0.001      -0.001          0.000     15.450
  56    56 -  57   Y      -0.001      -0.001          0.000     15.460
  57    57 -  58   Y      -0.001      -0.001          0.000      1.089
  58    58 -  59   Y      -0.001      -0.001          0.000      0.580
  59    59 -  60   Y      -0.001      -0.001          0.000      2.669
  60    60 -  61   Y      -0.001      -0.001          0.000      0.580
  61    61 -  62   Y      -0.001      -0.001          0.000      1.080
  62    62 -  63   Y      -0.001      -0.001          0.000     15.539
  63    63 -  64   Y      -0.001      -0.001          0.000     15.549
  64    64 -  65   Y      -0.001      -0.001          0.000     15.540
  65    65 -  66   Y      -0.001      -0.001          0.000     15.539
  66    66 -  67   Y      -0.001      -0.001          0.000     15.460
  67    67 -  68   Y      -0.001      -0.001          0.000     15.459
  68    68 -  69   Y      -0.001      -0.001          0.000     15.449
  69    69 -  70   Y      -0.001      -0.001          0.000     15.460
  70    70 -  71   Y      -0.001      -0.001          0.000      1.089
  71    71 -  72   Y      -0.001      -0.001          0.000      0.580
  72    72 -  73   Y      -0.001      -0.001          0.000      2.669
  73    73 -  74   Y      -0.001      -0.001          0.000      0.580
  74    74 -  75   Y      -0.001      -0.001          0.000      1.080
  75    75 -  76   Y      -0.001      -0.001          0.000     15.539
  76    76 -  77   Y      -0.001      -0.001          0.000     15.550
  77    77 -  78   Y      -0.001      -0.001          0.000     15.540
  78    78 -  79   Y      -0.001      -0.001          0.000     15.539
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
Load Combination    Self Wt  BLC    BLC    BLC    BLC    BLC          W  E
No.  Description    Dir Fac    Fac    Fac    Fac    Fac    Fac  DYNA  S  V
---------------------------------------------------------------------------
 1 1" SUPPORT DISPL          1 1
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=======================================================================

Dynamic Analysis Data

Number of modes (frequencies)  :   15
Basic Load Case for masses     :   1
BLC mass direction of action   :   Y only
Acceleration of Gravity        :   32.20 ft/sec**2

 Load Combination is 1 :   1" SUPPORT DISPL
 Nodal Displacements
-----------------------------------------------------------------------

     Node          Global X            Global Y           Rotation
--------------------(in)----------------(in)----------------(rad)---------
       1            0.00000            -0.00000            -0.00001
       2            0.00000            -0.00149            -0.00001
       3            0.00000            -0.00209             0.00000
       4            0.00000            -0.00148             0.00001
       5            0.00000            -0.00000             0.00001
       6            0.00000             0.00012             0.00001
       7            0.00000             0.00018             0.00001
       8            0.00000             0.00009            -0.00000
       9            0.00000             0.00006            -0.00000
      10            0.00000            -0.00000            -0.00000
      11            0.00000            -0.00075            -0.00000
      12            0.00000            -0.00089             0.00000
      13            0.00000            -0.00043             0.00000
      14            0.00000            -0.00000             0.00000
      15            0.00000            -0.00037            -0.00000
      16            0.00000            -0.00080            -0.00000
      17            0.00000            -0.00068             0.00000
      18            0.00000            -0.00000             0.00000
      19            0.00000             0.00006             0.00000
      20            0.00000             0.00008             0.00000
      21            0.00000            -0.00006             0.00000
      22            0.00000            -0.00004             0.00000
      23            0.00000            -0.00000             0.00000
      24            0.00000             0.00066             0.00000
      25            0.00000             0.00137             0.00000
      26            0.00000             0.00156            -0.00000
      27            0.00000            -0.00000            -0.00002
      28            0.00000            -0.00405            -0.00002
      29            0.00000            -0.00760            -0.00001
      30            0.00000            -0.00719             0.00002
      31            0.00000             0.00000             0.00006
      32            0.00000             0.00082             0.00006
      33            0.00000             0.00127             0.00007
      34            0.00000             0.03905            -0.00196
      35            0.00000             0.02542            -0.00196
      36            0.00000            -0.00000            -0.00196
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------

    Node          Global X             Global Y            Rotation
--------------------(in)-----------------(in)----------------(rad)---------
     37           0.00000             -0.36263             -0.00188
     38           0.00000             -0.68428             -0.00152
     39           0.00000             -0.91346             -0.00089
     40           0.00000             -1.00000              0.00001
     41           0.00000             -0.91155              0.00090
     42           0.00000             -0.68198              0.00153
     43           0.00000             -0.36143              0.00188
     44           0.00000             -0.00000              0.00197
     45           0.00000              0.02569              0.00196
     46           0.00000              0.03935              0.00196
     47           0.00000              0.00127             -0.00007
     48           0.00000              0.00082             -0.00006
     49           0.00000              0.00000             -0.00006
     50           0.00000             -0.00728             -0.00002
     51           0.00000             -0.00770              0.00001
     52           0.00000             -0.00411              0.00002
     53           0.00000             -0.00000              0.00002
     54           0.00000              0.00157              0.00000
     55           0.00000              0.00140             -0.00000
     56           0.00000              0.00068             -0.00000
     57           0.00000             -0.00000             -0.00000
     58           0.00000             -0.00004             -0.00000
     59           0.00000             -0.00007             -0.00000
     60           0.00000              0.00009             -0.00000
     61           0.00000              0.00006             -0.00000
     62           0.00000             -0.00000             -0.00000
     63           0.00000             -0.00070             -0.00000
     64           0.00000             -0.00084              0.00000
     65           0.00000             -0.00039              0.00000
     66           0.00000             -0.00000             -0.00000
     67           0.00000             -0.00041             -0.00000
     68           0.00000             -0.00086             -0.00000
     69           0.00000             -0.00073              0.00000
     70           0.00000             -0.00000              0.00000
     71           0.00000              0.00006              0.00000
     72           0.00000              0.00009              0.00000
     73           0.00000              0.00018             -0.00001
     74           0.00000              0.00012             -0.00001
     75           0.00000             -0.00000             -0.00001
     76           0.00000             -0.00151             -0.00001
     77           0.00000             -0.00213             -0.00000
     78           0.00000             -0.00152              0.00001
     79           0.00000             -0.00000              0.00001
```

5.42

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=============================================================================

 Load Combination is 1 :   1" SUPPORT DISPL
 Spring Reactions
-----------------------------------------------------------------------------

     Node          Global X             Global Y             Moment
----------------------(K)------------------(K)----------------(K-ft)---------
        1          0.00000              0.03069              0.00000
        5          0.00000              0.03679              0.00000
       10          0.00000              0.02374              0.00000
       14          0.00000              0.07710              0.00000
       18          0.00000              0.03130              0.00000
       23          0.00000              0.00784              0.00000
       27          0.00000              0.15946              0.00000
       31          0.00000             -1.25177              0.00000
       36          0.00000              2.45398              0.00000
       40          0.00000             -2.36558              0.00000
       44          0.00000              2.46705              0.00000
       49          0.00000             -1.25746              0.00000
       53          0.00000              0.15946              0.00000
       57          0.00000              0.00729              0.00000
       62          0.00000              0.03166              0.00000
       66          0.00000              0.07710              0.00000
       70          0.00000              0.02339              0.00000
       75          0.00000              0.03710              0.00000
       79          0.00000              0.03086              0.00000
   Totals          0.00000              0.78000              0.00000
```

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

 Load Combination is 1 :   1" SUPPORT DISPL
 Member End Forces
--------------------------------------------------------------------------
    Nodes     ========== I-End ==========      ========== J-End ==========
No  I   J     Axial      Shear     Moment      Axial      Shear     Moment
---------------(K)---------(K)------(K-ft)--------(K)---------(K)------(K-ft)--
 1   1-  2     0.00       0.03      -0.00       0.00      -0.02       0.35
 2   2-  3     0.00       0.02      -0.35       0.00       0.00       0.47
 3   3-  4     0.00      -0.00      -0.47       0.00       0.02       0.35
 4   4-  5     0.00      -0.02      -0.35       0.00       0.03      -0.01
 5   5-  6     0.00       0.01       0.01       0.00      -0.00      -0.01
 6   6-  7     0.00       0.00       0.01       0.00      -0.00      -0.01
 7   7-  8     0.00       0.00       0.01       0.00      -0.00       0.00
 8   8-  9     0.00       0.00      -0.00       0.00      -0.00       0.00
 9   9- 10     0.00       0.00      -0.00       0.00       0.00       0.00
10  10- 11     0.00       0.02      -0.00       0.00      -0.01       0.24
11  11- 12     0.00       0.01      -0.24       0.00       0.01       0.25
12  12- 13     0.00      -0.01      -0.25       0.00       0.02       0.01
13  13- 14     0.00      -0.02      -0.01       0.00       0.04      -0.48
14  14- 15     0.00       0.04       0.48       0.00      -0.02      -0.00
15  15- 16     0.00       0.02       0.00       0.00      -0.01       0.23
16  16- 17     0.00       0.01      -0.23       0.00       0.01       0.23
17  17- 18     0.00      -0.01      -0.23       0.00       0.02      -0.02
18  18- 19     0.00       0.01       0.02       0.00      -0.01      -0.01
19  19- 20     0.00       0.01       0.01       0.00      -0.01      -0.01
20  20- 21     0.00       0.01       0.01       0.00      -0.00       0.01
21  21- 22     0.00       0.00      -0.01       0.00      -0.00       0.01
22  22- 23     0.00       0.00      -0.01       0.00      -0.00       0.01
23  23- 24     0.00       0.01      -0.01       0.00       0.01       0.04
24  24- 25     0.00      -0.01      -0.04       0.00       0.02      -0.17
25  25- 26     0.00      -0.02       0.17       0.00       0.04      -0.63
26  26- 27     0.00      -0.04       0.63       0.00       0.05      -1.32
27  27- 28     0.00       0.11       1.32       0.00      -0.09       0.21
28  28- 29     0.00       0.09      -0.21       0.00      -0.08       1.50
29  29- 30     0.00       0.08      -1.50       0.00      -0.06       2.56
30  30- 31     0.00       0.06      -2.56       0.00      -0.05       3.37
31  31- 32     0.00      -1.21      -3.37       0.00       1.21       2.06
32  32- 33     0.00      -1.21      -2.06       0.00       1.21       1.36
33  33- 34     0.00      -1.21      -1.36       0.00       1.21      -1.87
34  34- 35     0.00      -1.21       1.87       0.00       1.21      -2.57
35  35- 36     0.00      -1.21       2.57       0.00       1.21      -3.88
36  36- 37     0.00       1.24       3.88       0.00      -1.23      15.29
37  37- 38     0.00       1.23     -15.29       0.00      -1.21      34.23
38  38- 39     0.00       1.21     -34.23       0.00      -1.19      52.91
39  39- 40     0.00       1.19     -52.91       0.00      -1.18      71.36
40  40- 41     0.00      -1.19     -71.36       0.00       1.20      52.89
41  41- 42     0.00      -1.20     -52.89       0.00       1.22      34.19
42  42- 43     0.00      -1.22     -34.19       0.00       1.23      15.26
43  43- 44     0.00      -1.23     -15.26       0.00       1.25      -3.91
```

5.44

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------
    Nodes     ========== I-End ==========       ========== J-End ==========
No  I   J     Axial      Shear     Moment        Axial      Shear     Moment
---------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
44  44- 45     0.00       1.22       3.91         0.00      -1.22      -2.59
45  45- 46     0.00       1.22       2.59         0.00      -1.22      -1.88
46  46- 47     0.00       1.22       1.88         0.00      -1.21       1.37
47  47- 48     0.00       1.21      -1.37         0.00      -1.21       2.07
48  48- 49     0.00       1.21      -2.07         0.00      -1.21       3.38
49  49- 50     0.00      -0.04      -3.38         0.00       0.06       2.57
50  50- 51     0.00      -0.06      -2.57         0.00       0.08       1.51
51  51- 52     0.00      -0.08      -1.51         0.00       0.09       0.21
52  52- 53     0.00      -0.09      -0.21         0.00       0.11      -1.33
53  53- 54     0.00       0.05       1.33         0.00      -0.04      -0.64
54  54- 55     0.00       0.04       0.64         0.00      -0.02      -0.18
55  55- 56     0.00       0.02       0.18         0.00      -0.01       0.03
56  56- 57     0.00       0.01      -0.03         0.00       0.01       0.01
57  57- 58     0.00      -0.00      -0.01         0.00       0.00       0.01
58  58- 59     0.00      -0.00      -0.01         0.00       0.00       0.01
59  59- 60     0.00      -0.00      -0.01         0.00       0.01      -0.01
60  60- 61     0.00      -0.01       0.01         0.00       0.01      -0.01
61  61- 62     0.00      -0.01       0.01         0.00       0.01      -0.02
62  62- 63     0.00       0.02       0.02         0.00      -0.01       0.23
63  63- 64     0.00       0.01      -0.23         0.00       0.01       0.24
64  64- 65     0.00      -0.01      -0.24         0.00       0.02       0.00
65  65- 66     0.00      -0.02      -0.00         0.00       0.04      -0.48
66  66- 67     0.00       0.04       0.48         0.00      -0.02       0.00
67  67- 68     0.00       0.02      -0.00         0.00      -0.01       0.24
68  68- 69     0.00       0.01      -0.24         0.00       0.01       0.24
69  69- 70     0.00      -0.01      -0.24         0.00       0.02       0.00
70  70- 71     0.00       0.00      -0.00         0.00       0.00       0.00
71  71- 72     0.00      -0.00      -0.00         0.00       0.00       0.00
72  72- 73     0.00      -0.00      -0.00         0.00       0.00      -0.01
73  73- 74     0.00      -0.00       0.01         0.00       0.00      -0.01
74  74- 75     0.00      -0.00       0.01         0.00       0.01      -0.01
75  75- 76     0.00       0.03       0.01         0.00      -0.02       0.35
76  76- 77     0.00       0.02      -0.35         0.00      -0.00       0.48
77  77- 78     0.00       0.00      -0.48         0.00       0.02       0.36
78  78- 79     0.00      -0.02      -0.36         0.00       0.03      -0.00
```

5.45

```
LIGO TUBE - 1" DIFF'L SETTLMT FIXED SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

 Load Combination is 1 :   1" SUPPORT DISPL
 AISC Code Checks
---------------------------------------------------------------------------
       Nodes                             Member Quarter Points
 No    I   J   Maximum      0          1/4      1/2       3/4        L        Shear
---------------------------------------------------------------------------
  1    1-  2                            - Not Calculated -
  2    2-  3                            - Not Calculated -
  3    3-  4                            - Not Calculated -
  4    4-  5                            - Not Calculated -
  5    5-  6                            - Not Calculated -
  6    6-  7                            - Not Calculated -
  7    7-  8                            - Not Calculated -
  8    8-  9                            - Not Calculated -
  9    9- 10                            - Not Calculated -
 10   10- 11                            - Not Calculated -
 11   11- 12                            - Not Calculated -
 12   12- 13                            - Not Calculated -
 13   13- 14                            - Not Calculated -
 14   14- 15                            - Not Calculated -
 15   15- 16                            - Not Calculated -
 16   16- 17                            - Not Calculated -
 17   17- 18                            - Not Calculated -
 18   18- 19                            - Not Calculated -
 19   19- 20                            - Not Calculated -
 20   20- 21                            - Not Calculated -
 21   21- 22                            - Not Calculated -
 22   22- 23                            - Not Calculated -
 23   23- 24                            - Not Calculated -
 24   24- 25                            - Not Calculated -
 25   25- 26                            - Not Calculated -
 26   26- 27                            - Not Calculated -
 27   27- 28                            - Not Calculated -
 28   28- 29                            - Not Calculated -
 29   29- 30                            - Not Calculated -
 30   30- 31                            - Not Calculated -
 31   31- 32                            - Not Calculated -
 32   32- 33                            - Not Calculated -
 33   33- 34                            - Not Calculated -
 34   34- 35                            - Not Calculated -
 35   35- 36                            - Not Calculated -
 36   36- 37                            - Not Calculated -
 37   37- 38                            - Not Calculated -
 38   38- 39                            - Not Calculated -
 39   39- 40                            - Not Calculated -
 40   40- 41                            - Not Calculated -
 41   41- 42                            - Not Calculated -
 42   42- 43                            - Not Calculated -
 43   43- 44                            - Not Calculated -
```

RISA-2D MODEL OF LIGO BEAM TUBE MODULE: CASE #1B NODE NUMBERS
CASE #1B: SIMPLE SUPPORTS AT BOTH ENDS, TOTAL LENGTH = 780'
1" SUPPORT SETTLEMENT @ INTERIOR GUIDED SUPPORT

NODE	X (FT)	DESCRIPTION
50	473.375	
51	488.917	
52	504.458	
53	520.000	FIXED SUPP'T, ROTATION FREE
54	535.458	
55	550.917	
56	566.375	
57	581.833	GUIDED SUPP'T
58	583.500	END TUBE / START EJ STUB
59	584.083	END EJ STUB / START BELLOWS
60	585.583	END BELLOWS / START EJ STUB
61	586.167	END EJ STUB / START TUBE
62	587.833	GUIDED SUPP'T
63	603.375	
64	618.917	
65	634.458	
66	650.000	FIXED SUPP'T, ROTATION FREE
67	665.458	
68	680.917	
69	696.375	
70	711.833	GUIDED SUPP'T
71	713.500	END TUBE / START EJ STUB
72	714.083	END EJ STUB / START BELLOWS
73	715.583	END BELLOWS / START EJ STUB
74	716.167	END EJ STUB / START TUBE
75	717.833	GUIDED SUPP'T
76	733.375	
77	748.917	
78	764.458	
79	780.000	FIXED SUPP'T, ROTATION FREE

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
RISA-2D MODEL OF BEAM TUBE MODULE, CASE #1B NODE NUMBERS, COORDINATES & DESCRIPTION	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 2 OF 2
	DATE 2/28/94	DATE 18 MAR 94	DATE	DATE	5.49

RISA-2D (R) Version 3.01

CBI Technical Services

3/09/94

LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS

Units Option : US Standard

AISC Code Checks : 9th Edition ASD

Shear Deformation: No

P-Delta Effects : No

Redesign : No

Edge Forces : No

A.S.I.F. : 1.333

SUBJECT	CBI OFFICE NOE C		REVISION		REFERENCE NO.
	MADE BY WJC	CHKD BY RJW	MADE BY	CHKD BY	SHT ___ OF ___
	DATE 3-18-94	DATE 10 Mar 94	DATE	DATE	

5.50

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=========================================================================

-------------------------------------------------------------------------
Node                                          Boundary Conditions
 No        X-Coord      Y-Coord       X-dof        Y-dof     Rotation     Temp.
-----------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
  1          0.00         0.00           R            R                  0.00
  2         15.46         0.00                                           0.00
  3         30.92         0.00                                           0.00
  4         46.37         0.00                                           0.00
  5         61.83         0.00                        R                  0.00
  6         62.92         0.00                                           0.00
  7         63.50         0.00                                           0.00
  8         66.17         0.00                                           0.00
  9         66.75         0.00                                           0.00
 10         67.83         0.00                        R                  0.00
 11         83.37         0.00                                           0.00
 12         98.92         0.00                                           0.00
 13        114.46         0.00                                           0.00
 14        130.00         0.00           R            R                  0.00
 15        145.46         0.00                                           0.00
 16        160.92         0.00                                           0.00
 17        176.37         0.00                                           0.00
 18        191.83         0.00                        R                  0.00
 19        192.92         0.00                                           0.00
 20        193.50         0.00                                           0.00
 21        196.17         0.00                                           0.00
 22        196.75         0.00                                           0.00
 23        197.83         0.00                        R                  0.00
 24        213.37         0.00                                           0.00
 25        228.92         0.00                                           0.00
 26        244.46         0.00                                           0.00
 27        260.00         0.00           R            R                  0.00
 28        275.46         0.00                                           0.00
 29        290.92         0.00                                           0.00
 30        306.37         0.00                                           0.00
 31        321.83         0.00                D -1.00000                 0.00
 32        322.92         0.00                                           0.00
 33        323.50         0.00                                           0.00
 34        326.17         0.00                                           0.00
 35        326.75         0.00                                           0.00
 36        327.83         0.00                D -1.00000                 0.00
 37        343.37         0.00                                           0.00
 38        358.92         0.00                                           0.00
 39        374.46         0.00                                           0.00
 40        390.00         0.00           R            R                  0.00
 41        405.46         0.00                                           0.00
 42        420.92         0.00                                           0.00
 43        436.37         0.00                                           0.00
 44        451.83         0.00                        R                  0.00
 45        452.92         0.00                                           0.00
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------
Node                                   Boundary Conditions
 No      X-Coord     Y-Coord      X-dof        Y-dof      Rotation     Temp.
-----------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
 46      453.50        0.00                                             0.00
 47      456.17        0.00                                             0.00
 48      456.75        0.00                                             0.00
 49      457.83        0.00                         R                   0.00
 50      473.37        0.00                                             0.00
 51      488.92        0.00                                             0.00
 52      504.46        0.00                                             0.00
 53      520.00        0.00            R            R                   0.00
 54      535.46        0.00                                             0.00
 55      550.92        0.00                                             0.00
 56      566.37        0.00                                             0.00
 57      581.83        0.00                         R                   0.00
 58      582.92        0.00                                             0.00
 59      583.50        0.00                                             0.00
 60      586.17        0.00                                             0.00
 61      586.75        0.00                                             0.00
 62      587.83        0.00                         R                   0.00
 63      603.37        0.00                                             0.00
 64      618.92        0.00                                             0.00
 65      634.46        0.00                                             0.00
 66      650.00        0.00            R            R                   0.00
 67      665.46        0.00                                             0.00
 68      680.92        0.00                                             0.00
 69      696.37        0.00                                             0.00
 70      711.83        0.00                         R                   0.00
 71      712.92        0.00                                             0.00
 72      713.50        0.00                                             0.00
 73      716.17        0.00                                             0.00
 74      716.75        0.00                                             0.00
 75      717.83        0.00                         R                   0.00
 76      733.37        0.00                                             0.00
 77      748.92        0.00                                             0.00
 78      764.46        0.00                                             0.00
 79      780.00        0.00            R            R                   0.00
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=====================================================================

---------------------------------------------------------------------
Material       Elastic      Poisson's    Thermal       Weight  Yield Stress
 Label         Modulus       Ratio     Coefficient    Density     (Fy)
--------------(Ksi)--------------------(F)--------(K/ft3)------(Ksi)----
 1              27000.00     0.30000       0.65000    0.000      19.200
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
  Section      Database       Matl.     Area       Moment of      As    y/y
   Label        Shape         Set                  Inertia       Coef
-------------------------------------(in^2)---------(in^4)-----------------
BEAMTUBE                       1        19.19       5731.030      1.20
STUBEND                        1        16.13       4820.000      1.20
EXPJOINT                       1         0.01          1.803      1.20
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=============================================================================

-----------------------------------------------------------------------------
      I      J                 I  Releases  J              End Offsets
 No Node   Node    Section     x y z    x y z  Sec   Sway  I       J      Length
-------------------------------------------------------------(in)----(in)------(ft)
  1    1 -    2  BEAMTUBE                                                  15.46
  2    2 -    3  BEAMTUBE                                                  15.46
  3    3 -    4  BEAMTUBE                                                  15.45
  4    4 -    5  BEAMTUBE                                                  15.46
  5    5 -    6  BEAMTUBE                                                   1.09
  6    6 -    7  STUBEND                                                    0.58
  7    7 -    8  EXPJOINT                                                   2.67
  8    8 -    9  STUBEND                                                    0.58
  9    9 -   10  BEAMTUBE                                                   1.08
 10   10 -   11  BEAMTUBE                                                  15.54
 11   11 -   12  BEAMTUBE                                                  15.55
 12   12 -   13  BEAMTUBE                                                  15.54
 13   13 -   14  BEAMTUBE                                                  15.54
 14   14 -   15  BEAMTUBE                                                  15.46
 15   15 -   16  BEAMTUBE                                                  15.46
 16   16 -   17  BEAMTUBE                                                  15.45
 17   17 -   18  BEAMTUBE                                                  15.46
 18   18 -   19  BEAMTUBE                                                   1.09
 19   19 -   20  STUBEND                                                    0.58
 20   20 -   21  EXPJOINT                                                   2.67
 21   21 -   22  STUBEND                                                    0.58
 22   22 -   23  BEAMTUBE                                                   1.08
 23   23 -   24  BEAMTUBE                                                  15.54
 24   24 -   25  BEAMTUBE                                                  15.55
 25   25 -   26  BEAMTUBE                                                  15.54
 26   26 -   27  BEAMTUBE                                                  15.54
 27   27 -   28  BEAMTUBE                                                  15.46
 28   28 -   29  BEAMTUBE                                                  15.46
 29   29 -   30  BEAMTUBE                                                  15.45
 30   30 -   31  BEAMTUBE                                                  15.46
 31   31 -   32  BEAMTUBE                                                   1.09
 32   32 -   33  STUBEND                                                    0.58
 33   33 -   34  EXPJOINT                                                   2.67
 34   34 -   35  STUBEND                                                    0.58
 35   35 -   36  BEAMTUBE                                                   1.08
 36   36 -   37  BEAMTUBE                                                  15.54
 37   37 -   38  BEAMTUBE                                                  15.55
 38   38 -   39  BEAMTUBE                                                  15.54
 39   39 -   40  BEAMTUBE                                                  15.54
 40   40 -   41  BEAMTUBE                                                  15.46
 41   41 -   42  BEAMTUBE                                                  15.46
 42   42 -   43  BEAMTUBE                                                  15.45
 43   43 -   44  BEAMTUBE                                                  15.46
 44   44 -   45  BEAMTUBE                                                   1.09
 45   45 -   46  STUBEND                                                    0.58
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=======================================================================

-----------------------------------------------------------------------
      I      J                  I  Releases  J          End Offsets
 No Node   Node   Section      x y z    x y z  Sec  Sway  I       J      Length
-----------------------------------------------------------(in)----(in)------(ft)
 46   46 -  47  EXPJOINT                                                   2.67
 47   47 -  48  STUBEND                                                    0.58
 48   48 -  49  BEAMTUBE                                                   1.08
 49   49 -  50  BEAMTUBE                                                  15.54
 50   50 -  51  BEAMTUBE                                                  15.55
 51   51 -  52  BEAMTUBE                                                  15.54
 52   52 -  53  BEAMTUBE                                                  15.54
 53   53 -  54  BEAMTUBE                                                  15.46
 54   54 -  55  BEAMTUBE                                                  15.46
 55   55 -  56  BEAMTUBE                                                  15.45
 56   56 -  57  BEAMTUBE                                                  15.46
 57   57 -  58  BEAMTUBE                                                   1.09
 58   58 -  59  STUBEND                                                    0.58
 59   59 -  60  EXPJOINT                                                   2.67
 60   60 -  61  STUBEND                                                    0.58
 61   61 -  62  BEAMTUBE                                                   1.08
 62   62 -  63  BEAMTUBE                                                  15.54
 63   63 -  64  BEAMTUBE                                                  15.55
 64   64 -  65  BEAMTUBE                                                  15.54
 65   65 -  66  BEAMTUBE                                                  15.54
 66   66 -  67  BEAMTUBE                                                  15.46
 67   67 -  68  BEAMTUBE                                                  15.46
 68   68 -  69  BEAMTUBE                                                  15.45
 69   69 -  70  BEAMTUBE                                                  15.46
 70   70 -  71  BEAMTUBE                                                   1.09
 71   71 -  72  STUBEND                                                    0.58
 72   72 -  73  EXPJOINT                                                   2.67
 73   73 -  74  STUBEND                                                    0.58
 74   74 -  75  BEAMTUBE                                                   1.08
 75   75 -  76  BEAMTUBE                                                  15.54
 76   76 -  77  BEAMTUBE                                                  15.55
 77   77 -  78  BEAMTUBE                                                  15.54
 78   78 -  79  BEAMTUBE                                                  15.54
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
       I      J         Unbraced Lengths          K Factors    Bending Coefs
 No Node   Node     Lb-in     Lb-out      Lc       In     Out      Cm      Cb
--------------------(ft)-----(ft)-----(ft)---------------------------------
  1    1 -    2
  2    2 -    3
  3    3 -    4
  4    4 -    5
  5    5 -    6
  6    6 -    7
  7    7 -    8
  8    8 -    9
  9    9 -   10
 10   10 -   11
 11   11 -   12
 12   12 -   13
 13   13 -   14
 14   14 -   15
 15   15 -   16
 16   16 -   17
 17   17 -   18
 18   18 -   19
 19   19 -   20
 20   20 -   21
 21   21 -   22
 22   22 -   23
 23   23 -   24
 24   24 -   25
 25   25 -   26
 26   26 -   27
 27   27 -   28
 28   28 -   29
 29   29 -   30
 30   30 -   31
 31   31 -   32
 32   32 -   33
 33   33 -   34
 34   34 -   35
 35   35 -   36
 36   36 -   37
 37   37 -   38
 38   38 -   39
 39   39 -   40
 40   40 -   41
 41   41 -   42
 42   42 -   43
 43   43 -   44
 44   44 -   45
 45   45 -   46
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===============================================================================

-------------------------------------------------------------------------------
      I      J            Unbraced Lengths           K Factors    Bending Coefs
 No Node   Node       Lb-in     Lb-out      Lc         In     Out      Cm      Cb
---------------------(ft)-----(ft)-----(ft)------------------------------------
 46   46 -  47
 47   47 -  48
 48   48 -  49
 49   49 -  50
 50   50 -  51
 51   51 -  52
 52   52 -  53
 53   53 -  54
 54   54 -  55
 55   55 -  56
 56   56 -  57
 57   57 -  58
 58   58 -  59
 59   59 -  60
 60   60 -  61
 61   61 -  62
 62   62 -  63
 63   63 -  64
 64   64 -  65
 65   65 -  66
 66   66 -  67
 67   67 -  68
 68   68 -  69
 69   69 -  70
 70   70 -  71
 71   71 -  72
 72   72 -  73
 73   73 -  74
 74   74 -  75
 75   75 -  76
 76   76 -  77
 77   77 -  78
 78   78 -  79
```

```
                                                             3/09/94

LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==============================================================================

------------------------------------------------------------------------------
        BLC            Basic Load Case                       Load Totals
        No.              Description                   Nodal    Point   Dist.
------------------------------------------------------------------------------
          1  1" SETTLEMENT AT GUIDED SUPPORT                               78
```

5.59

```
                                                             3/09/94

LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==============================================================

Member Distributed Loads,BLC 1: 1" SETTLEMENT AT GUIDED SUPPORT
--------------------------------------------------------------
Memb  I     J          Start        End            Start       End
 No  Node  Node  Dir  Magnitude   Magnitude      Location    Location
---------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
  1     1 -   2   Y    -0.001      -0.001          0.000      15.460
  2     2 -   3   Y    -0.001      -0.001          0.000      15.460
  3     3 -   4   Y    -0.001      -0.001          0.000      15.449
  4     4 -   5   Y    -0.001      -0.001          0.000      15.460
  5     5 -   6   Y    -0.001      -0.001          0.000       1.089
  6     6 -   7   Y    -0.001      -0.001          0.000       0.580
  7     7 -   8   Y    -0.001      -0.001          0.000       2.669
  8     8 -   9   Y    -0.001      -0.001          0.000       0.580
  9     9 -  10   Y    -0.001      -0.001          0.000       1.080
 10    10 -  11   Y    -0.001      -0.001          0.000      15.540
 11    11 -  12   Y    -0.001      -0.001          0.000      15.550
 12    12 -  13   Y    -0.001      -0.001          0.000      15.539
 13    13 -  14   Y    -0.001      -0.001          0.000      15.540
 14    14 -  15   Y    -0.001      -0.001          0.000      15.460
 15    15 -  16   Y    -0.001      -0.001          0.000      15.459
 16    16 -  17   Y    -0.001      -0.001          0.000      15.449
 17    17 -  18   Y    -0.001      -0.001          0.000      15.460
 18    18 -  19   Y    -0.001      -0.001          0.000       1.089
 19    19 -  20   Y    -0.001      -0.001          0.000       0.580
 20    20 -  21   Y    -0.001      -0.001          0.000       2.669
 21    21 -  22   Y    -0.001      -0.001          0.000       0.580
 22    22 -  23   Y    -0.001      -0.001          0.000       1.080
 23    23 -  24   Y    -0.001      -0.001          0.000      15.539
 24    24 -  25   Y    -0.001      -0.001          0.000      15.550
 25    25 -  26   Y    -0.001      -0.001          0.000      15.540
 26    26 -  27   Y    -0.001      -0.001          0.000      15.539
 27    27 -  28   Y    -0.001      -0.001          0.000      15.459
 28    28 -  29   Y    -0.001      -0.001          0.000      15.460
 29    29 -  30   Y    -0.001      -0.001          0.000      15.449
 30    30 -  31   Y    -0.001      -0.001          0.000      15.459
 31    31 -  32   Y    -0.001      -0.001          0.000       1.090
 32    32 -  33   Y    -0.001      -0.001          0.000       0.579
 33    33 -  34   Y    -0.001      -0.001          0.000       2.670
 34    34 -  35   Y    -0.001      -0.001          0.000       0.579
 35    35 -  36   Y    -0.001      -0.001          0.000       1.079
 36    36 -  37   Y    -0.001      -0.001          0.000      15.540
 37    37 -  38   Y    -0.001      -0.001          0.000      15.550
 38    38 -  39   Y    -0.001      -0.001          0.000      15.539
 39    39 -  40   Y    -0.001      -0.001          0.000      15.540
 40    40 -  41   Y    -0.001      -0.001          0.000      15.459
 41    41 -  42   Y    -0.001      -0.001          0.000      15.460
 42    42 -  43   Y    -0.001      -0.001          0.000      15.449
 43    43 -  44   Y    -0.001      -0.001          0.000      15.459
 44    44 -  45   Y    -0.001      -0.001          0.000       1.090
```

LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS

```
==============================================================================

------------------------------------------------------------------------------
 Memb   I       J            Start         End           Start        End
  No  Node    Node   Dir   Magnitude     Magnitude      Location     Location
-------------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
  45    45  -  46     Y      -0.001        -0.001         0.000        0.579
  46    46  -  47     Y      -0.001        -0.001         0.000        2.670
  47    47  -  48     Y      -0.001        -0.001         0.000        0.579
  48    48  -  49     Y      -0.001        -0.001         0.000        1.079
  49    49  -  50     Y      -0.001        -0.001         0.000       15.540
  50    50  -  51     Y      -0.001        -0.001         0.000       15.550
  51    51  -  52     Y      -0.001        -0.001         0.000       15.539
  52    52  -  53     Y      -0.001        -0.001         0.000       15.540
  53    53  -  54     Y      -0.001        -0.001         0.000       15.460
  54    54  -  55     Y      -0.001        -0.001         0.000       15.459
  55    55  -  56     Y      -0.001        -0.001         0.000       15.450
  56    56  -  57     Y      -0.001        -0.001         0.000       15.460
  57    57  -  58     Y      -0.001        -0.001         0.000        1.089
  58    58  -  59     Y      -0.001        -0.001         0.000        0.580
  59    59  -  60     Y      -0.001        -0.001         0.000        2.669
  60    60  -  61     Y      -0.001        -0.001         0.000        0.580
  61    61  -  62     Y      -0.001        -0.001         0.000        1.080
  62    62  -  63     Y      -0.001        -0.001         0.000       15.539
  63    63  -  64     Y      -0.001        -0.001         0.000       15.549
  64    64  -  65     Y      -0.001        -0.001         0.000       15.540
  65    65  -  66     Y      -0.001        -0.001         0.000       15.539
  66    66  -  67     Y      -0.001        -0.001         0.000       15.460
  67    67  -  68     Y      -0.001        -0.001         0.000       15.459
  68    68  -  69     Y      -0.001        -0.001         0.000       15.449
  69    69  -  70     Y      -0.001        -0.001         0.000       15.460
  70    70  -  71     Y      -0.001        -0.001         0.000        1.089
  71    71  -  72     Y      -0.001        -0.001         0.000        0.580
  72    72  -  73     Y      -0.001        -0.001         0.000        2.669
  73    73  -  74     Y      -0.001        -0.001         0.000        0.580
  74    74  -  75     Y      -0.001        -0.001         0.000        1.080
  75    75  -  76     Y      -0.001        -0.001         0.000       15.539
  76    76  -  77     Y      -0.001        -0.001         0.000       15.550
  77    77  -  78     Y      -0.001        -0.001         0.000       15.540
  78    78  -  79     Y      -0.001        -0.001         0.000       15.539
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=====================================================================

---------------------------------------------------------------------
Load Combination     Self Wt  BLC    BLC    BLC    BLC    BLC        W  E
No.  Description     Dir Fac    Fac    Fac    Fac    Fac    Fac  DYNA S  V
---------------------------------------------------------------------
 1 1" SUPPORT DISPL          1 1
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
===========================================================================

Dynamic Analysis Data

Number of modes (frequencies)   :   15
Basic Load Case for masses      :   1
BLC mass direction of action    :   Y only
Acceleration of Gravity         :   32.20 ft/sec**2

 Load Combination is 1 :   1" SUPPORT DISPL
 Nodal Displacements
---------------------------------------------------------------------------

     Node           Global X             Global Y             Rotation
--------------------(in)-----------------(in)----------------(rad)---------
        1           0.00000             -0.00000             -0.00001
        2           0.00000             -0.00149             -0.00001
        3           0.00000             -0.00209              0.00000
        4           0.00000             -0.00149              0.00001
        5           0.00000             -0.00000              0.00001
        6           0.00000              0.00012              0.00001
        7           0.00000              0.00018              0.00001
        8           0.00000              0.00012             -0.00001
        9           0.00000              0.00008             -0.00001
       10           0.00000             -0.00000             -0.00001
       11           0.00000             -0.00098             -0.00000
       12           0.00000             -0.00126              0.00000
       13           0.00000             -0.00075              0.00000
       14           0.00000             -0.00000              0.00000
       15           0.00000              0.00023              0.00000
       16           0.00000              0.00030              0.00000
       17           0.00000              0.00038             -0.00000
       18           0.00000             -0.00000             -0.00001
       19           0.00000             -0.00007             -0.00001
       20           0.00000             -0.00011             -0.00001
       21           0.00000             -0.00643              0.00032
       22           0.00000             -0.00419              0.00032
       23           0.00000              0.00000              0.00032
       24           0.00000              0.05727              0.00027
       25           0.00000              0.09265              0.00009
       26           0.00000              0.08184             -0.00023
       27           0.00000             -0.00000             -0.00067
       28           0.00000             -0.16872             -0.00112
       29           0.00000             -0.40789             -0.00143
       30           0.00000             -0.69281             -0.00162
       31           0.00000             -1.00000             -0.00167
       32           0.00000             -1.02188             -0.00167
       33           0.00000             -1.03353             -0.00167
       34           0.00000             -1.03319              0.00167
       35           0.00000             -1.02160              0.00167
       36           0.00000             -1.00000              0.00167
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=========================================================================

-------------------------------------------------------------------------

     Node            Global X               Global Y           Rotation
--------------------(in)-----------------(in)---------------(rad)---------
      37             0.00000              -0.69253             0.00161
      38             0.00000              -0.40715             0.00143
      39             0.00000              -0.16818             0.00111
      40             0.00000              -0.00000             0.00067
      41             0.00000               0.08051             0.00022
      42             0.00000               0.09111            -0.00009
      43             0.00000               0.05634            -0.00027
      44             0.00000               0.00000            -0.00032
      45             0.00000              -0.00418            -0.00032
      46             0.00000              -0.00640            -0.00032
      47             0.00000              -0.00010             0.00001
      48             0.00000              -0.00007             0.00001
      49             0.00000              -0.00000             0.00000
      50             0.00000               0.00035            -0.00000
      51             0.00000               0.00026            -0.00000
      52             0.00000               0.00020            -0.00000
      53             0.00000              -0.00000            -0.00000
      54             0.00000              -0.00071            -0.00000
      55             0.00000              -0.00121            -0.00000
      56             0.00000              -0.00093             0.00000
      57             0.00000              -0.00000             0.00001
      58             0.00000               0.00008             0.00001
      59             0.00000               0.00012             0.00001
      60             0.00000               0.00009            -0.00000
      61             0.00000               0.00006            -0.00000
      62             0.00000              -0.00000            -0.00000
      63             0.00000              -0.00073            -0.00000
      64             0.00000              -0.00087             0.00000
      65             0.00000              -0.00041             0.00000
      66             0.00000              -0.00000             0.00000
      67             0.00000              -0.00040            -0.00000
      68             0.00000              -0.00085            -0.00000
      69             0.00000              -0.00072             0.00000
      70             0.00000              -0.00000             0.00000
      71             0.00000               0.00006             0.00000
      72             0.00000               0.00009             0.00000
      73             0.00000               0.00018            -0.00001
      74             0.00000               0.00012            -0.00001
      75             0.00000              -0.00000            -0.00001
      76             0.00000              -0.00151            -0.00001
      77             0.00000              -0.00213            -0.00000
      78             0.00000              -0.00152             0.00001
      79             0.00000              -0.00000             0.00001
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

 Load Combination is 1 :   1" SUPPORT DISPL
 Spring Reactions
----------------------------------------------------------------------------

     Node             Global X              Global Y             Moment
---------------------(K)------------------(K)----------------(K-ft)---------
        1              0.00000              0.03073              0.00000
        5              0.00000              0.03597              0.00000
       10              0.00000              0.02679              0.00000
       14              0.00000              0.06366              0.00000
       18              0.00000              0.24021              0.00000
       23              0.00000             -0.75450              0.00000
       27              0.00000              1.23407              0.00000
       31              0.00000             -0.55994              0.00000
       36              0.00000             -0.53684              0.00000
       40              0.00000              1.22669              0.00000
       44              0.00000             -0.75307              0.00000
       49              0.00000              0.23882              0.00000
       53              0.00000              0.06365              0.00000
       57              0.00000              0.02935              0.00000
       62              0.00000              0.02565              0.00000
       66              0.00000              0.07748              0.00000
       70              0.00000              0.02330              0.00000
       75              0.00000              0.03712              0.00000
       79              0.00000              0.03085              0.00000
   Totals              0.00000              0.78000              0.00000
```

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```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
=============================================================================

 Load Combination is 1 :   1" SUPPORT DISPL
 Member End Forces
-----------------------------------------------------------------------------
    Nodes       ========== I-End ==========       ========== J-End ==========
No  I   J      Axial      Shear      Moment      Axial      Shear      Moment
--------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
 1   1-  2      0.00       0.03      -0.00        0.00      -0.02       0.36
 2   2-  3      0.00       0.02      -0.36        0.00       0.00       0.47
 3   3-  4      0.00      -0.00      -0.47        0.00       0.02       0.35
 4   4-  5      0.00      -0.02      -0.35        0.00       0.03      -0.01
 5   5-  6      0.00       0.00       0.01        0.00      -0.00      -0.01
 6   6-  7      0.00       0.00       0.01        0.00      -0.00      -0.00
 7   7-  8      0.00       0.00       0.00        0.00      -0.00      -0.00
 8   8-  9      0.00       0.00       0.00        0.00       0.00       0.00
 9   9- 10      0.00      -0.00      -0.00        0.00       0.00      -0.00
10  10- 11      0.00       0.03       0.00        0.00      -0.01       0.28
11  11- 12      0.00       0.01      -0.28        0.00       0.01       0.31
12  12- 13      0.00      -0.01      -0.31        0.00       0.02       0.11
13  13- 14      0.00      -0.02      -0.11        0.00       0.04      -0.34
14  14- 15      0.00       0.03       0.34        0.00      -0.01      -0.04
15  15- 16      0.00       0.01       0.04        0.00       0.00       0.02
16  16- 17      0.00      -0.00      -0.02        0.00       0.02      -0.15
17  17- 18      0.00      -0.02       0.15        0.00       0.03      -0.57
18  18- 19      0.00       0.21       0.57        0.00      -0.20      -0.35
19  19- 20      0.00       0.20       0.35        0.00      -0.20      -0.23
20  20- 21      0.00       0.20       0.23        0.00      -0.20       0.31
21  21- 22      0.00       0.20      -0.31        0.00      -0.20       0.43
22  22- 23      0.00       0.20      -0.43        0.00      -0.20       0.64
23  23- 24      0.00      -0.55      -0.64        0.00       0.57      -8.10
24  24- 25      0.00      -0.57       8.10        0.00       0.59     -17.09
25  25- 26      0.00      -0.59      17.09        0.00       0.60     -26.32
26  26- 27      0.00      -0.60      26.32        0.00       0.62     -35.79
27  27- 28      0.00       0.62      35.79        0.00      -0.60     -26.37
28  28- 29      0.00       0.60      26.37        0.00      -0.59     -17.19
29  29- 30      0.00       0.59      17.19        0.00      -0.57      -8.26
30  30- 31      0.00       0.57       8.26        0.00      -0.56       0.44
31  31- 32      0.00      -0.00      -0.44        0.00       0.01       0.44
32  32- 33      0.00      -0.01      -0.44        0.00       0.01       0.43
33  33- 34      0.00      -0.01      -0.43        0.00       0.01       0.41
34  34- 35      0.00      -0.01      -0.41        0.00       0.01       0.41
35  35- 36      0.00      -0.01      -0.41        0.00       0.01       0.40
36  36- 37      0.00      -0.55      -0.40        0.00       0.56      -8.24
37  37- 38      0.00      -0.56       8.24        0.00       0.58     -17.12
38  38- 39      0.00      -0.58      17.12        0.00       0.59     -26.23
39  39- 40      0.00      -0.59      26.23        0.00       0.61     -35.59
40  40- 41      0.00       0.62      35.59        0.00      -0.60     -26.17
41  41- 42      0.00       0.60      26.17        0.00      -0.59     -16.99
42  42- 43      0.00       0.59      16.99        0.00      -0.57      -8.06
43  43- 44      0.00       0.57       8.06        0.00      -0.56       0.64
```

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------
    Nodes    ========== I-End ==========      ========== J-End ==========
No  I   J    Axial      Shear     Moment      Axial      Shear     Moment
---------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
44  44- 45      0.00      -0.20     -0.64       0.00       0.20       0.42
45  45- 46      0.00      -0.20     -0.42       0.00       0.20       0.31
46  46- 47      0.00      -0.20     -0.31       0.00       0.20      -0.23
47  47- 48      0.00      -0.20      0.23       0.00       0.20      -0.35
48  48- 49      0.00      -0.20      0.35       0.00       0.20      -0.57
49  49- 50      0.00       0.03      0.57       0.00      -0.02      -0.15
50  50- 51      0.00       0.02      0.15       0.00      -0.00       0.03
51  51- 52      0.00       0.00     -0.03       0.00       0.01      -0.03
52  52- 53      0.00      -0.01      0.03       0.00       0.03      -0.34
53  53- 54      0.00       0.04      0.34       0.00      -0.02       0.10
54  54- 55      0.00       0.02     -0.10       0.00      -0.01       0.31
55  55- 56      0.00       0.01     -0.31       0.00       0.01       0.27
56  56- 57      0.00      -0.01     -0.27       0.00       0.03      -0.01
57  57- 58      0.00       0.00      0.01       0.00      -0.00      -0.00
58  58- 59      0.00       0.00      0.00       0.00      -0.00      -0.00
59  59- 60      0.00       0.00      0.00       0.00       0.00      -0.00
60  60- 61      0.00      -0.00      0.00       0.00       0.00      -0.00
61  61- 62      0.00      -0.00      0.00       0.00       0.00      -0.00
62  62- 63      0.00       0.02      0.00       0.00      -0.01       0.24
63  63- 64      0.00       0.01     -0.24       0.00       0.01       0.24
64  64- 65      0.00      -0.01     -0.24       0.00       0.02       0.00
65  65- 66      0.00      -0.02     -0.00       0.00       0.04      -0.48
66  66- 67      0.00       0.04      0.48       0.00      -0.02      -0.00
67  67- 68      0.00       0.02      0.00       0.00      -0.01       0.24
68  68- 69      0.00       0.01     -0.24       0.00       0.01       0.24
69  69- 70      0.00      -0.01     -0.24       0.00       0.02       0.00
70  70- 71      0.00       0.00     -0.00       0.00       0.00       0.00
71  71- 72      0.00      -0.00     -0.00       0.00       0.00       0.00
72  72- 73      0.00      -0.00     -0.00       0.00       0.00      -0.01
73  73- 74      0.00      -0.00      0.01       0.00       0.00      -0.01
74  74- 75      0.00      -0.00      0.01       0.00       0.01      -0.01
75  75- 76      0.00       0.03      0.01       0.00      -0.02       0.35
76  76- 77      0.00       0.02     -0.35       0.00      -0.00       0.48
77  77- 78      0.00       0.00     -0.48       0.00       0.02       0.36
78  78- 79      0.00      -0.02     -0.36       0.00       0.03      -0.00
```

5.67

```
LIGO TUBE - 1" DIFF'L SETTLMT GUIDE SUP
780' LENGTH, SIMPLE SUPP'TS @ BOTH ENDS
==========================================================================

 Load Combination is 1 :   1" SUPPORT DISPL
 AISC Code Checks
--------------------------------------------------------------------------
    Nodes                                Member Quarter Points
 No  I  J   Maximum       0        1/4     1/2       3/4       L      Shear
--------------------------------------------------------------------------
  1   1-  2                         - Not Calculated -
  2   2-  3                         - Not Calculated -
  3   3-  4                         - Not Calculated -
  4   4-  5                         - Not Calculated -
  5   5-  6                         - Not Calculated -
  6   6-  7                         - Not Calculated -
  7   7-  8                         - Not Calculated -
  8   8-  9                         - Not Calculated -
  9   9- 10                         - Not Calculated -
 10  10- 11                         - Not Calculated -
 11  11- 12                         - Not Calculated -
 12  12- 13                         - Not Calculated -
 13  13- 14                         - Not Calculated -
 14  14- 15                         - Not Calculated -
 15  15- 16                         - Not Calculated -
 16  16- 17                         - Not Calculated -
 17  17- 18                         - Not Calculated -
 18  18- 19                         - Not Calculated -
 19  19- 20                         - Not Calculated -
 20  20- 21                         - Not Calculated -
 21  21- 22                         - Not Calculated -
 22  22- 23                         - Not Calculated -
 23  23- 24                         - Not Calculated -
 24  24- 25                         - Not Calculated -
 25  25- 26                         - Not Calculated -
 26  26- 27                         - Not Calculated -
 27  27- 28                         - Not Calculated -
 28  28- 29                         - Not Calculated -
 29  29- 30                         - Not Calculated -
 30  30- 31                         - Not Calculated -
 31  31- 32                         - Not Calculated -
 32  32- 33                         - Not Calculated -
 33  33- 34                         - Not Calculated -
 34  34- 35                         - Not Calculated -
 35  35- 36                         - Not Calculated -
 36  36- 37                         - Not Calculated -
 37  37- 38                         - Not Calculated -
 38  38- 39                         - Not Calculated -
 39  39- 40                         - Not Calculated -
 40  40- 41                         - Not Calculated -
 41  41- 42                         - Not Calculated -
 42  42- 43                         - Not Calculated -
 43  43- 44                         - Not Calculated -
```

5.68

RISA-2D MODEL OF LIGO BEAM TUBE MODULE @ HANFORD SITE: CASE #2 NODE NUMBERS
CASE #2: SIMPLE SUPPORTS AT ONE END, RIGID SUPPORT AT OTHER, TOTAL LENGTH = 858.8'

NODE	X (FT)	DESCRIPTION
1	0.000	FIXED SUPP'T, ROTATION FREE
2	15.458	
3	30.917	
4	46.375	
5	61.833	GUIDED SUPP'T
6	63.500	END TUBE / START EJ STUB
7	64.083	END EJ STUB / START BELLOWS
8	65.583	END BELLOWS / START EJ STUB
9	66.167	END EJ STUB / START TUBE
10	67.833	GUIDED SUPP'T
11	83.375	
12	98.917	
13	114.458	
14	130.000	FIXED SUPP'T, ROTATION FREE
15	145.458	
16	160.917	
17	176.375	
18	191.833	GUIDED SUPP'T
19	193.500	END TUBE / START EJ STUB
20	194.083	END EJ STUB / START BELLOWS
21	195.583	END BELLOWS / START EJ STUB
22	196.167	END EJ STUB / START TUBE
23	197.833	GUIDED SUPP'T
24	213.375	
25	228.917	
26	244.458	
27	260.000	FIXED SUPP'T, ROTATION FREE
28	275.458	
29	290.917	
30	306.375	
31	321.833	GUIDED SUPP'T
32	323.500	END TUBE / START EJ STUB
33	324.083	END EJ STUB / START BELLOWS
34	325.583	END BELLOWS / START EJ STUB
35	326.167	END EJ STUB / START TUBE
36	327.833	GUIDED SUPP'T
37	343.375	
38	358.917	
39	374.458	
40	390.000	FIXED SUPP'T, ROTATION FREE
41	405.458	
42	420.917	
43	436.375	
44	451.833	GUIDED SUPP'T
45	453.500	END TUBE / START EJ STUB
46	454.083	END EJ STUB / START BELLOWS
47	455.583	END BELLOWS / START EJ STUB
48	456.167	END EJ STUB / START TUBE
49	457.833	GUIDED SUPP'T

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
RISA-2D MODEL OF BEAM TUBE MODULE, CASE #2 NODE NUMBERS, COORDINATES & DESCRIPTION	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 2
	DATE 2/28/94	DATE 19MAR94	DATE	DATE	5.70

RISA-2D MODEL OF LIGO BEAM TUBE MODULE @ HANFORD SITE: CASE #2 NODE NUMBERS

CASE #2: SIMPLE SUPPORTS AT ONE END, RIGID SUPPORT AT OTHER, TOTAL LENGTH = 858.8'

NODE	X (FT)	DESCRIPTION
50	473.375	
51	488.917	
52	504.458	
53	520.000	FIXED SUPP'T, ROTATION FREE
54	535.458	
55	550.917	
56	566.375	
57	581.833	GUIDED SUPP'T
58	583.500	END TUBE / START EJ STUB
59	584.083	END EJ STUB / START BELLOWS
60	585.583	END BELLOWS / START EJ STUB
61	586.167	END EJ STUB / START TUBE
62	587.833	GUIDED SUPP'T
63	603.375	
64	618.917	
65	634.458	
66	650.000	FIXED SUPP'T, ROTATION FREE
67	665.458	
68	680.917	
69	696.375	
70	711.833	GUIDED SUPP'T
71	713.500	END TUBE / START EJ STUB
72	714.083	END EJ STUB / START BELLOWS
73	715.583	END BELLOWS / START EJ STUB
74	716.167	END EJ STUB / START TUBE
75	717.833	GUIDED SUPP'T
76	733.375	
77	748.917	
78	764.458	
79	780.000	FIXED SUPP'T, ROTATION FREE
80	795.458	
81	810.917	
82	826.375	
83	841.833	GUIDED SUPP'T
84	843.500	END TUBE / START EJ STUB
85	844.083	END EJ STUB / START BELLOWS
86	845.583	END BELLOWS / START EJ STUB
87	846.167	END EJ STUB / START TUBE
88	847.833	GUIDED SUPP'T
89	850.581	
90	853.328	
91	856.075	
92	858.823	RIGID SUPP'T, ROTATION FIXED

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
RISA-2D MODEL OF BEAM TUBE MODULE, CASE #2 NODE NUMBERS, COORDINATES & DESCRIPTION	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 2 OF 2
	DATE 2/28/94	DATE 18mar94	DATE	DATE	5.71

```
                         RISA-2D (R) Version 3.01
CBI Technical Services                                          Page :    1

                                                                3/09/94

LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
==========================================================================

Units Option      : US Standard

AISC Code Checks  : 9th Edition ASD

Shear Deformation: No

P-Delta Effects   : No

Redesign          : No

Edge Forces       : No

A.S.I.F.          : 1.333
```

SUBJECT	CBI OFFICE NoE C		REVISION		REFERENCE NO.
	MADE BY WJC	CHKD BY RJW	MADE BY	CHKD BY	SHT___ OF___
	DATE 3-18-94	DATE 18MAR94	DATE	DATE	

5.72

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=============================================================================

-----------------------------------------------------------------------------
Node                                   Boundary Conditions
 No      X-Coord     Y-Coord       X-dof       Y-dof      Rotation     Temp.
-----------(ft)---------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
   1       0.00        0.00            R            R                    0.00
   2      15.46        0.00                                              0.00
   3      30.92        0.00                                              0.00
   4      46.37        0.00                                              0.00
   5      61.83        0.00                         R                    0.00
   6      62.92        0.00                                              0.00
   7      63.50        0.00                                              0.00
   8      66.17        0.00                                              0.00
   9      66.75        0.00                                              0.00
  10      67.83        0.00                         R                    0.00
  11      83.37        0.00                                              0.00
  12      98.92        0.00                                              0.00
  13     114.46        0.00                                              0.00
  14     130.00        0.00            R            R                    0.00
  15     145.46        0.00                                              0.00
  16     160.92        0.00                                              0.00
  17     176.37        0.00                                              0.00
  18     191.83        0.00                         R                    0.00
  19     192.92        0.00                                              0.00
  20     193.50        0.00                                              0.00
  21     196.17        0.00                                              0.00
  22     196.75        0.00                                              0.00
  23     197.83        0.00                         R                    0.00
  24     213.37        0.00                                              0.00
  25     228.92        0.00                                              0.00
  26     244.46        0.00                                              0.00
  27     260.00        0.00            R            R                    0.00
  28     275.46        0.00                                              0.00
  29     290.92        0.00                                              0.00
  30     306.37        0.00                                              0.00
  31     321.83        0.00                         R                    0.00
  32     322.92        0.00                                              0.00
  33     323.50        0.00                                              0.00
  34     326.17        0.00                                              0.00
  35     326.75        0.00                                              0.00
  36     327.83        0.00                         R                    0.00
  37     343.37        0.00                                              0.00
  38     358.92        0.00                                              0.00
  39     374.46        0.00                                              0.00
  40     390.00        0.00            R            R                    0.00
  41     405.46        0.00                                              0.00
  42     420.92        0.00                                              0.00
  43     436.37        0.00                                              0.00
  44     451.83        0.00                         R                    0.00
  45     452.92        0.00                                              0.00
```

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                                                                       3/09/94

LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

----------------------------------------------------------------------------
Node                                   Boundary Conditions
 No      X-Coord     Y-Coord      X-dof        Y-dof      Rotation     Temp.
-----------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
 46      453.50        0.00                                             0.00
 47      456.17        0.00                                             0.00
 48      456.75        0.00                                             0.00
 49      457.83        0.00                         R                   0.00
 50      473.37        0.00                                             0.00
 51      488.92        0.00                                             0.00
 52      504.46        0.00                                             0.00
 53      520.00        0.00             R           R                   0.00
 54      535.46        0.00                                             0.00
 55      550.92        0.00                                             0.00
 56      566.37        0.00                                             0.00
 57      581.83        0.00                         R                   0.00
 58      582.92        0.00                                             0.00
 59      583.50        0.00                                             0.00
 60      586.17        0.00                                             0.00
 61      586.75        0.00                                             0.00
 62      587.83        0.00                         R                   0.00
 63      603.37        0.00                                             0.00
 64      618.92        0.00                                             0.00
 65      634.46        0.00                                             0.00
 66      650.00        0.00             R           R                   0.00
 67      665.46        0.00                                             0.00
 68      680.92        0.00                                             0.00
 69      696.37        0.00                                             0.00
 70      711.83        0.00                         R                   0.00
 71      712.92        0.00                                             0.00
 72      713.50        0.00                                             0.00
 73      716.17        0.00                                             0.00
 74      716.75        0.00                                             0.00
 75      717.83        0.00                         R                   0.00
 76      733.37        0.00                                             0.00
 77      748.92        0.00                                             0.00
 78      764.46        0.00                                             0.00
 79      780.00        0.00             R           R                   0.00
 80      795.46        0.00                                             0.00
 81      810.92        0.00                                             0.00
 82      826.37        0.00                                             0.00
 83      841.83        0.00                         R                   0.00
 84      843.50        0.00                                             0.00
 85      844.08        0.00                                             0.00
 86      845.58        0.00                                             0.00
 87      846.17        0.00                                             0.00
 88      847.83        0.00                         R                   0.00
 89      850.58        0.00                                             0.00
 90      853.33        0.00                                             0.00
```

5.74

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

----------------------------------------------------------------------------
Node                                       Boundary Conditions
 No       X-Coord     Y-Coord       X-dof        Y-dof      Rotation    Temp.
-----------(ft)---------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
  91      856.08        0.00                                              0.00
  92      858.82        0.00          R             R            R        0.00
```

5.75

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

----------------------------------------------------------------------------
Material       Elastic      Poisson's     Thermal        Weight  Yield Stress
 Label         Modulus        Ratio     Coefficient     Density      (Fy)
--------------(Ksi)--------------------------(F)--------(K/ft3)------(Ksi)----
 1              27000.00     0.30000       0.65000        0.000      19.200
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

----------------------------------------------------------------------------
  Section      Database      Matl.     Area        Moment of      As     y/y
   Label        Shape        Set                    Inertia      Coef
--------------------------------------(in^2)---------(in^4)-----------------
BEAMTUBE                    1           19.19         5731.030    1.20
STUBEND                     1           16.13         4820.000    1.20
EXPJOINT                    1            0.01            1.803    1.20
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=============================================================================

-----------------------------------------------------------------------------
     I     J                    I  Releases  J            End Offsets
 No Node  Node   Section       x y z     x y z  Sec  Sway  I       J    Length
----------------------------------------------------------(in)----(in)------(ft)
  1    1 -   2  BEAMTUBE                                                 15.46
  2    2 -   3  BEAMTUBE                                                 15.46
  3    3 -   4  BEAMTUBE                                                 15.45
  4    4 -   5  BEAMTUBE                                                 15.46
  5    5 -   6  BEAMTUBE                                                  1.09
  6    6 -   7  STUBEND                                                   0.58
  7    7 -   8  EXPJOINT                                                  2.67
  8    8 -   9  STUBEND                                                   0.58
  9    9 -  10  BEAMTUBE                                                  1.08
 10   10 -  11  BEAMTUBE                                                 15.54
 11   11 -  12  BEAMTUBE                                                 15.55
 12   12 -  13  BEAMTUBE                                                 15.54
 13   13 -  14  BEAMTUBE                                                 15.54
 14   14 -  15  BEAMTUBE                                                 15.46
 15   15 -  16  BEAMTUBE                                                 15.46
 16   16 -  17  BEAMTUBE                                                 15.45
 17   17 -  18  BEAMTUBE                                                 15.46
 18   18 -  19  BEAMTUBE                                                  1.09
 19   19 -  20  STUBEND                                                   0.58
 20   20 -  21  EXPJOINT                                                  2.67
 21   21 -  22  STUBEND                                                   0.58
 22   22 -  23  BEAMTUBE                                                  1.08
 23   23 -  24  BEAMTUBE                                                 15.54
 24   24 -  25  BEAMTUBE                                                 15.55
 25   25 -  26  BEAMTUBE                                                 15.54
 26   26 -  27  BEAMTUBE                                                 15.54
 27   27 -  28  BEAMTUBE                                                 15.46
 28   28 -  29  BEAMTUBE                                                 15.46
 29   29 -  30  BEAMTUBE                                                 15.45
 30   30 -  31  BEAMTUBE                                                 15.46
 31   31 -  32  BEAMTUBE                                                  1.09
 32   32 -  33  STUBEND                                                   0.58
 33   33 -  34  EXPJOINT                                                  2.67
 34   34 -  35  STUBEND                                                   0.58
 35   35 -  36  BEAMTUBE                                                  1.08
 36   36 -  37  BEAMTUBE                                                 15.54
 37   37 -  38  BEAMTUBE                                                 15.55
 38   38 -  39  BEAMTUBE                                                 15.54
 39   39 -  40  BEAMTUBE                                                 15.54
 40   40 -  41  BEAMTUBE                                                 15.46
 41   41 -  42  BEAMTUBE                                                 15.46
 42   42 -  43  BEAMTUBE                                                 15.45
 43   43 -  44  BEAMTUBE                                                 15.46
 44   44 -  45  BEAMTUBE                                                  1.09
 45   45 -  46  STUBEND                                                   0.58
```

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                                                         3/09/94

LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=========================================================================

-------------------------------------------------------------------------
     I     J                I  Releases  J          End Offsets
No Node  Node   Section     x y z     x y z  Sec  Sway  I       J      Length
------------------------------------------------------(in)----(in)------(ft)
46   46 -  47  EXPJOINT                                                  2.67
47   47 -  48  STUBEND                                                   0.58
48   48 -  49  BEAMTUBE                                                  1.08
49   49 -  50  BEAMTUBE                                                 15.54
50   50 -  51  BEAMTUBE                                                 15.55
51   51 -  52  BEAMTUBE                                                 15.54
52   52 -  53  BEAMTUBE                                                 15.54
53   53 -  54  BEAMTUBE                                                 15.46
54   54 -  55  BEAMTUBE                                                 15.46
55   55 -  56  BEAMTUBE                                                 15.45
56   56 -  57  BEAMTUBE                                                 15.46
57   57 -  58  BEAMTUBE                                                  1.09
58   58 -  59  STUBEND                                                   0.58
59   59 -  60  EXPJOINT                                                  2.67
60   60 -  61  STUBEND                                                   0.58
61   61 -  62  BEAMTUBE                                                  1.08
62   62 -  63  BEAMTUBE                                                 15.54
63   63 -  64  BEAMTUBE                                                 15.55
64   64 -  65  BEAMTUBE                                                 15.54
65   65 -  66  BEAMTUBE                                                 15.54
66   66 -  67  BEAMTUBE                                                 15.46
67   67 -  68  BEAMTUBE                                                 15.46
68   68 -  69  BEAMTUBE                                                 15.45
69   69 -  70  BEAMTUBE                                                 15.46
70   70 -  71  BEAMTUBE                                                  1.09
71   71 -  72  STUBEND                                                   0.58
72   72 -  73  EXPJOINT                                                  2.67
73   73 -  74  STUBEND                                                   0.58
74   74 -  75  BEAMTUBE                                                  1.08
75   75 -  76  BEAMTUBE                                                 15.54
76   76 -  77  BEAMTUBE                                                 15.55
77   77 -  78  BEAMTUBE                                                 15.54
78   78 -  79  BEAMTUBE                                                 15.54
79   79 -  80  BEAMTUBE                                                 15.46
80   80 -  81  BEAMTUBE                                                 15.46
81   81 -  82  BEAMTUBE                                                 15.45
82   82 -  83  BEAMTUBE                                                 15.46
83   83 -  84  BEAMTUBE                                                  1.67
84   84 -  85  STUBEND                                                   0.58
85   85 -  86  EXPJOINT                                                  1.50
86   86 -  87  STUBEND                                                   0.59
87   87 -  88  BEAMTUBE                                                  1.66
88   88 -  89  BEAMTUBE                                                  2.75
89   89 -  90  BEAMTUBE                                                  2.75
90   90 -  91  BEAMTUBE                                                  2.75
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

----------------------------------------------------------------------------
     I      J                   I  Releases  J               End Offsets
 No Node  Node   Section        x y z    x y z  Sec  Sway  I       J       Length
-----------------------------------------------------------(in)----(in)------(ft)
 91   91 -  92  BEAMTUBE                                                   2.74
```

5.20

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------
       I      J           Unbraced Lengths         K Factors    Bending Coefs
 No Node   Node      Lb-in     Lb-out       Lc     In     Out      Cm      Cb
--------------------(ft)-----(ft)-----(ft)---------------------------------
  1     1 -   2
  2     2 -   3
  3     3 -   4
  4     4 -   5
  5     5 -   6
  6     6 -   7
  7     7 -   8
  8     8 -   9
  9     9 -  10
 10    10 -  11
 11    11 -  12
 12    12 -  13
 13    13 -  14
 14    14 -  15
 15    15 -  16
 16    16 -  17
 17    17 -  18
 18    18 -  19
 19    19 -  20
 20    20 -  21
 21    21 -  22
 22    22 -  23
 23    23 -  24
 24    24 -  25
 25    25 -  26
 26    26 -  27
 27    27 -  28
 28    28 -  29
 29    29 -  30
 30    30 -  31
 31    31 -  32
 32    32 -  33
 33    33 -  34
 34    34 -  35
 35    35 -  36
 36    36 -  37
 37    37 -  38
 38    38 -  39
 39    39 -  40
 40    40 -  41
 41    41 -  42
 42    42 -  43
 43    43 -  44
 44    44 -  45
 45    45 -  46
```

5.2

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
==============================================================================

------------------------------------------------------------------------------
      I     J           Unbraced Lengths           K Factors    Bending Coefs
 No Node  Node     Lb-in     Lb-out       Lc       In     Out     Cm      Cb
-------------------(ft)-----(ft)-----(ft)-------------------------------------
 46   46 -  47
 47   47 -  48
 48   48 -  49
 49   49 -  50
 50   50 -  51
 51   51 -  52
 52   52 -  53
 53   53 -  54
 54   54 -  55
 55   55 -  56
 56   56 -  57
 57   57 -  58
 58   58 -  59
 59   59 -  60
 60   60 -  61
 61   61 -  62
 62   62 -  63
 63   63 -  64
 64   64 -  65
 65   65 -  66
 66   66 -  67
 67   67 -  68
 68   68 -  69
 69   69 -  70
 70   70 -  71
 71   71 -  72
 72   72 -  73
 73   73 -  74
 74   74 -  75
 75   75 -  76
 76   76 -  77
 77   77 -  78
 78   78 -  79
 79   79 -  80
 80   80 -  81
 81   81 -  82
 82   82 -  83
 83   83 -  84
 84   84 -  85
 85   85 -  86
 86   86 -  87
 87   87 -  88
 88   88 -  89
 89   89 -  90
 90   90 -  91
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

----------------------------------------------------------------------------
      I      J         Unbraced Lengths          K Factors    Bending Coefs
 No Node  Node     Lb-in    Lb-out       Lc       In     Out      Cm      Cb
-------------------(ft)-----(ft)-----(ft)-----------------------------------
 91   91 -  92
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------
        BLC          Basic Load Case                       Load Totals
        No.            Description                    Nodal   Point   Dist.
---------------------------------------------------------------------------
          1  SELF WEIGHT + INSULATION                                   91
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===============================================================================

Member Distributed Loads,BLC 1: SELF WEIGHT + INSULATION
-------------------------------------------------------------------------------
 Memb  I      J             Start         End            Start        End
  No  Node   Node  Dir    Magnitude    Magnitude        Location     Location
-------------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
   1     1 -   2    Y       -0.091       -0.091          0.000       15.460
   2     2 -   3    Y       -0.091       -0.091          0.000       15.460
   3     3 -   4    Y       -0.091       -0.091          0.000       15.449
   4     4 -   5    Y       -0.091       -0.091          0.000       15.460
   5     5 -   6    Y       -0.091       -0.091          0.000        1.089
   6     6 -   7    Y       -0.091       -0.091          0.000        0.580
   7     7 -   8    Y       -0.091       -0.091          0.000        2.669
   8     8 -   9    Y       -0.091       -0.091          0.000        0.580
   9     9 -  10    Y       -0.091       -0.091          0.000        1.080
  10    10 -  11    Y       -0.091       -0.091          0.000       15.540
  11    11 -  12    Y       -0.091       -0.091          0.000       15.550
  12    12 -  13    Y       -0.091       -0.091          0.000       15.539
  13    13 -  14    Y       -0.091       -0.091          0.000       15.540
  14    14 -  15    Y       -0.091       -0.091          0.000       15.460
  15    15 -  16    Y       -0.091       -0.091          0.000       15.459
  16    16 -  17    Y       -0.091       -0.091          0.000       15.449
  17    17 -  18    Y       -0.091       -0.091          0.000       15.460
  18    18 -  19    Y       -0.091       -0.091          0.000        1.089
  19    19 -  20    Y       -0.091       -0.091          0.000        0.580
  20    20 -  21    Y       -0.091       -0.091          0.000        2.669
  21    21 -  22    Y       -0.091       -0.091          0.000        0.580
  22    22 -  23    Y       -0.091       -0.091          0.000        1.080
  23    23 -  24    Y       -0.091       -0.091          0.000       15.539
  24    24 -  25    Y       -0.091       -0.091          0.000       15.550
  25    25 -  26    Y       -0.091       -0.091          0.000       15.540
  26    26 -  27    Y       -0.091       -0.091          0.000       15.539
  27    27 -  28    Y       -0.091       -0.091          0.000       15.459
  28    28 -  29    Y       -0.091       -0.091          0.000       15.460
  29    29 -  30    Y       -0.091       -0.091          0.000       15.449
  30    30 -  31    Y       -0.091       -0.091          0.000       15.459
  31    31 -  32    Y       -0.091       -0.091          0.000        1.090
  32    32 -  33    Y       -0.091       -0.091          0.000        0.579
  33    33 -  34    Y       -0.091       -0.091          0.000        2.670
  34    34 -  35    Y       -0.091       -0.091          0.000        0.579
  35    35 -  36    Y       -0.091       -0.091          0.000        1.079
  36    36 -  37    Y       -0.091       -0.091          0.000       15.540
  37    37 -  38    Y       -0.091       -0.091          0.000       15.550
  38    38 -  39    Y       -0.091       -0.091          0.000       15.539
  39    39 -  40    Y       -0.091       -0.091          0.000       15.540
  40    40 -  41    Y       -0.091       -0.091          0.000       15.459
  41    41 -  42    Y       -0.091       -0.091          0.000       15.460
  42    42 -  43    Y       -0.091       -0.091          0.000       15.449
  43    43 -  44    Y       -0.091       -0.091          0.000       15.459
  44    44 -  45    Y       -0.091       -0.091          0.000        1.090
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

----------------------------------------------------------------------------
Memb   I      J              Start         End          Start        End
 No   Node   Node   Dir    Magnitude    Magnitude      Location    Location
-------------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
  45    45 -  46     Y       -0.091       -0.091         0.000       0.579
  46    46 -  47     Y       -0.091       -0.091         0.000       2.670
  47    47 -  48     Y       -0.091       -0.091         0.000       0.579
  48    48 -  49     Y       -0.091       -0.091         0.000       1.079
  49    49 -  50     Y       -0.091       -0.091         0.000      15.540
  50    50 -  51     Y       -0.091       -0.091         0.000      15.550
  51    51 -  52     Y       -0.091       -0.091         0.000      15.539
  52    52 -  53     Y       -0.091       -0.091         0.000      15.540
  53    53 -  54     Y       -0.091       -0.091         0.000      15.460
  54    54 -  55     Y       -0.091       -0.091         0.000      15.459
  55    55 -  56     Y       -0.091       -0.091         0.000      15.450
  56    56 -  57     Y       -0.091       -0.091         0.000      15.460
  57    57 -  58     Y       -0.091       -0.091         0.000       1.089
  58    58 -  59     Y       -0.091       -0.091         0.000       0.580
  59    59 -  60     Y       -0.091       -0.091         0.000       2.669
  60    60 -  61     Y       -0.091       -0.091         0.000       0.580
  61    61 -  62     Y       -0.091       -0.091         0.000       1.080
  62    62 -  63     Y       -0.091       -0.091         0.000      15.539
  63    63 -  64     Y       -0.091       -0.091         0.000      15.549
  64    64 -  65     Y       -0.091       -0.091         0.000      15.540
  65    65 -  66     Y       -0.091       -0.091         0.000      15.539
  66    66 -  67     Y       -0.091       -0.091         0.000      15.460
  67    67 -  68     Y       -0.091       -0.091         0.000      15.459
  68    68 -  69     Y       -0.091       -0.091         0.000      15.449
  69    69 -  70     Y       -0.091       -0.091         0.000      15.460
  70    70 -  71     Y       -0.091       -0.091         0.000       1.089
  71    71 -  72     Y       -0.091       -0.091         0.000       0.580
  72    72 -  73     Y       -0.091       -0.091         0.000       2.669
  73    73 -  74     Y       -0.091       -0.091         0.000       0.580
  74    74 -  75     Y       -0.091       -0.091         0.000       1.080
  75    75 -  76     Y       -0.091       -0.091         0.000      15.539
  76    76 -  77     Y       -0.091       -0.091         0.000      15.550
  77    77 -  78     Y       -0.091       -0.091         0.000      15.540
  78    78 -  79     Y       -0.091       -0.091         0.000      15.539
  79    79 -  80     Y       -0.091       -0.091         0.000      15.460
  80    80 -  81     Y       -0.091       -0.091         0.000      15.459
  81    81 -  82     Y       -0.091       -0.091         0.000      15.449
  82    82 -  83     Y       -0.091       -0.091         0.000      15.460
  83    83 -  84     Y       -0.091       -0.091         0.000       1.669
  84    84 -  85     Y       -0.091       -0.091         0.000       0.580
  85    85 -  86     Y       -0.091       -0.091         0.000       1.500
  86    86 -  87     Y       -0.091       -0.091         0.000       0.589
  87    87 -  88     Y       -0.091       -0.091         0.000       1.660
  88    88 -  89     Y       -0.091       -0.091         0.000       2.750
  89    89 -  90     Y       -0.091       -0.091         0.000       2.750
```

5.8✓

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------
 Memb  I      J              Start        End            Start        End
  No  Node   Node  Dir    Magnitude    Magnitude       Location    Location
-------------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
  90    90 -  91    Y       -0.091       -0.091          0.000       2.750
  91    91 -  92    Y       -0.091       -0.091          0.000       2.739
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------
Load Combination    Self Wt  BLC    BLC    BLC    BLC    BLC          W  E
No.  Description    Dir Fac    Fac    Fac    Fac    Fac    Fac  DYNA  S  V
---------------------------------------------------------------------------
 1 DEAD LD + INSUL'N         1 1
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

Dynamic Analysis Data

Number of modes (frequencies)  :    15
Basic Load Case for masses     :    1
BLC mass direction of action   :    Y only
Acceleration of Gravity        :    32.20 ft/sec**2

 Load Combination is 1 :   DEAD LD + INSUL'N
 Nodal Displacements
---------------------------------------------------------------------------

     Node          Global X             Global Y             Rotation
--------------------(in)-----------------(in)-----------------(rad)---------
        1          0.00000             -0.00000             -0.00082
        2          0.00000             -0.13569             -0.00056
        3          0.00000             -0.19000              0.00000
        4          0.00000             -0.13484              0.00056
        5          0.00000             -0.00000              0.00081
        6          0.00000              0.01058              0.00081
        7          0.00000              0.01621              0.00081
        8          0.00000              0.00858             -0.00043
        9          0.00000              0.00558             -0.00043
       10          0.00000             -0.00000             -0.00043
       11          0.00000             -0.06767             -0.00024
       12          0.00000             -0.08041              0.00011
       13          0.00000             -0.03810              0.00029
       14          0.00000             -0.00000              0.00001
       15          0.00000             -0.03509             -0.00028
       16          0.00000             -0.07566             -0.00010
       17          0.00000             -0.06390              0.00023
       18          0.00000             -0.00000              0.00041
       19          0.00000              0.00531              0.00041
       20          0.00000              0.00814              0.00041
       21          0.00000              0.00834             -0.00042
       22          0.00000              0.00543             -0.00042
       23          0.00000             -0.00000             -0.00042
       24          0.00000             -0.06633             -0.00024
       25          0.00000             -0.07900              0.00010
       26          0.00000             -0.03734              0.00029
       27          0.00000             -0.00000              0.00000
       28          0.00000             -0.03549             -0.00028
       29          0.00000             -0.07612             -0.00010
       30          0.00000             -0.06418              0.00023
       31          0.00000             -0.00000              0.00041
       32          0.00000              0.00533              0.00041
       33          0.00000              0.00817              0.00041
       34          0.00000              0.00834             -0.00042
       35          0.00000              0.00543             -0.00042
       36          0.00000             -0.00000             -0.00042
```

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LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------

     Node            Global X             Global Y            Rotation
---------------------(in)----------------(in)----------------(rad)---------
      37            0.00000             -0.06633             -0.00024
      38            0.00000             -0.07901              0.00010
      39            0.00000             -0.03735              0.00029
      40            0.00000             -0.00000              0.00000
      41            0.00000             -0.03549             -0.00028
      42            0.00000             -0.07611             -0.00010
      43            0.00000             -0.06418              0.00023
      44            0.00000             -0.00000              0.00041
      45            0.00000              0.00533              0.00041
      46            0.00000              0.00817              0.00041
      47            0.00000              0.00834             -0.00042
      48            0.00000              0.00543             -0.00042
      49            0.00000             -0.00000             -0.00042
      50            0.00000             -0.06633             -0.00024
      51            0.00000             -0.07901              0.00010
      52            0.00000             -0.03735              0.00029
      53            0.00000             -0.00000              0.00000
      54            0.00000             -0.03549             -0.00028
      55            0.00000             -0.07611             -0.00010
      56            0.00000             -0.06418              0.00023
      57            0.00000             -0.00000              0.00041
      58            0.00000              0.00533              0.00041
      59            0.00000              0.00817              0.00041
      60            0.00000              0.00834             -0.00042
      61            0.00000              0.00543             -0.00042
      62            0.00000             -0.00000             -0.00042
      63            0.00000             -0.06633             -0.00024
      64            0.00000             -0.07900              0.00010
      65            0.00000             -0.03734              0.00029
      66            0.00000             -0.00000              0.00000
      67            0.00000             -0.03551             -0.00028
      68            0.00000             -0.07614             -0.00010
      69            0.00000             -0.06421              0.00023
      70            0.00000             -0.00000              0.00041
      71            0.00000              0.00534              0.00041
      72            0.00000              0.00818              0.00041
      73            0.00000              0.00850             -0.00043
      74            0.00000              0.00553             -0.00043
      75            0.00000             -0.00000             -0.00043
      76            0.00000             -0.06781             -0.00025
      77            0.00000             -0.08139              0.00010
      78            0.00000             -0.03944              0.00030
      79            0.00000             -0.00000              0.00002
      80            0.00000             -0.03160             -0.00026
      81            0.00000             -0.06893             -0.00009
```

5.90

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LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------

     Node             Global X                Global Y            Rotation
--------------------(in)-----------------(in)---------------(rad)---------
       82              0.00000               -0.05730              0.00021
       83              0.00000               -0.00000              0.00035
       84              0.00000                0.00692              0.00034
       85              0.00000                0.00931              0.00034
       86              0.00000                0.00034             -0.00001
       87              0.00000                0.00024             -0.00001
       88              0.00000                0.00000             -0.00001
       89              0.00000               -0.00021             -0.00000
       90              0.00000               -0.00021              0.00000
       91              0.00000               -0.00008              0.00000
       92              0.00000               -0.00000              0.00000
```

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                                                           3/09/94

LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 Spring Reactions
---------------------------------------------------------------------------

     Node             Global X             Global Y             Moment
---------------------(K)------------------(K)---------------(K-ft)---------
        1             0.00000              2.79271             0.00000
        5             0.00000              3.35017             0.00000
       10             0.00000              2.15310             0.00000
       14             0.00000              7.04581             0.00000
       18             0.00000              2.38115             0.00000
       23             0.00000              2.41705             0.00000
       27             0.00000              7.02891             0.00000
       31             0.00000              2.38504             0.00000
       36             0.00000              2.41599             0.00000
       40             0.00000              7.02898             0.00000
       44             0.00000              2.38502             0.00000
       49             0.00000              2.41600             0.00000
       53             0.00000              7.02898             0.00000
       57             0.00000              2.38505             0.00000
       62             0.00000              2.41592             0.00000
       66             0.00000              7.02933             0.00000
       70             0.00000              2.37957             0.00000
       75             0.00000              2.43589             0.00000
       79             0.00000              6.94163             0.00000
       83             0.00000              3.65638             0.00000
       88             0.00000             -0.96797             0.00000
       92             0.00000              1.04790            -2.92290
   Totals             0.00000             78.15262            -2.92290
```

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                                                             3/09/94

LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 Member End Forces
-------------------------------------------------------------------
   Nodes     ========== I-End ==========     ========== J-End ==========
No  I   J    Axial     Shear    Moment       Axial     Shear    Moment
-------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
 1   1-  2    0.00      2.79     -0.00        0.00     -1.39     32.30
 2   2-  3    0.00      1.39    -32.30        0.00      0.02     42.85
 3   3-  4    0.00     -0.02    -42.85        0.00      1.43     31.67
 4   4-  5    0.00     -1.43    -31.67        0.00      2.83     -1.27
 5   5-  6    0.00      0.52      1.27        0.00     -0.42     -0.76
 6   6-  7    0.00      0.42      0.76        0.00     -0.36     -0.54
 7   7-  8    0.00      0.36      0.54        0.00     -0.12      0.11
 8   8-  9    0.00      0.12     -0.11        0.00     -0.07      0.17
 9   9- 10    0.00      0.07     -0.17        0.00      0.03      0.19
10  10- 11    0.00      2.12     -0.19        0.00     -0.71     22.20
11  11- 12    0.00      0.71    -22.20        0.00      0.71     22.23
12  12- 13    0.00     -0.71    -22.23        0.00      2.12      0.27
13  13- 14    0.00     -2.12     -0.27        0.00      3.53    -43.66
14  14- 15    0.00      3.51     43.66        0.00     -2.10     -0.24
15  15- 16    0.00      2.10      0.24        0.00     -0.70     21.43
16  16- 17    0.00      0.70    -21.43        0.00      0.71     21.35
17  17- 18    0.00     -0.71    -21.35        0.00      2.11     -0.47
18  18- 19    0.00      0.27      0.47        0.00     -0.17     -0.23
19  19- 20    0.00      0.17      0.23        0.00     -0.11     -0.15
20  20- 21    0.00      0.11      0.15        0.00      0.13     -0.17
21  21- 22    0.00     -0.13      0.17        0.00      0.18     -0.26
22  22- 23    0.00     -0.18      0.26        0.00      0.28     -0.51
23  23- 24    0.00      2.14      0.51        0.00     -0.72     21.72
24  24- 25    0.00      0.72    -21.72        0.00      0.69     21.97
25  25- 26    0.00     -0.69    -21.97        0.00      2.11      0.23
26  26- 27    0.00     -2.11     -0.23        0.00      3.52    -43.48
27  27- 28    0.00      3.51     43.48        0.00     -2.10     -0.11
28  28- 29    0.00      2.10      0.11        0.00     -0.70     21.51
29  29- 30    0.00      0.70    -21.51        0.00      0.71     21.39
30  30- 31    0.00     -0.71    -21.39        0.00      2.12     -0.47
31  31- 32    0.00      0.27      0.47        0.00     -0.17     -0.23
32  32- 33    0.00      0.17      0.23        0.00     -0.12     -0.15
33  33- 34    0.00      0.12      0.15        0.00      0.13     -0.17
34  34- 35    0.00     -0.13      0.17        0.00      0.18     -0.26
35  35- 36    0.00     -0.18      0.26        0.00      0.28     -0.50
36  36- 37    0.00      2.14      0.50        0.00     -0.72     21.72
37  37- 38    0.00      0.72    -21.72        0.00      0.69     21.97
38  38- 39    0.00     -0.69    -21.97        0.00      2.11      0.23
39  39- 40    0.00     -2.11     -0.23        0.00      3.52    -43.48
40  40- 41    0.00      3.51     43.48        0.00     -2.10     -0.11
41  41- 42    0.00      2.10      0.11        0.00     -0.70     21.51
42  42- 43    0.00      0.70    -21.51        0.00      0.71     21.39
43  43- 44    0.00     -0.71    -21.39        0.00      2.12     -0.47
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------
    Nodes     ========== I-End ==========      ========== J-End ==========
No  I   J     Axial      Shear     Moment      Axial      Shear     Moment
--------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
44  44- 45     0.00       0.27       0.47       0.00      -0.17      -0.23
45  45- 46     0.00       0.17       0.23       0.00      -0.12      -0.15
46  46- 47     0.00       0.12       0.15       0.00       0.13      -0.17
47  47- 48     0.00      -0.13       0.17       0.00       0.18      -0.26
48  48- 49     0.00      -0.18       0.26       0.00       0.28      -0.50
49  49- 50     0.00       2.14       0.50       0.00      -0.72      21.72
50  50- 51     0.00       0.72     -21.72       0.00       0.69      21.97
51  51- 52     0.00      -0.69     -21.97       0.00       2.11       0.23
52  52- 53     0.00      -2.11      -0.23       0.00       3.52     -43.48
53  53- 54     0.00       3.51      43.48       0.00      -2.10      -0.11
54  54- 55     0.00       2.10       0.11       0.00      -0.70      21.51
55  55- 56     0.00       0.70     -21.51       0.00       0.71      21.39
56  56- 57     0.00      -0.71     -21.39       0.00       2.12      -0.47
57  57- 58     0.00       0.27       0.47       0.00      -0.17      -0.23
58  58- 59     0.00       0.17       0.23       0.00      -0.12      -0.15
59  59- 60     0.00       0.12       0.15       0.00       0.13      -0.17
60  60- 61     0.00      -0.13       0.17       0.00       0.18      -0.26
61  61- 62     0.00      -0.18       0.26       0.00       0.28      -0.50
62  62- 63     0.00       2.14       0.50       0.00      -0.72      21.72
63  63- 64     0.00       0.72     -21.72       0.00       0.69      21.97
64  64- 65     0.00      -0.69     -21.97       0.00       2.11       0.23
65  65- 66     0.00      -2.11      -0.23       0.00       3.52     -43.49
66  66- 67     0.00       3.51      43.49       0.00      -2.10      -0.11
67  67- 68     0.00       2.10       0.11       0.00      -0.70      21.52
68  68- 69     0.00       0.70     -21.52       0.00       0.71      21.40
69  69- 70     0.00      -0.71     -21.40       0.00       2.12      -0.46
70  70- 71     0.00       0.26       0.46       0.00      -0.16      -0.22
71  71- 72     0.00       0.16       0.22       0.00      -0.11      -0.14
72  72- 73     0.00       0.11       0.14       0.00       0.13      -0.17
73  73- 74     0.00      -0.13       0.17       0.00       0.19      -0.27
74  74- 75     0.00      -0.19       0.27       0.00       0.28      -0.52
75  75- 76     0.00       2.15       0.52       0.00      -0.74      21.94
76  76- 77     0.00       0.74     -21.94       0.00       0.68      22.41
77  77- 78     0.00      -0.68     -22.41       0.00       2.09       0.90
78  78- 79     0.00      -2.09      -0.90       0.00       3.51     -42.58
79  79- 80     0.00       3.44      42.58       0.00      -2.03      -0.33
80  80- 81     0.00       2.03       0.33       0.00      -0.62      20.17
81  81- 82     0.00       0.62     -20.17       0.00       0.78      18.92
82  82- 83     0.00      -0.78     -18.92       0.00       2.19      -4.06
83  83- 84     0.00       1.47       4.06       0.00      -1.31      -1.74
84  84- 85     0.00       1.31       1.74       0.00      -1.26      -0.99
85  85- 86     0.00       1.26       0.99       0.00      -1.12       0.80
86  86- 87     0.00       1.12      -0.80       0.00      -1.07       1.45
87  87- 88     0.00       1.07      -1.45       0.00      -0.92       3.10
88  88- 89     0.00      -0.05      -3.10       0.00       0.30       2.62
```

5.94

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------
    Nodes    ========== I-End ==========      ========== J-End ==========
No  I   J    Axial      Shear     Moment      Axial      Shear     Moment
---------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
89  89- 90    0.00      -0.30     -2.62       0.00       0.55       1.46
90  90- 91    0.00      -0.55     -1.46       0.00       0.80      -0.39
91  91- 92    0.00      -0.80      0.39       0.00       1.05      -2.92
```

5.95

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LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=========================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 AISC Code Checks
-------------------------------------------------------------------------
      Nodes                          Member Quarter Points
 No   I   J   Maximum     0         1/4     1/2       3/4        L       Shear
-------------------------------------------------------------------------
  1   1-  2                          - Not Calculated -
  2   2-  3                          - Not Calculated -
  3   3-  4                          - Not Calculated -
  4   4-  5                          - Not Calculated -
  5   5-  6                          - Not Calculated -
  6   6-  7                          - Not Calculated -
  7   7-  8                          - Not Calculated -
  8   8-  9                          - Not Calculated -
  9   9- 10                          - Not Calculated -
 10  10- 11                          - Not Calculated -
 11  11- 12                          - Not Calculated -
 12  12- 13                          - Not Calculated -
 13  13- 14                          - Not Calculated -
 14  14- 15                          - Not Calculated -
 15  15- 16                          - Not Calculated -
 16  16- 17                          - Not Calculated -
 17  17- 18                          - Not Calculated -
 18  18- 19                          - Not Calculated -
 19  19- 20                          - Not Calculated -
 20  20- 21                          - Not Calculated -
 21  21- 22                          - Not Calculated -
 22  22- 23                          - Not Calculated -
 23  23- 24                          - Not Calculated -
 24  24- 25                          - Not Calculated -
 25  25- 26                          - Not Calculated -
 26  26- 27                          - Not Calculated -
 27  27- 28                          - Not Calculated -
 28  28- 29                          - Not Calculated -
 29  29- 30                          - Not Calculated -
 30  30- 31                          - Not Calculated -
 31  31- 32                          - Not Calculated -
 32  32- 33                          - Not Calculated -
 33  33- 34                          - Not Calculated -
 34  34- 35                          - Not Calculated -
 35  35- 36                          - Not Calculated -
 36  36- 37                          - Not Calculated -
 37  37- 38                          - Not Calculated -
 38  38- 39                          - Not Calculated -
 39  39- 40                          - Not Calculated -
 40  40- 41                          - Not Calculated -
 41  41- 42                          - Not Calculated -
 42  42- 43                          - Not Calculated -
 43  43- 44                          - Not Calculated -
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=======================================================================

-----------------------------------------------------------------------
      Nodes                           Member Quarter Points
 No    I   J   Maximum      0        1/4      1/2       3/4       L       Shear
-----------------------------------------------------------------------
 44   44- 45                           - Not Calculated -
 45   45- 46                           - Not Calculated -
 46   46- 47                           - Not Calculated -
 47   47- 48                           - Not Calculated -
 48   48- 49                           - Not Calculated -
 49   49- 50                           - Not Calculated -
 50   50- 51                           - Not Calculated -
 51   51- 52                           - Not Calculated -
 52   52- 53                           - Not Calculated -
 53   53- 54                           - Not Calculated -
 54   54- 55                           - Not Calculated -
 55   55- 56                           - Not Calculated -
 56   56- 57                           - Not Calculated -
 57   57- 58                           - Not Calculated -
 58   58- 59                           - Not Calculated -
 59   59- 60                           - Not Calculated -
 60   60- 61                           - Not Calculated -
 61   61- 62                           - Not Calculated -
 62   62- 63                           - Not Calculated -
 63   63- 64                           - Not Calculated -
 64   64- 65                           - Not Calculated -
 65   65- 66                           - Not Calculated -
 66   66- 67                           - Not Calculated -
 67   67- 68                           - Not Calculated -
 68   68- 69                           - Not Calculated -
 69   69- 70                           - Not Calculated -
 70   70- 71                           - Not Calculated -
 71   71- 72                           - Not Calculated -
 72   72- 73                           - Not Calculated -
 73   73- 74                           - Not Calculated -
 74   74- 75                           - Not Calculated -
 75   75- 76                           - Not Calculated -
 76   76- 77                           - Not Calculated -
 77   77- 78                           - Not Calculated -
 78   78- 79                           - Not Calculated -
 79   79- 80                           - Not Calculated -
 80   80- 81                           - Not Calculated -
 81   81- 82                           - Not Calculated -
 82   82- 83                           - Not Calculated -
 83   83- 84                           - Not Calculated -
 84   84- 85                           - Not Calculated -
 85   85- 86                           - Not Calculated -
 86   86- 87                           - Not Calculated -
 87   87- 88                           - Not Calculated -
 88   88- 89                           - Not Calculated -
```

```
LIGO BEAM TUBE - BAKE + SELF WT, HANFORD
859' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=============================================================================

-----------------------------------------------------------------------------
       Nodes                             Member Quarter Points
 No    I   J   Maximum       0        1/4      1/2       3/4        L        Shear
-----------------------------------------------------------------------------
 89   89- 90                           - Not Calculated -
 90   90- 91                           - Not Calculated -
 91   91- 92                           - Not Calculated -
```

RISA-2D MODEL OF LIGO BEAM TUBE MODULE @ LIVINGSTON SITE: CASE #3 NODE NUMBERS
CASE #3: SIMPLE SUPPORTS AT ONE END, RIGID SUPPORT AT OTHER, TOTAL LENGTH = 878.5'

NODE	X (FT)	DESCRIPTION
1	0.000	FIXED SUPP'T, ROTATION FREE
2	15.458	
3	30.917	
4	46.375	
5	61.833	GUIDED SUPP'T
6	63.500	END TUBE / START EJ STUB
7	64.083	END EJ STUB / START BELLOWS
8	65.583	END BELLOWS / START EJ STUB
9	66.167	END EJ STUB / START TUBE
10	67.833	GUIDED SUPP'T
11	83.375	
12	98.917	
13	114.458	
14	130.000	FIXED SUPP'T, ROTATION FREE
15	145.458	
16	160.917	
17	176.375	
18	191.833	GUIDED SUPP'T
19	193.500	END TUBE / START EJ STUB
20	194.083	END EJ STUB / START BELLOWS
21	195.583	END BELLOWS / START EJ STUB
22	196.167	END EJ STUB / START TUBE
23	197.833	GUIDED SUPP'T
24	213.375	
25	228.917	
26	244.458	
27	260.000	FIXED SUPP'T, ROTATION FREE
28	275.458	
29	290.917	
30	306.375	
31	321.833	GUIDED SUPP'T
32	323.500	END TUBE / START EJ STUB
33	324.083	END EJ STUB / START BELLOWS
34	325.583	END BELLOWS / START EJ STUB
35	326.167	END EJ STUB / START TUBE
36	327.833	GUIDED SUPP'T
37	343.375	
38	358.917	
39	374.458	
40	390.000	FIXED SUPP'T, ROTATION FREE
41	405.458	
42	420.917	
43	436.375	
44	451.833	GUIDED SUPP'T
45	453.500	END TUBE / START EJ STUB
46	454.083	END EJ STUB / START BELLOWS
47	455.583	END BELLOWS / START EJ STUB
48	456.167	END EJ STUB / START TUBE
49	457.833	GUIDED SUPP'T

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
RISA-2D MODEL OF BEAM TUBE MODULE, CASE #3 **NODE NUMBERS, COORDINATES & DESCRIPTION**	MADE BY WJC	CHKD PJ[illegible]	MADE BY	CHKD BY	SHT 1 OF 2
	DATE 2/28/94	DATE [illegible]	DATE	DATE	5.99

RISA-2D MODEL OF LIGO BEAM TUBE MODULE @ LIVINGSTON SITE: CASE #3 NODE NUMBERS

CASE #3: SIMPLE SUPPORTS AT ONE END, RIGID SUPPORT AT OTHER, TOTAL LENGTH = 878.5'

NODE	X (FT)	DESCRIPTION
50	473.375	
51	488.917	
52	504.458	
53	520.000	FIXED SUPP'T, ROTATION FREE
54	535.458	
55	550.917	
56	566.375	
57	581.833	GUIDED SUPP'T
58	583.500	END TUBE / START EJ STUB
59	584.083	END EJ STUB / START BELLOWS
60	585.583	END BELLOWS / START EJ STUB
61	586.167	END EJ STUB / START TUBE
62	587.833	GUIDED SUPP'T
63	603.375	
64	618.917	
65	634.458	
66	650.000	FIXED SUPP'T, ROTATION FREE
67	665.458	
68	680.917	
69	696.375	
70	711.833	GUIDED SUPP'T
71	713.500	END TUBE / START EJ STUB
72	714.083	END EJ STUB / START BELLOWS
73	715.583	END BELLOWS / START EJ STUB
74	716.167	END EJ STUB / START TUBE
75	717.833	GUIDED SUPP'T
76	733.375	
77	748.917	
78	764.458	
79	780.000	FIXED SUPP'T, ROTATION FREE
80	795.458	
81	810.917	
82	826.375	
83	841.833	GUIDED SUPP'T
84	843.500	END TUBE / START EJ STUB
85	844.083	END EJ STUB / START BELLOWS
86	845.583	END BELLOWS / START EJ STUB
87	846.167	END EJ STUB / START TUBE
88	847.833	GUIDED SUPP'T
89	855.501	
90	863.169	
91	870.837	
92	878.505	RIGID SUPP'T, ROTATION FIXED

SUBJECT RISA-2D MODEL OF BEAM TUBE MODULE, CASE #3 NODE NUMBERS, COORDINATES & DESCRIPTION	OFFICE: NOE		REVISION		REFERENCE NO. 930212
	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 2 OF 2
	DATE 2/28/94	DATE 15 MAR 94	DATE	DATE	5.100.

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
==========================================================================

Units Option      : US Standard

AISC Code Checks : 9th Edition ASD

Shear Deformation: No

P-Delta Effects   : No

Redesign          : No

Edge Forces       : No

A.S.I.F.          : 1.333
```

CALC BY W.C	CHKD BY RJW	REV	BY	
			CHKD	
DATE 3-18-94	DATE 18 MAR 94		DATE	

```
                                      RISA-2D (R) Version 3.01
    CBI Technical Services
                                                                        Page :

                                                                        3/09/94

    LIGO BEAM TUBE -- NATURAL PERIOD MODEL
    130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
    ===========================================================================

    Units Option       : US Standard

    AISC Code Checks : 9th Edition ASD

    Shear Deformation: No

    P-Delta Effects    : No

    Redesign           : No

    Edge Forces        : No

    A.S.I.F.           : 1.333
```

SUBJECT	CBI OFFICE NoE C		REVISION		REFERENCE NO.
	MADE BY AJC	CHKD BY KJW	MADE BY	CHKD BY	SHT ___ OF ___
	DATE 3-18-94	DATE 15 MAR 94	DATE	DATE	

LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT

```
==============================================================================

------------------------------------------------------------------------------
Node                                  Boundary Conditions
 No      X-Coord     Y-Coord      X-dof       Y-dof      Rotation    Temp.
-----------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
  1        0.00        0.00            R           R                  0.00
  2       15.46        0.00                                           0.00
  3       30.92        0.00                                           0.00
  4       46.37        0.00                                           0.00
  5       61.83        0.00                        R                  0.00
  6       62.92        0.00                                           0.00
  7       63.50        0.00                                           0.00
  8       66.17        0.00                                           0.00
  9       66.75        0.00                                           0.00
 10       67.83        0.00                        R                  0.00
 11       83.37        0.00                                           0.00
 12       98.92        0.00                                           0.00
 13      114.46        0.00                                           0.00
 14      130.00        0.00            R           R                  0.00
 15      145.46        0.00                                           0.00
 16      160.92        0.00                                           0.00
 17      176.37        0.00                                           0.00
 18      191.83        0.00                        R                  0.00
 19      192.92        0.00                                           0.00
 20      193.50        0.00                                           0.00
 21      196.17        0.00                                           0.00
 22      196.75        0.00                                           0.00
 23      197.83        0.00                        R                  0.00
 24      213.37        0.00                                           0.00
 25      228.92        0.00                                           0.00
 26      244.46        0.00                                           0.00
 27      260.00        0.00            R           R                  0.00
 28      275.46        0.00                                           0.00
 29      290.92        0.00                                           0.00
 30      306.37        0.00                                           0.00
 31      321.83        0.00                        R                  0.00
 32      322.92        0.00                                           0.00
 33      323.50        0.00                                           0.00
 34      326.17        0.00                                           0.00
 35      326.75        0.00                                           0.00
 36      327.83        0.00                        R                  0.00
 37      343.37        0.00                                           0.00
 38      358.92        0.00                                           0.00
 39      374.46        0.00                                           0.00
 40      390.00        0.00            R           R                  0.00
 41      405.46        0.00                                           0.00
 42      420.92        0.00                                           0.00
 43      436.37        0.00                                           0.00
 44      451.83        0.00                        R                  0.00
 45      452.92        0.00                                           0.00
```

5.102

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=====================================================================

---------------------------------------------------------------------
Node                                  Boundary Conditions
 No      X-Coord    Y-Coord     X-dof      Y-dof      Rotation     Temp.
------------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)-
 91      870.84       0.00                                          0.0
 92      878.51       0.00          R          R           R        0.0
```

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=========================================================================

-------------------------------------------------------------------------
Material        Elastic      Poisson's     Thermal      Weight  Yield Stress
 Label          Modulus        Ratio     Coefficient   Density      (Fy)
---------------(Ksi)-----------------------(F)--------(K/ft3)------(Ksi)----
 1              27000.00      0.30000       0.65000     0.000      19.200
```

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
==============================================================

--------------------------------------------------------------
 Section      Database    Matl.   Area        Moment of   As    y/y
  Label        Shape       Set                 Inertia    Coef
-----------------------------(in^2)---------(in^4)------------
BEAMTUBE                    1     19.19       5731.030   1.20
STUBEND                     1     16.13       4820.000   1.20
EXPJOINT                    1      0.01          1.803   1.20
```

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=============================================================================

-----------------------------------------------------------------------------
     I     J                  I  Releases  J            End Offsets
 No Node  Node   Section     x y z     x y z  Sec  Sway  I       J      Length
----------------------------------------------------------(in)----(in)------(ft)
  1     1 -   2 BEAMTUBE                                                 15.46
  2     2 -   3 BEAMTUBE                                                 15.46
  3     3 -   4 BEAMTUBE                                                 15.45
  4     4 -   5 BEAMTUBE                                                 15.46
  5     5 -   6 BEAMTUBE                                                  1.09
  6     6 -   7 STUBEND                                                   0.58
  7     7 -   8 EXPJOINT                                                  2.67
  8     8 -   9 STUBEND                                                   0.58
  9     9 -  10 BEAMTUBE                                                  1.08
 10    10 -  11 BEAMTUBE                                                 15.54
 11    11 -  12 BEAMTUBE                                                 15.55
 12    12 -  13 BEAMTUBE                                                 15.54
 13    13 -  14 BEAMTUBE                                                 15.54
 14    14 -  15 BEAMTUBE                                                 15.46
 15    15 -  16 BEAMTUBE                                                 15.46
 16    16 -  17 BEAMTUBE                                                 15.45
 17    17 -  18 BEAMTUBE                                                 15.46
 18    18 -  19 BEAMTUBE                                                  1.09
 19    19 -  20 STUBEND                                                   0.58
 20    20 -  21 EXPJOINT                                                  2.67
 21    21 -  22 STUBEND                                                   0.58
 22    22 -  23 BEAMTUBE                                                  1.08
 23    23 -  24 BEAMTUBE                                                 15.54
 24    24 -  25 BEAMTUBE                                                 15.55
 25    25 -  26 BEAMTUBE                                                 15.54
 26    26 -  27 BEAMTUBE                                                 15.54
 27    27 -  28 BEAMTUBE                                                 15.46
 28    28 -  29 BEAMTUBE                                                 15.46
 29    29 -  30 BEAMTUBE                                                 15.45
 30    30 -  31 BEAMTUBE                                                 15.46
 31    31 -  32 BEAMTUBE                                                  1.09
 32    32 -  33 STUBEND                                                   0.58
 33    33 -  34 EXPJOINT                                                  2.67
 34    34 -  35 STUBEND                                                   0.58
 35    35 -  36 BEAMTUBE                                                  1.08
 36    36 -  37 BEAMTUBE                                                 15.5
 37    37 -  38 BEAMTUBE                                                 15.55
 38    38 -  39 BEAMTUBE                                                 15.5
 39    39 -  40 BEAMTUBE                                                 15.5
 40    40 -  41 BEAMTUBE                                                 15.4
 41    41 -  42 BEAMTUBE                                                 15.4
 42    42 -  43 BEAMTUBE                                                 15.4
 43    43 -  44 BEAMTUBE                                                 15.4
 44    44 -  45 BEAMTUBE                                                  1.0
 45    45 -  46 STUBEND                                                   0.5
```

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
==========================================================================

--------------------------------------------------------------------------
     I     J                    I  Releases  J              End Offsets
 No Node  Node    Section     x y z      x y z  Sec   Sway  I       J       Length
----------------------------------------------------------(in)----(in)------(ft)
 46   46 -  47   EXPJOINT                                                   2.67
 47   47 -  48   STUBEND                                                    0.58
 48   48 -  49   BEAMTUBE                                                   1.08
 49   49 -  50   BEAMTUBE                                                  15.54
 50   50 -  51   BEAMTUBE                                                  15.55
 51   51 -  52   BEAMTUBE                                                  15.54
 52   52 -  53   BEAMTUBE                                                  15.54
 53   53 -  54   BEAMTUBE                                                  15.46
 54   54 -  55   BEAMTUBE                                                  15.46
 55   55 -  56   BEAMTUBE                                                  15.45
 56   56 -  57   BEAMTUBE                                                  15.46
 57   57 -  58   BEAMTUBE                                                   1.09
 58   58 -  59   STUBEND                                                    0.58
 59   59 -  60   EXPJOINT                                                   2.67
 60   60 -  61   STUBEND                                                    0.58
 61   61 -  62   BEAMTUBE                                                   1.08
 62   62 -  63   BEAMTUBE                                                  15.54
 63   63 -  64   BEAMTUBE                                                  15.55
 64   64 -  65   BEAMTUBE                                                  15.54
 65   65 -  66   BEAMTUBE                                                  15.54
 66   66 -  67   BEAMTUBE                                                  15.46
 67   67 -  68   BEAMTUBE                                                  15.46
 68   68 -  69   BEAMTUBE                                                  15.45
 69   69 -  70   BEAMTUBE                                                  15.46
 70   70 -  71   BEAMTUBE                                                   1.09
 71   71 -  72   STUBEND                                                    0.58
 72   72 -  73   EXPJOINT                                                   2.67
 73   73 -  74   STUBEND                                                    0.58
 74   74 -  75   BEAMTUBE                                                   1.08
 75   75 -  76   BEAMTUBE                                                  15.54
 76   76 -  77   BEAMTUBE                                                  15.55
 77   77 -  78   BEAMTUBE                                                  15.54
 78   78 -  79   BEAMTUBE                                                  15.54
 79   79 -  80   BEAMTUBE                                                  15.46
 80   80 -  81   BEAMTUBE                                                  15.46
 81   81 -  82   BEAMTUBE                                                  15.45
 82   82 -  83   BEAMTUBE                                                  15.46
 83   83 -  84   BEAMTUBE                                                   1.67
 84   84 -  85   STUBEND                                                    0.58
 85   85 -  86   EXPJOINT                                                   1.50
 86   86 -  87   STUBEND                                                    0.59
 87   87 -  88   BEAMTUBE                                                   1.66
 88   88 -  89   BEAMTUBE                                                   7.67
 89   89 -  90   BEAMTUBE                                                   7.67
 90   90 -  91   BEAMTUBE                                                   7.67
```

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
==============================================================================

------------------------------------------------------------------------------
     I      J                  I  Releases  J              End Offsets
 No Node  Node   Section      x y z     x y z  Sec   Sway  I       J       Length
------------------------------------------------------(in)----(in)------(ft)
 91   91 -  92  BEAMTUBE                                                  7.67
```

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
==========================================================================

--------------------------------------------------------------------------
     I     J          Unbraced Lengths           K Factors     Bending Coefs
 No Node  Node     Lb-in    Lb-out     Lc        In     Out      Cm      Cb
--------------------(ft)-----(ft)-----(ft)-------------------------------------
  1    1 -   2
  2    2 -   3
  3    3 -   4
  4    4 -   5
  5    5 -   6
  6    6 -   7
  7    7 -   8
  8    8 -   9
  9    9 -  10
 10   10 -  11
 11   11 -  12
 12   12 -  13
 13   13 -  14
 14   14 -  15
 15   15 -  16
 16   16 -  17
 17   17 -  18
 18   18 -  19
 19   19 -  20
 20   20 -  21
 21   21 -  22
 22   22 -  23
 23   23 -  24
 24   24 -  25
 25   25 -  26
 26   26 -  27
 27   27 -  28
 28   28 -  29
 29   29 -  30
 30   30 -  31
 31   31 -  32
 32   32 -  33
 33   33 -  34
 34   34 -  35
 35   35 -  36
 36   36 -  37
 37   37 -  38
 38   38 -  39
 39   39 -  40
 40   40 -  41
 41   41 -  42
 42   42 -  43
 43   43 -  44
 44   44 -  45
 45   45 -  46
```

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
==============================================================================

------------------------------------------------------------------------------
     I      J            Unbraced Lengths           K Factors     Bending Coefs
 No Node   Node       Lb-in     Lb-out     Lc       In     Out      Cm      Cb
-------------------(ft)-----(ft)-----(ft)-------------------------------------
 46   46 -  47
 47   47 -  48
 48   48 -  49
 49   49 -  50
 50   50 -  51
 51   51 -  52
 52   52 -  53
 53   53 -  54
 54   54 -  55
 55   55 -  56
 56   56 -  57
 57   57 -  58
 58   58 -  59
 59   59 -  60
 60   60 -  61
 61   61 -  62
 62   62 -  63
 63   63 -  64
 64   64 -  65
 65   65 -  66
 66   66 -  67
 67   67 -  68
 68   68 -  69
 69   69 -  70
 70   70 -  71
 71   71 -  72
 72   72 -  73
 73   73 -  74
 74   74 -  75
 75   75 -  76
 76   76 -  77
 77   77 -  78
 78   78 -  79
 79   79 -  80
 80   80 -  81
 81   81 -  82
 82   82 -  83
 83   83 -  84
 84   84 -  85
 85   85 -  86
 86   86 -  87
 87   87 -  88
 88   88 -  89
 89   89 -  90
 90   90 -  91
```

5.111

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

----------------------------------------------------------------------------
     I      J           Unbraced Lengths          K Factors    Bending Coefs
 No Node  Node      Lb-in    Lb-out     Lc        In     Out     Cm     Cb
--------------------(ft)-----(ft)-----(ft)-----------------------------------
 91   91 -  92
```

```
3/09/94

LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------
        BLC          Basic Load Case                      Load Totals
        No.            Description                   Nodal   Point   Dist.
---------------------------------------------------------------------------
          1  SELF WEIGHT + INSULATION                                  91
```

5.113

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

Member Distributed Loads,BLC 1: SELF WEIGHT + INSULATION
----------------------------------------------------------------------------
 Memb   I     J          Start        End            Start       End
  No   Node  Node  Dir  Magnitude    Magnitude       Location    Location
-----------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
   1     1 -   2    Y    -0.091       -0.091          0.000      15.460
   2     2 -   3    Y    -0.091       -0.091          0.000      15.460
   3     3 -   4    Y    -0.091       -0.091          0.000      15.449
   4     4 -   5    Y    -0.091       -0.091          0.000      15.460
   5     5 -   6    Y    -0.091       -0.091          0.000       1.089
   6     6 -   7    Y    -0.091       -0.091          0.000       0.580
   7     7 -   8    Y    -0.091       -0.091          0.000       2.669
   8     8 -   9    Y    -0.091       -0.091          0.000       0.580
   9     9 -  10    Y    -0.091       -0.091          0.000       1.080
  10    10 -  11    Y    -0.091       -0.091          0.000      15.540
  11    11 -  12    Y    -0.091       -0.091          0.000      15.550
  12    12 -  13    Y    -0.091       -0.091          0.000      15.539
  13    13 -  14    Y    -0.091       -0.091          0.000      15.540
  14    14 -  15    Y    -0.091       -0.091          0.000      15.460
  15    15 -  16    Y    -0.091       -0.091          0.000      15.459
  16    16 -  17    Y    -0.091       -0.091          0.000      15.449
  17    17 -  18    Y    -0.091       -0.091          0.000      15.460
  18    18 -  19    Y    -0.091       -0.091          0.000       1.089
  19    19 -  20    Y    -0.091       -0.091          0.000       0.580
  20    20 -  21    Y    -0.091       -0.091          0.000       2.669
  21    21 -  22    Y    -0.091       -0.091          0.000       0.580
  22    22 -  23    Y    -0.091       -0.091          0.000       1.080
  23    23 -  24    Y    -0.091       -0.091          0.000      15.539
  24    24 -  25    Y    -0.091       -0.091          0.000      15.550
  25    25 -  26    Y    -0.091       -0.091          0.000      15.540
  26    26 -  27    Y    -0.091       -0.091          0.000      15.539
  27    27 -  28    Y    -0.091       -0.091          0.000      15.459
  28    28 -  29    Y    -0.091       -0.091          0.000      15.460
  29    29 -  30    Y    -0.091       -0.091          0.000      15.449
  30    30 -  31    Y    -0.091       -0.091          0.000      15.459
  31    31 -  32    Y    -0.091       -0.091          0.000       1.090
  32    32 -  33    Y    -0.091       -0.091          0.000       0.579
  33    33 -  34    Y    -0.091       -0.091          0.000       2.670
  34    34 -  35    Y    -0.091       -0.091          0.000       0.579
  35    35 -  36    Y    -0.091       -0.091          0.000       1.079
  36    36 -  37    Y    -0.091       -0.091          0.000      15.540
  37    37 -  38    Y    -0.091       -0.091          0.000      15.550
  38    38 -  39    Y    -0.091       -0.091          0.000      15.539
  39    39 -  40    Y    -0.091       -0.091          0.000      15.540
  40    40 -  41    Y    -0.091       -0.091          0.000      15.459
  41    41 -  42    Y    -0.091       -0.091          0.000      15.460
  42    42 -  43    Y    -0.091       -0.091          0.000      15.449
  43    43 -  44    Y    -0.091       -0.091          0.000      15.459
  44    44 -  45    Y    -0.091       -0.091          0.000       1.090
```

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LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
==========================================================================

--------------------------------------------------------------------------
 Memb   I      J            Start        End           Start       End
  No   Node   Node   Dir  Magnitude    Magnitude      Location    Location
-----------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
  45    45  -  46     Y     -0.091       -0.091         0.000       0.579
  46    46  -  47     Y     -0.091       -0.091         0.000       2.670
  47    47  -  48     Y     -0.091       -0.091         0.000       0.579
  48    48  -  49     Y     -0.091       -0.091         0.000       1.079
  49    49  -  50     Y     -0.091       -0.091         0.000      15.540
  50    50  -  51     Y     -0.091       -0.091         0.000      15.550
  51    51  -  52     Y     -0.091       -0.091         0.000      15.539
  52    52  -  53     Y     -0.091       -0.091         0.000      15.540
  53    53  -  54     Y     -0.091       -0.091         0.000      15.460
  54    54  -  55     Y     -0.091       -0.091         0.000      15.459
  55    55  -  56     Y     -0.091       -0.091         0.000      15.450
  56    56  -  57     Y     -0.091       -0.091         0.000      15.460
  57    57  -  58     Y     -0.091       -0.091         0.000       1.089
  58    58  -  59     Y     -0.091       -0.091         0.000       0.580
  59    59  -  60     Y     -0.091       -0.091         0.000       2.669
  60    60  -  61     Y     -0.091       -0.091         0.000       0.580
  61    61  -  62     Y     -0.091       -0.091         0.000       1.080
  62    62  -  63     Y     -0.091       -0.091         0.000      15.539
  63    63  -  64     Y     -0.091       -0.091         0.000      15.549
  64    64  -  65     Y     -0.091       -0.091         0.000      15.540
  65    65  -  66     Y     -0.091       -0.091         0.000      15.539
  66    66  -  67     Y     -0.091       -0.091         0.000      15.460
  67    67  -  68     Y     -0.091       -0.091         0.000      15.459
  68    68  -  69     Y     -0.091       -0.091         0.000      15.449
  69    69  -  70     Y     -0.091       -0.091         0.000      15.460
  70    70  -  71     Y     -0.091       -0.091         0.000       1.089
  71    71  -  72     Y     -0.091       -0.091         0.000       0.580
  72    72  -  73     Y     -0.091       -0.091         0.000       2.669
  73    73  -  74     Y     -0.091       -0.091         0.000       0.580
  74    74  -  75     Y     -0.091       -0.091         0.000       1.080
  75    75  -  76     Y     -0.091       -0.091         0.000      15.539
  76    76  -  77     Y     -0.091       -0.091         0.000      15.550
  77    77  -  78     Y     -0.091       -0.091         0.000      15.540
  78    78  -  79     Y     -0.091       -0.091         0.000      15.539
  79    79  -  80     Y     -0.091       -0.091         0.000      15.460
  80    80  -  81     Y     -0.091       -0.091         0.000      15.459
  81    81  -  82     Y     -0.091       -0.091         0.000      15.449
  82    82  -  83     Y     -0.091       -0.091         0.000      15.460
  83    83  -  84     Y     -0.091       -0.091         0.000       1.669
  84    84  -  85     Y     -0.091       -0.091         0.000       0.580
  85    85  -  86     Y     -0.091       -0.091         0.000       1.500
  86    86  -  87     Y     -0.091       -0.091         0.000       0.589
  87    87  -  88     Y     -0.091       -0.091         0.000       1.660
  88    88  -  89     Y     -0.091       -0.091         0.000       7.669
  89    89  -  90     Y     -0.091       -0.091         0.000       7.669
```

5.5

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LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------
 Memb   I      J             Start         End            Start        End
  No  Node   Node  Dir    Magnitude     Magnitude       Location    Location
-------------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)---
  90    90 -  91    Y       -0.091        -0.091          0.000        7.670
  91    91 -  92    Y       -0.091        -0.091          0.000        7.669
```

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LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------
Load Combination     Self Wt  BLC     BLC     BLC     BLC     BLC           W  E
No.  Description     Dir Fac   Fac     Fac     Fac     Fac     Fac    DYNA  S  V
---------------------------------------------------------------------------
 1 DEAD LD + INSUL'N          1 1
```

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                                                                3/09/94

LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

Dynamic Analysis Data

Number of modes (frequencies)  :   15
Basic Load Case for masses     :   1
BLC mass direction of action   :   Y only
Acceleration of Gravity        :   32.20 ft/sec**2

 Load Combination is 1 :   DEAD LD + INSUL'N
 Nodal Displacements
---------------------------------------------------------------------------

     Node            Global X             Global Y            Rotation
---------------------(in)-----------------(in)----------------(rad)---------
       1            0.00000             -0.00000             -0.00082
       2            0.00000             -0.13569             -0.00056
       3            0.00000             -0.19000              0.00000
       4            0.00000             -0.13484              0.00056
       5            0.00000             -0.00000              0.00081
       6            0.00000              0.01058              0.00081
       7            0.00000              0.01621              0.00081
       8            0.00000              0.00858             -0.00043
       9            0.00000              0.00558             -0.00043
      10            0.00000             -0.00000             -0.00043
      11            0.00000             -0.06767             -0.00024
      12            0.00000             -0.08041              0.00011
      13            0.00000             -0.03810              0.00029
      14            0.00000             -0.00000              0.00001
      15            0.00000             -0.03509             -0.00028
      16            0.00000             -0.07566             -0.00010
      17            0.00000             -0.06390              0.00023
      18            0.00000             -0.00000              0.00041
      19            0.00000              0.00531              0.00041
      20            0.00000              0.00814              0.00041
      21            0.00000              0.00834             -0.00042
      22            0.00000              0.00543             -0.00042
      23            0.00000             -0.00000             -0.00042
      24            0.00000             -0.06633             -0.00024
      25            0.00000             -0.07900              0.00010
      26            0.00000             -0.03734              0.00029
      27            0.00000             -0.00000              0.00000
      28            0.00000             -0.03549             -0.00028
      29            0.00000             -0.07612             -0.00010
      30            0.00000             -0.06418              0.00023
      31            0.00000             -0.00000              0.00041
      32            0.00000              0.00533              0.00041
      33            0.00000              0.00817              0.00041
      34            0.00000              0.00834             -0.00042
      35            0.00000              0.00543             -0.00042
      36            0.00000             -0.00000             -0.00042
```

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LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=======================================================================

-----------------------------------------------------------------------

     Node          Global X             Global Y            Rotation
--------------------(in)----------------(in)---------------(rad)--------
      37          0.00000             -0.06633             -0.00024
      38          0.00000             -0.07901              0.00010
      39          0.00000             -0.03735              0.00029
      40          0.00000             -0.00000              0.00000
      41          0.00000             -0.03549             -0.00028
      42          0.00000             -0.07611             -0.00010
      43          0.00000             -0.06418              0.00023
      44          0.00000             -0.00000              0.00041
      45          0.00000              0.00533              0.00041
      46          0.00000              0.00817              0.00041
      47          0.00000              0.00834             -0.00042
      48          0.00000              0.00543             -0.00042
      49          0.00000             -0.00000             -0.00042
      50          0.00000             -0.06633             -0.00024
      51          0.00000             -0.07901              0.00010
      52          0.00000             -0.03735              0.00029
      53          0.00000             -0.00000              0.00000
      54          0.00000             -0.03549             -0.00028
      55          0.00000             -0.07611             -0.00010
      56          0.00000             -0.06418              0.00023
      57          0.00000             -0.00000              0.00041
      58          0.00000              0.00533              0.00041
      59          0.00000              0.00817              0.00041
      60          0.00000              0.00834             -0.00042
      61          0.00000              0.00543             -0.00042
      62          0.00000             -0.00000             -0.00042
      63          0.00000             -0.06633             -0.00024
      64          0.00000             -0.07900              0.00010
      65          0.00000             -0.03734              0.00029
      66          0.00000             -0.00000              0.00000
      67          0.00000             -0.03550             -0.00028
      68          0.00000             -0.07614             -0.00010
      69          0.00000             -0.06421              0.00023
      70          0.00000             -0.00000              0.00041
      71          0.00000              0.00534              0.00041
      72          0.00000              0.00818              0.00041
      73          0.00000              0.00848             -0.00043
      74          0.00000              0.00552             -0.00043
      75          0.00000             -0.00000             -0.00043
      76          0.00000             -0.06760             -0.00024
      77          0.00000             -0.08105              0.00010
      78          0.00000             -0.03914              0.00030
      79          0.00000             -0.00000              0.00002
      80          0.00000             -0.03216             -0.00026
      81          0.00000             -0.06997             -0.00009
```

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LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===========================================================================

---------------------------------------------------------------------------

     Node            Global X              Global Y           Rotation
---------------------(in)----------------(in)---------------(rad)---------
       82             0.00000              -0.05829              0.00022
       83             0.00000              -0.00000              0.00036
       84             0.00000               0.00710              0.00035
       85             0.00000               0.00955              0.00035
       86             0.00000               0.00192             -0.00007
       87             0.00000               0.00141             -0.00007
       88             0.00000              -0.00000             -0.00007
       89             0.00000              -0.00490             -0.00003
       90             0.00000              -0.00553              0.00002
       91             0.00000              -0.00251              0.00004
       92             0.00000              -0.00000              0.00000
```

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LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
===============================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 Spring Reactions
-------------------------------------------------------------------------------

    Node         Global X              Global Y             Moment
---------------------(K)------------------(K)---------------(K-ft)---------
       1          0.00000              2.79271              0.00000
       5          0.00000              3.35017              0.00000
      10          0.00000              2.15310              0.00000
      14          0.00000              7.04581              0.00000
      18          0.00000              2.38115              0.00000
      23          0.00000              2.41705              0.00000
      27          0.00000              7.02891              0.00000
      31          0.00000              2.38504              0.00000
      36          0.00000              2.41599              0.00000
      40          0.00000              7.02898              0.00000
      44          0.00000              2.38502              0.00000
      49          0.00000              2.41600              0.00000
      53          0.00000              7.02898              0.00000
      57          0.00000              2.38504              0.00000
      62          0.00000              2.41593              0.00000
      66          0.00000              7.02928              0.00000
      70          0.00000              2.38036              0.00000
      75          0.00000              2.43302              0.00000
      79          0.00000              6.95421              0.00000
      83          0.00000              3.46843              0.00000
      88          0.00000              0.17960              0.00000
      92          0.00000              1.86962            -11.98205
  Totals          0.00000             79.94441            -11.98205
```

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LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=============================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 Member End Forces
-----------------------------------------------------------------------------
    Nodes     ========== I-End ==========       ========== J-End ==========
No  I   J     Axial      Shear     Moment       Axial      Shear     Moment
--------------(K)---------(K)------(K-ft)-------(K)---------(K)------(K-ft)--
 1   1-  2     0.00       2.79      -0.00        0.00      -1.39      32.30
 2   2-  3     0.00       1.39     -32.30        0.00       0.02      42.85
 3   3-  4     0.00      -0.02     -42.85        0.00       1.43      31.67
 4   4-  5     0.00      -1.43     -31.67        0.00       2.83      -1.27
 5   5-  6     0.00       0.52       1.27        0.00      -0.42      -0.76
 6   6-  7     0.00       0.42       0.76        0.00      -0.36      -0.54
 7   7-  8     0.00       0.36       0.54        0.00      -0.12       0.11
 8   8-  9     0.00       0.12      -0.11        0.00      -0.07       0.17
 9   9- 10     0.00       0.07      -0.17        0.00       0.03       0.19
10  10- 11     0.00       2.12      -0.19        0.00      -0.71      22.20
11  11- 12     0.00       0.71     -22.20        0.00       0.71      22.23
12  12- 13     0.00      -0.71     -22.23        0.00       2.12       0.27
13  13- 14     0.00      -2.12      -0.27        0.00       3.53     -43.66
14  14- 15     0.00       3.51      43.66        0.00      -2.10      -0.24
15  15- 16     0.00       2.10       0.24        0.00      -0.70      21.43
16  16- 17     0.00       0.70     -21.43        0.00       0.71      21.35
17  17- 18     0.00      -0.71     -21.35        0.00       2.11      -0.47
18  18- 19     0.00       0.27       0.47        0.00      -0.17      -0.23
19  19- 20     0.00       0.17       0.23        0.00      -0.11      -0.15
20  20- 21     0.00       0.11       0.15        0.00       0.13      -0.17
21  21- 22     0.00      -0.13       0.17        0.00       0.18      -0.26
22  22- 23     0.00      -0.18       0.26        0.00       0.28      -0.51
23  23- 24     0.00       2.14       0.51        0.00      -0.72      21.72
24  24- 25     0.00       0.72     -21.72        0.00       0.69      21.97
25  25- 26     0.00      -0.69     -21.97        0.00       2.11       0.23
26  26- 27     0.00      -2.11      -0.23        0.00       3.52     -43.48
27  27- 28     0.00       3.51      43.48        0.00      -2.10      -0.11
28  28- 29     0.00       2.10       0.11        0.00      -0.70      21.51
29  29- 30     0.00       0.70     -21.51        0.00       0.71      21.39
30  30- 31     0.00      -0.71     -21.39        0.00       2.12      -0.47
31  31- 32     0.00       0.27       0.47        0.00      -0.17      -0.23
32  32- 33     0.00       0.17       0.23        0.00      -0.12      -0.15
33  33- 34     0.00       0.12       0.15        0.00       0.13      -0.17
34  34- 35     0.00      -0.13       0.17        0.00       0.18      -0.26
35  35- 36     0.00      -0.18       0.26        0.00       0.28      -0.50
36  36- 37     0.00       2.14       0.50        0.00      -0.72      21.72
37  37- 38     0.00       0.72     -21.72        0.00       0.69      21.97
38  38- 39     0.00      -0.69     -21.97        0.00       2.11       0.23
39  39- 40     0.00      -2.11      -0.23        0.00       3.52     -43.48
40  40- 41     0.00       3.51      43.48        0.00      -2.10      -0.11
41  41- 42     0.00       2.10       0.11        0.00      -0.70      21.51
42  42- 43     0.00       0.70     -21.51        0.00       0.71      21.39
43  43- 44     0.00      -0.71     -21.39        0.00       2.12      -0.47
```

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                                                                 3/09/94

LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=========================================================================

-------------------------------------------------------------------------
     Nodes     ========== I-End ==========       ========== J-End =========
No   I   J     Axial       Shear     Moment      Axial       Shear     Moment
--------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
44   44- 45     0.00        0.27       0.47       0.00       -0.17      -0.2
45   45- 46     0.00        0.17       0.23       0.00       -0.12      -0.1
46   46- 47     0.00        0.12       0.15       0.00        0.13      -0.1
47   47- 48     0.00       -0.13       0.17       0.00        0.18      -0.2
48   48- 49     0.00       -0.18       0.26       0.00        0.28      -0.5
49   49- 50     0.00        2.14       0.50       0.00       -0.72      21.7
50   50- 51     0.00        0.72     -21.72       0.00        0.69      21.9
51   51- 52     0.00       -0.69     -21.97       0.00        2.11       0.2
52   52- 53     0.00       -2.11      -0.23       0.00        3.52     -43.4
53   53- 54     0.00        3.51      43.48       0.00       -2.10      -0.1
54   54- 55     0.00        2.10       0.11       0.00       -0.70      21.5
55   55- 56     0.00        0.70     -21.51       0.00        0.71      21.3
56   56- 57     0.00       -0.71     -21.39       0.00        2.12      -0.4
57   57- 58     0.00        0.27       0.47       0.00       -0.17      -0.2
58   58- 59     0.00        0.17       0.23       0.00       -0.12      -0.1
59   59- 60     0.00        0.12       0.15       0.00        0.13      -0.1
60   60- 61     0.00       -0.13       0.17       0.00        0.18      -0.2
61   61- 62     0.00       -0.18       0.26       0.00        0.28      -0.5
62   62- 63     0.00        2.14       0.50       0.00       -0.72      21.7
63   63- 64     0.00        0.72     -21.72       0.00        0.69      21.9
64   64- 65     0.00       -0.69     -21.97       0.00        2.11       0.2
65   65- 66     0.00       -2.11      -0.23       0.00        3.52     -43.4
66   66- 67     0.00        3.51      43.49       0.00       -2.10      -0.1
67   67- 68     0.00        2.10       0.11       0.00       -0.70      21.5
68   68- 69     0.00        0.70     -21.52       0.00        0.71      21.4
69   69- 70     0.00       -0.71     -21.40       0.00        2.12      -0.4
70   70- 71     0.00        0.26       0.46       0.00       -0.16      -0.2
71   71- 72     0.00        0.16       0.23       0.00       -0.11      -0.1
72   72- 73     0.00        0.11       0.15       0.00        0.13      -0.1
73   73- 74     0.00       -0.13       0.17       0.00        0.18      -0.2
74   74- 75     0.00       -0.18       0.27       0.00        0.28      -0.5
75   75- 76     0.00        2.15       0.52       0.00       -0.74      21.9
76   76- 77     0.00        0.74     -21.91       0.00        0.68      22.3
77   77- 78     0.00       -0.68     -22.35       0.00        2.09       0.8
78   78- 79     0.00       -2.09      -0.80       0.00        3.51     -42.7
79   79- 80     0.00        3.45      42.71       0.00       -2.04      -0.3
80   80- 81     0.00        2.04       0.30       0.00       -0.63      20.3
81   81- 82     0.00        0.63     -20.36       0.00        0.77      19.2
82   82- 83     0.00       -0.77     -19.28       0.00        2.18      -3.5
83   83- 84     0.00        1.29       3.54       0.00       -1.14      -1.5
84   84- 85     0.00        1.14       1.52       0.00       -1.08      -0.8
85   85- 86     0.00        1.08       0.87       0.00       -0.95       0.6
36   86- 87     0.00        0.95      -0.65       0.00       -0.89       1.1
87   87- 88     0.00        0.89      -1.19       0.00       -0.74       2.5
88   88- 89     0.00        0.92      -2.55       0.00       -0.22       6.9
```

5.123

```
                                                               3/09/94

LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=======================================================================

-----------------------------------------------------------------------
    Nodes     ========== I-End ==========      ========== J-End =========
No  I   J     Axial      Shear      Moment       Axial      Shear     Moment
--------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
89  89- 90     0.00       0.22      -6.95        0.00       0.47       5.9
90  90- 91     0.00      -0.47      -5.99        0.00       1.17      -0.3
91  91- 92     0.00      -1.17       0.32        0.00       1.87     -11.9
```

5.124

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
=============================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 AISC Code Checks
-----------------------------------------------------------------------------
     Nodes                             Member Quarter Points
 No   I   J   Maximum      0       1/4      1/2       3/4       L        Shear
-----------------------------------------------------------------------------

  1   1-  2                         - Not Calculated -
  2   2-  3                         - Not Calculated -
  3   3-  4                         - Not Calculated -
  4   4-  5                         - Not Calculated -
  5   5-  6                         - Not Calculated -
  6   6-  7                         - Not Calculated -
  7   7-  8                         - Not Calculated -
  8   8-  9                         - Not Calculated -
  9   9- 10                         - Not Calculated -
 10  10- 11                         - Not Calculated -
 11  11- 12                         - Not Calculated -
 12  12- 13                         - Not Calculated -
 13  13- 14                         - Not Calculated -
 14  14- 15                         - Not Calculated -
 15  15- 16                         - Not Calculated -
 16  16- 17                         - Not Calculated -
 17  17- 18                         - Not Calculated -
 18  18- 19                         - Not Calculated -
 19  19- 20                         - Not Calculated -
 20  20- 21                         - Not Calculated -
 21  21- 22                         - Not Calculated -
 22  22- 23                         - Not Calculated -
 23  23- 24                         - Not Calculated -
 24  24- 25                         - Not Calculated -
 25  25- 26                         - Not Calculated -
 26  26- 27                         - Not Calculated -
 27  27- 28                         - Not Calculated -
 28  28- 29                         - Not Calculated -
 29  29- 30                         - Not Calculated -
 30  30- 31                         - Not Calculated -
 31  31- 32                         - Not Calculated -
 32  32- 33                         - Not Calculated -
 33  33- 34                         - Not Calculated -
 34  34- 35                         - Not Calculated -
 35  35- 36                         - Not Calculated -
 36  36- 37                         - Not Calculated -
 37  37- 38                         - Not Calculated -
 38  38- 39                         - Not Calculated -
 39  39- 40                         - Not Calculated -
 40  40- 41                         - Not Calculated -
 41  41- 42                         - Not Calculated -
 42  42- 43                         - Not Calculated -
 43  43- 44                         - Not Calculated -
```

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
============================================================================

----------------------------------------------------------------------------
     Nodes                           Member Quarter Points
 No   I   J   Maximum      0         1/4      1/2         3/4       L        Shear
----------------------------------------------------------------------------
 44  44- 45                           - Not Calculated -
 45  45- 46                           - Not Calculated -
 46  46- 47                           - Not Calculated -
 47  47- 48                           - Not Calculated -
 48  48- 49                           - Not Calculated -
 49  49- 50                           - Not Calculated -
 50  50- 51                           - Not Calculated -
 51  51- 52                           - Not Calculated -
 52  52- 53                           - Not Calculated -
 53  53- 54                           - Not Calculated -
 54  54- 55                           - Not Calculated -
 55  55- 56                           - Not Calculated -
 56  56- 57                           - Not Calculated -
 57  57- 58                           - Not Calculated -
 58  58- 59                           - Not Calculated -
 59  59- 60                           - Not Calculated -
 60  60- 61                           - Not Calculated -
 61  61- 62                           - Not Calculated -
 62  62- 63                           - Not Calculated -
 63  63- 64                           - Not Calculated -
 64  64- 65                           - Not Calculated -
 65  65- 66                           - Not Calculated -
 66  66- 67                           - Not Calculated -
 67  67- 68                           - Not Calculated -
 68  68- 69                           - Not Calculated -
 69  69- 70                           - Not Calculated -
 70  70- 71                           - Not Calculated -
 71  71- 72                           - Not Calculated -
 72  72- 73                           - Not Calculated -
 73  73- 74                           - Not Calculated -
 74  74- 75                           - Not Calculated -
 75  75- 76                           - Not Calculated -
 76  76- 77                           - Not Calculated -
 77  77- 78                           - Not Calculated -
 78  78- 79                           - Not Calculated -
 79  79- 80                           - Not Calculated -
 80  80- 81                           - Not Calculated -
 81  81- 82                           - Not Calculated -
 82  82- 83                           - Not Calculated -
 83  83- 84                           - Not Calculated -
 84  84- 85                           - Not Calculated -
 85  85- 86                           - Not Calculated -
 86  86- 87                           - Not Calculated -
 87  87- 88                           - Not Calculated -
 88  88- 89                           - Not Calculated -
```

```
LIGO BEAM TUBE - BAKE + SELF WT, LIVINGS
879' LENGTH, SIMPLE SUPPT - FIXED SUPPT
================================================================================

--------------------------------------------------------------------------------
     Nodes                                 Member Quarter Points
 No   I   J    Maximum      0         1/4      1/2        3/4        L        Shear
--------------------------------------------------------------------------------
 89  89- 90                            - Not Calculated -
 90  90- 91                            - Not Calculated -
 91  91- 92                            - Not Calculated -
```

RISA-2D MODEL OF LIGO BEAM TUBE MODULE: CASE #4 NODE NUMBERS
MODEL FOR DETERMINATION OF NATURAL PERIOD
CASE #4: RIGID SUPPORTS AT BOTH ENDS, TOTAL LENGTH = 130'

NODE	X (FT)	DESCRIPTION
1	0.000	FIXED SUPP'T, ROTATION FIXED
2	6.870	
3	13.740	
4	20.610	
5	27.480	
6	34.350	
7	41.220	
8	48.090	
9	54.960	
10	61.830	GUIDED SUPP'T
11	62.920	END TUBE / START EJ STUB
12	63.500	END EJ STUB / START BELLOWS
13	66.170	END BELLOWS / START EJ STUB
14	66.750	END EJ STUB / START TUBE
15	67.830	GUIDED SUPP'T
16	74.740	
17	81.650	
18	88.550	
19	95.460	
20	102.370	
21	109.280	
22	116.180	
23	123.090	
24	130.000	FIXED SUPP'T, ROTATION FIXED

SUBJECT RISA-2D MODEL OF BEAM TUBE MODULE, CASE #4 NODE NUMBERS, COORDINATES & DESCRIPTION	OFFICE: NOE		REVISION		REFERENCE NO. 930212
	MADE BY WJC	CHKD [illegible]	MADE BY	CHKD BY	SHT 1 OF 1
	DATE 3/9/94	DATE [illegible]	DATE	DATE	5.128

```
                                                                       3/09/94

LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------
Node                                    Boundary Conditions
 No       X-Coord      Y-Coord      X-dof        Y-dof      Rotation     Temp
----------(ft)--------(ft)-----(in,K/in)----(in,K/in)---(r,K-ft/r)-----(F)
  1        0.00         0.00          R            R           R         0.0
  2        6.87         0.00                                             0.0
  3       13.74         0.00                                             0.0
  4       20.61         0.00                                             0.0
  5       27.48         0.00                                             0.0
  6       34.35         0.00                                             0.0
  7       41.22         0.00                                             0.0
  8       48.09         0.00                                             0.0
  9       54.96         0.00                                             0.0
 10       61.83         0.00                       R                     0.0
 11       62.92         0.00                                             0.0
 12       63.50         0.00                                             0.0
 13       66.17         0.00                                             0.0
 14       66.75         0.00                                             0.0
 15       67.83         0.00                       R                     0.0
 16       74.74         0.00                                             0.0
 17       81.65         0.00                                             0.0
 18       88.55         0.00                                             0.0
 19       95.46         0.00                                             0.0
 20      102.37         0.00                                             0.0
 21      109.28         0.00                                             0.0
 22      116.18         0.00                                             0.0
 23      123.09         0.00                                             0.0
 24      130.00         0.00          R            R           R         0.0
```

SUBJECT	CBI OFFICE ____		REVISION		REFERENCE NO.
	MADE BY	CHKD BY	MADE BY	CHKD BY	SHT ___ OF ___
	DATE	DATE	DATE	DATE	

5.133

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
Material        Elastic      Poisson's    Thermal      Weight   Yield Stress
 Label          Modulus        Ratio     Coefficient   Density      (Fy)
----------------(Ksi)-----------------------(F)--------(K/ft3)------(Ksi)----
 1               27000.00     0.30000      0.65000      0.000      19.200
```

```
                                                           3/09/94

LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
=========================================================================

-------------------------------------------------------------------------
  Section       Database      Matl.     Area          Moment of    As    y/y
   Label         Shape        Set                      Inertia    Coef
-----------------------------------(in^2)---------(in^4)-----------------
BEAMTUBE                      1         19.19         5731.030    1.20
STUBEND                       1         16.13         4820.000    1.20
EXPJOINT                      1          0.01            1.803    1.20
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==========================================================================

--------------------------------------------------------------------------
      I     J                    I  Releases  J          End Offsets
 No Node  Node   Section        x y z    x y z  Sec  Sway  I       J       Length
-----------------------------------------------------------(in)----(in)------(ft)
  1    1 -   2  BEAMTUBE                                                    6.87
  2    2 -   3  BEAMTUBE                                                    6.87
  3    3 -   4  BEAMTUBE                                                    6.87
  4    4 -   5  BEAMTUBE                                                    6.87
  5    5 -   6  BEAMTUBE                                                    6.87
  6    6 -   7  BEAMTUBE                                                    6.87
  7    7 -   8  BEAMTUBE                                                    6.87
  8    8 -   9  BEAMTUBE                                                    6.87
  9    9 -  10  BEAMTUBE                                                    6.87
 10   10 -  11  BEAMTUBE                                                    1.09
 11   11 -  12  STUBEND                                                     0.58
 12   12 -  13  EXPJOINT                                                    2.67
 13   13 -  14  STUBEND                                                     0.58
 14   14 -  15  BEAMTUBE                                                    1.08
 15   15 -  16  BEAMTUBE                                                    6.91
 16   16 -  17  BEAMTUBE                                                    6.91
 17   17 -  18  BEAMTUBE                                                    6.90
 18   18 -  19  BEAMTUBE                                                    6.91
 19   19 -  20  BEAMTUBE                                                    6.91
 20   20 -  21  BEAMTUBE                                                    6.91
 21   21 -  22  BEAMTUBE                                                    6.90
 22   22 -  23  BEAMTUBE                                                    6.91
 23   23 -  24  BEAMTUBE                                                    6.91
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==============================================================================

------------------------------------------------------------------------------
     I     J          Unbraced Lengths           K Factors    Bending Coefs
 No Node  Node     Lb-in    Lb-out      Lc       In     Out      Cm      Cb
-------------------(ft)-----(ft)-----(ft)------------------------------------
  1    1 -   2
  2    2 -   3
  3    3 -   4
  4    4 -   5
  5    5 -   6
  6    6 -   7
  7    7 -   8
  8    8 -   9
  9    9 -  10
 10   10 -  11
 11   11 -  12
 12   12 -  13
 13   13 -  14
 14   14 -  15
 15   15 -  16
 16   16 -  17
 17   17 -  18
 18   18 -  19
 19   19 -  20
 20   20 -  21
 21   21 -  22
 22   22 -  23
 23   23 -  24
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
============================================================================

----------------------------------------------------------------------------
       BLC           Basic Load Case                        Load Totals
       No.             Description                   Nodal   Point   Dist.
----------------------------------------------------------------------------
         1  SELF WEIGHT + INSULATION                                    23
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==============================================================================

Member Distributed Loads,BLC 1: SELF WEIGHT + INSULATION
------------------------------------------------------------------------------
 Memb  I     J            Start       End           Start       End
  No  Node  Node  Dir   Magnitude   Magnitude      Location    Location
------------------------(K/ft,F)-----(K/ft,F)---------(ft)---------(ft)----
   1     1 -   2   Y      -0.091      -0.091         0.000       6.870
   2     2 -   3   Y      -0.091      -0.091         0.000       6.870
   3     3 -   4   Y      -0.091      -0.091         0.000       6.869
   4     4 -   5   Y      -0.091      -0.091         0.000       6.870
   5     5 -   6   Y      -0.091      -0.091         0.000       6.869
   6     6 -   7   Y      -0.091      -0.091         0.000       6.870
   7     7 -   8   Y      -0.091      -0.091         0.000       6.869
   8     8 -   9   Y      -0.091      -0.091         0.000       6.870
   9     9 -  10   Y      -0.091      -0.091         0.000       6.869
  10    10 -  11   Y      -0.091      -0.091         0.000       1.089
  11    11 -  12   Y      -0.091      -0.091         0.000       0.580
  12    12 -  13   Y      -0.091      -0.091         0.000       2.669
  13    13 -  14   Y      -0.091      -0.091         0.000       0.580
  14    14 -  15   Y      -0.091      -0.091         0.000       1.080
  15    15 -  16   Y      -0.091      -0.091         0.000       6.909
  16    16 -  17   Y      -0.091      -0.091         0.000       6.910
  17    17 -  18   Y      -0.091      -0.091         0.000       6.900
  18    18 -  19   Y      -0.091      -0.091         0.000       6.909
  19    19 -  20   Y      -0.091      -0.091         0.000       6.910
  20    20 -  21   Y      -0.091      -0.091         0.000       6.909
  21    21 -  22   Y      -0.091      -0.091         0.000       6.900
  22    22 -  23   Y      -0.091      -0.091         0.000       6.909
  23    23 -  24   Y      -0.091      -0.091         0.000       6.910
```

5.136

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
===========================================================================

---------------------------------------------------------------------------
Load Combination     Self Wt  BLC     BLC     BLC     BLC     BLC          W  E
No.  Description     Dir Fac    Fac     Fac     Fac     Fac     Fac   DYNA S  V
---------------------------------------------------------------------------
 1 DEAD LD + INSUL'N          1 1
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
===========================================================================

Dynamic Analysis Data

Number of modes (frequencies)  :   12
Basic Load Case for masses     :   1
BLC mass direction of action   :   Y only
Acceleration of Gravity        :   32.20 ft/sec**2

 Load Combination is 1 :   DEAD LD + INSUL'N
 Nodal Displacements
---------------------------------------------------------------------------

     Node             Global X             Global Y             Rotation
-------------------(in)-----------------(in)----------------(rad)---------
        1              0.00000             -0.00000             -0.00000
        2              0.00000             -0.00938             -0.00020
        3              0.00000             -0.03017             -0.00028
        4              0.00000             -0.05310             -0.00026
        5              0.00000             -0.07112             -0.00017
        6              0.00000             -0.07947             -0.00003
        7              0.00000             -0.07564              0.00012
        8              0.00000             -0.05940              0.00027
        9              0.00000             -0.03275              0.00037
       10              0.00000             -0.00000              0.00041
       11              0.00000              0.00536              0.00041
       12              0.00000              0.00821              0.00041
       13              0.00000              0.00830             -0.00042
       14              0.00000              0.00540             -0.00042
       15              0.00000             -0.00000             -0.00042
       16              0.00000             -0.03348             -0.00038
       17              0.00000             -0.06071             -0.00027
       18              0.00000             -0.07730             -0.00013
       19              0.00000             -0.08122              0.00003
       20              0.00000             -0.07268              0.00017
       21              0.00000             -0.05426              0.00026
       22              0.00000             -0.03085              0.00029
       23              0.00000             -0.00959              0.00021
       24              0.00000             -0.00000              0.00000
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
============================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 Spring Reactions
----------------------------------------------------------------------------

     Node             Global X             Global Y             Moment
----------------------(K)------------------(K)---------------(K-ft)---------
        1              0.00000              3.50498             43.24687
       10              0.00000              2.39166              0.00000
       15              0.00000              2.40941              0.00000
       24              0.00000              3.52396            -43.71775
   Totals              0.00000             11.83000             -0.47088
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
===========================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 Member End Forces
---------------------------------------------------------------------------
    Nodes     ========== I-End ==========        ========== J-End ==========
No  I   J     Axial      Shear     Moment        Axial      Shear     Moment
---------------(K)--------(K)------(K-ft)-------(K)--------(K)------(K-ft)--
 1   1-  2     0.00       3.50      43.25         0.00      -2.88     -21.32
 2   2-  3     0.00       2.88      21.32         0.00      -2.25      -3.68
 3   3-  4     0.00       2.25       3.68         0.00      -1.63       9.66
 4   4-  5     0.00       1.63      -9.66         0.00      -1.00      18.71
 5   5-  6     0.00       1.00     -18.71         0.00      -0.38      23.46
 6   6-  7     0.00       0.38     -23.46         0.00       0.25      23.92
 7   7-  8     0.00      -0.25     -23.92         0.00       0.87      20.08
 8   8-  9     0.00      -0.87     -20.08         0.00       1.50      11.95
 9   9- 10     0.00      -1.50     -11.95         0.00       2.12      -0.48
10  10- 11     0.00       0.27       0.48         0.00      -0.17      -0.24
11  11- 12     0.00       0.17       0.24         0.00      -0.12      -0.15
12  12- 13     0.00       0.12       0.15         0.00       0.12      -0.16
13  13- 14     0.00      -0.12       0.16         0.00       0.18      -0.25
14  14- 15     0.00      -0.18       0.25         0.00       0.28      -0.50
15  15- 16     0.00       2.13       0.50         0.00      -1.50      12.07
16  16- 17     0.00       1.50     -12.07         0.00      -0.88      20.30
17  17- 18     0.00       0.88     -20.30         0.00      -0.25      24.18
18  18- 19     0.00       0.25     -24.18         0.00       0.38      23.72
19  19- 20     0.00      -0.38     -23.72         0.00       1.01      18.91
20  20- 21     0.00      -1.01     -18.91         0.00       1.64       9.76
21  21- 22     0.00      -1.64      -9.76         0.00       2.27      -3.71
22  22- 23     0.00      -2.27       3.71         0.00       2.90     -21.54
23  23- 24     0.00      -2.90      21.54         0.00       3.52     -43.72
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==============================================================================

 Load Combination is 1 :   DEAD LD + INSUL'N
 AISC Code Checks
------------------------------------------------------------------------------
      Nodes                                Member Quarter Points
 No   I    J    Maximum      0        1/4      1/2        3/4        L        Shear
------------------------------------------------------------------------------

  1   1-   2                           - Not Calculated -
  2   2-   3                           - Not Calculated -
  3   3-   4                           - Not Calculated -
  4   4-   5                           - Not Calculated -
  5   5-   6                           - Not Calculated -
  6   6-   7                           - Not Calculated -
  7   7-   8                           - Not Calculated -
  8   8-   9                           - Not Calculated -
  9   9-  10                           - Not Calculated -
 10  10-  11                           - Not Calculated -
 11  11-  12                           - Not Calculated -
 12  12-  13                           - Not Calculated -
 13  13-  14                           - Not Calculated -
 14  14-  15                           - Not Calculated -
 15  15-  16                           - Not Calculated -
 16  16-  17                           - Not Calculated -
 17  17-  18                           - Not Calculated -
 18  18-  19                           - Not Calculated -
 19  19-  20                           - Not Calculated -
 20  20-  21                           - Not Calculated -
 21  21-  22                           - Not Calculated -
 22  22-  23                           - Not Calculated -
 23  23-  24                           - Not Calculated -
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==========================================================================

 Frequencies
--------------------------------------------------------------------------
 Mode
  No.        Frequency (Hz)      Period (Sec)
--------------------------------------------------------------------------
   1              12.43124           0.08044
   2              12.64979           0.07905
   3              40.13626           0.02492
   4              40.60882           0.02463
   5              83.44815           0.01198
   6              84.37569           0.01185
   7             141.78408           0.00705
   8             143.31877           0.00698
   9             213.26871           0.00469
  10             215.61330           0.00464
  11             293.23037           0.00341
  12             296.47407           0.00337
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
===========================================================================

 Mode Shape 1
---------------------------------------------------------------------------

    Node           Global X               Global Y            Rotation
---------------------------------------------------------------------------
       1            0.00000                0.00000             0.00000
       2            0.00000                0.57763             0.01282
       3            0.00000                1.92170             0.01864
       4            0.00000                3.47250             0.01798
       5            0.00000                4.74021             0.01202
       6            0.00000                5.35744             0.00254
       7            0.00000                5.12237            -0.00827
       8            0.00000                4.01954            -0.01814
       9            0.00000                2.21144            -0.02509
      10            0.00000                0.00000            -0.02777
      11            0.00000               -0.36346            -0.02780
      12            0.00000               -0.55702            -0.02782
      13            0.00000               -1.12756             0.05657
      14            0.00000               -0.73376             0.05659
      15            0.00000                0.00000             0.05665
      16            0.00000                4.57149             0.05191
      17            0.00000                8.35349             0.03794
      18            0.00000               10.68467             0.01761
      19            0.00000               11.20956            -0.00493
      20            0.00000                9.94052            -0.02483
      21            0.00000                7.29357            -0.03743
      22            0.00000                4.04456            -0.03894
      23            0.00000                1.21701            -0.02685
      24            0.00000                0.00000            -0.00000
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
===========================================================================

 Mode Shape 2
---------------------------------------------------------------------------

     Node          Global X             Global Y             Rotation
---------------------------------------------------------------------------
        1           0.00000             -0.00000             -0.00000
        2           0.00000             -1.22509             -0.02718
        3           0.00000             -4.06935             -0.03937
        4           0.00000             -7.33777             -0.03777
        5           0.00000             -9.98857             -0.02494
        6           0.00000            -11.24774             -0.00476
        7           0.00000            -10.70232              0.01800
        8           0.00000             -8.34450              0.03841
        9           0.00000             -4.55138              0.05220
       10           0.00000             -0.00000              0.05646
       11           0.00000              0.73763              0.05633
       12           0.00000              1.12949              0.05628
       13           0.00000             -0.51982              0.02602
       14           0.00000             -0.33858              0.02607
       15           0.00000              0.00000              0.02619
       16           0.00000              2.14082              0.02458
       17           0.00000              3.94734              0.01829
       18           0.00000              5.08243              0.00873
       19           0.00000              5.35868             -0.00208
       20           0.00000              4.76997             -0.01173
       21           0.00000              3.50984             -0.01791
       22           0.00000              1.95053             -0.01873
       23           0.00000              0.58785             -0.01296
       24           0.00000              0.00000             -0.00000
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==========================================================================

 Mode Shape 3
--------------------------------------------------------------------------

     Node          Global X            Global Y            Rotation
--------------------------------------------------------------------------
        1          0.00000            -0.00000            -0.00000
        2          0.00000            -0.65967            -0.01319
        3          0.00000            -1.75287            -0.01101
        4          0.00000            -2.20314             0.00108
        5          0.00000            -1.54714             0.01416
        6          0.00000            -0.07368             0.01975
        7          0.00000             1.40277             0.01418
        8          0.00000             2.04047             0.00046
        9          0.00000             1.46824            -0.01363
       10          0.00000             0.00000            -0.02017
       11          0.00000            -0.26483            -0.02031
       12          0.00000            -0.40637            -0.02036
       13          0.00000            -2.15388             0.10805
       14          0.00000            -1.40165             0.10811
       15          0.00000             0.00000             0.10819
       16          0.00000             8.10754             0.07669
       17          0.00000            11.46377            -0.00019
       18          0.00000             8.07413            -0.07737
       19          0.00000            -0.13738            -0.11018
       20          0.00000            -8.46396            -0.08025
       21          0.00000           -12.25883            -0.00736
       22          0.00000            -9.82154             0.06078
       23          0.00000            -3.70977             0.07364
       24          0.00000            -0.00000             0.00000
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
=============================================================================

 Mode Shape 4
-----------------------------------------------------------------------------

    Node           Global X            Global Y             Rotation
-----------------------------------------------------------------------------
      1            0.00000            -0.00000             -0.00000
      2            0.00000            -3.71935             -0.07426
      3            0.00000            -9.84661             -0.06128
      4            0.00000           -12.28895              0.00755
      5            0.00000            -8.47481              0.08102
      6            0.00000            -0.12191              0.11112
      7            0.00000             8.10826              0.07795
      8            0.00000            11.49993             -0.00001
      9            0.00000             8.12221             -0.07741
     10            0.00000             0.00000             -0.10885
     11            0.00000            -1.42279             -0.10871
     12            0.00000            -2.17910             -0.10862
     13            0.00000             0.36679             -0.01830
     14            0.00000             0.23919             -0.01837
     15            0.00000            -0.00000             -0.01855
     16            0.00000            -1.42780             -0.01387
     17            0.00000            -2.05788             -0.00043
     18            0.00000            -1.48557              0.01354
     19            0.00000            -0.02710              0.01976
     20            0.00000             1.47737              0.01463
     21            0.00000             2.18014              0.00158
     22            0.00000             1.75922             -0.01078
     23            0.00000             0.66698             -0.01322
     24            0.00000             0.00000             -0.00000
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==========================================================================

 Mode Shape 5
--------------------------------------------------------------------------

     Node          Global X            Global Y           Rotation
--------------------------------------------------------------------------
        1           0.00000            -0.00000           -0.00000
        2           0.00000            -0.59273           -0.01011
        3           0.00000            -1.12096           -0.00036
        4           0.00000            -0.56747            0.01249
        5           0.00000             0.56994            0.01195
        6           0.00000             1.03629           -0.00194
        7           0.00000             0.31436           -0.01350
        8           0.00000            -0.76304           -0.00954
        9           0.00000            -0.95222            0.00556
       10           0.00000            -0.00000            0.01505
       11           0.00000             0.19866            0.01530
       12           0.00000             0.30547            0.01539
       13           0.00000             3.15350           -0.15831
       14           0.00000             2.05147           -0.15835
       15           0.00000            -0.00000           -0.15817
       16           0.00000           -10.53105           -0.06588
       17           0.00000            -8.84953            0.10150
       18           0.00000             3.03702            0.15148
       19           0.00000            11.41685            0.02646
       20           0.00000             6.55323           -0.13012
       21           0.00000            -6.09813           -0.13966
       22           0.00000           -12.41794            0.00214
       23           0.00000            -6.61926            0.11178
       24           0.00000            -0.00000            0.00000
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
============================================================================

 Mode Shape 6
----------------------------------------------------------------------------

     Node          Global X            Global Y           Rotation
----------------------------------------------------------------------------
        1          0.00000             0.00000            0.00000
        2          0.00000             6.63494            0.11272
        3          0.00000            12.45184            0.00224
        4          0.00000             6.10865           -0.14083
        5          0.00000            -6.57122           -0.13115
        6          0.00000           -11.44514            0.02666
        7          0.00000            -3.04814            0.15270
        8          0.00000             8.88171            0.10222
        9          0.00000            10.55691           -0.06651
       10          0.00000             0.00000           -0.15939
       11          0.00000            -2.08624           -0.15955
       12          0.00000            -3.19652           -0.15948
       13          0.00000             0.26393           -0.01310
       14          0.00000             0.17241           -0.01320
       15          0.00000            -0.00000           -0.01342
       16          0.00000            -0.93900           -0.00631
       17          0.00000            -0.82758            0.00874
       18          0.00000             0.23190            0.01380
       19          0.00000             1.01589            0.00283
       20          0.00000             0.60830           -0.01150
       21          0.00000            -0.52864           -0.01270
       22          0.00000            -1.11234            0.00003
       23          0.00000            -0.59756            0.01005
       24          0.00000            -0.00000            0.00000
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
===============================================================================

 Mode Shape 7
-------------------------------------------------------------------------------

     Node          Global X             Global Y              Rotation
-------------------------------------------------------------------------------
       1           0.00000              0.00000               0.00000
       2           0.00000              0.50134               0.00655
       3           0.00000              0.54213              -0.00646
       4           0.00000             -0.29271              -0.00960
       5           0.00000             -0.57620               0.00416
       6           0.00000              0.18495               0.01033
       7           0.00000              0.61454              -0.00214
       8           0.00000             -0.06063              -0.01070
       9           0.00000             -0.61264               0.00028
      10           0.00000             -0.00000               0.01180
      11           0.00000              0.15706               0.01218
      12           0.00000              0.24228               0.01230
      13           0.00000              4.10133              -0.20628
      14           0.00000              2.66569              -0.20619
      15           0.00000             -0.00000              -0.20490
      16           0.00000            -11.54311              -0.01463
      17           0.00000             -1.81479               0.19775
      18           0.00000             11.26454               0.04951
      19           0.00000              3.87908              -0.18884
      20           0.00000            -10.54197              -0.08309
      21           0.00000             -5.67308               0.17559
      22           0.00000              9.93379               0.12246
      23           0.00000              9.36175              -0.12047
      24           0.00000              0.00000              -0.00000
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==========================================================================

 Mode Shape 7
--------------------------------------------------------------------------

     Node          Global X            Global Y             Rotation
--------------------------------------------------------------------------
        1           0.00000             0.00000              0.00000
        2           0.00000             0.50134              0.00655
        3           0.00000             0.54213             -0.00646
        4           0.00000            -0.29271             -0.00960
        5           0.00000            -0.57620              0.00416
        6           0.00000             0.18495              0.01033
        7           0.00000             0.61454             -0.00214
        8           0.00000            -0.06063             -0.01070
        9           0.00000            -0.61264              0.00028
       10           0.00000            -0.00000              0.01180
       11           0.00000             0.15706              0.01218
       12           0.00000             0.24228              0.01230
       13           0.00000             4.10133             -0.20628
       14           0.00000             2.66569             -0.20619
       15           0.00000            -0.00000             -0.20490
       16           0.00000           -11.54311             -0.01463
       17           0.00000            -1.81479              0.19775
       18           0.00000            11.26454              0.04951
       19           0.00000             3.87908             -0.18884
       20           0.00000           -10.54197             -0.08309
       21           0.00000            -5.67308              0.17559
       22           0.00000             9.93379              0.12246
       23           0.00000             9.36175             -0.12047
       24           0.00000             0.00000             -0.00000
```

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LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==========================================================================

 Mode Shape 8
--------------------------------------------------------------------------

     Node          Global X            Global Y            Rotation
--------------------------------------------------------------------------
       1            0.00000            -0.00000            -0.00000
       2            0.00000            -9.38431            -0.12153
       3            0.00000            -9.96984             0.12333
       4            0.00000             5.69539             0.17696
       5            0.00000            10.56776            -0.08380
       6            0.00000            -3.88538            -0.19039
       7            0.00000           -11.29517             0.04975
       8            0.00000             1.82622             0.19922
       9            0.00000            11.56402            -0.01480
      10            0.00000             0.00000            -0.20650
      11            0.00000            -2.71166            -0.20784
      12            0.00000            -4.15874            -0.20792
      13            0.00000             0.19944            -0.00984
      14            0.00000             0.13055            -0.00996
      15            0.00000            -0.00000            -0.01020
      16            0.00000            -0.62340            -0.00130
      17            0.00000            -0.13407             0.01055
      18            0.00000             0.59353             0.00317
      19            0.00000             0.23093            -0.00999
      20            0.00000            -0.55497            -0.00478
      21            0.00000            -0.31656             0.00930
      22            0.00000             0.52484             0.00672
      23            0.00000             0.50367            -0.00643
      24            0.00000             0.00000            -0.00000
```

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LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
=========================================================================

 Mode Shape 9
-------------------------------------------------------------------------

    Node           Global X            Global Y            Rotation
-------------------------------------------------------------------------
       1            0.00000             0.00000             0.00000
       2            0.00000             0.37991             0.00293
       3            0.00000             0.11234            -0.00763
       4            0.00000            -0.38546            -0.00027
       5            0.00000             0.08190             0.00759
       6            0.00000             0.34716            -0.00343
       7            0.00000            -0.24967            -0.00594
       8            0.00000            -0.22810             0.00626
       9            0.00000             0.35018             0.00271
      10            0.00000             0.00000            -0.00881
      11            0.00000            -0.11900            -0.00932
      12            0.00000            -0.18451            -0.00948
      13            0.00000            -4.88557             0.24663
      14            0.00000            -3.16986             0.24619
      15            0.00000             0.00000             0.24221
      16            0.00000            10.99622            -0.06635
      17            0.00000            -6.09366            -0.19725
      18            0.00000            -8.02079             0.16747
      19            0.00000            10.11072             0.11322
      20            0.00000             2.92311            -0.22441
      21            0.00000           -11.55024             0.00075
      22            0.00000             3.10960             0.22937
      23            0.00000            11.44308            -0.08547
      24            0.00000             0.00000            -0.00000
```

LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS

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==========================================================================

 Mode Shape 10
--------------------------------------------------------------------------

    Node          Global X            Global Y           Rotation
--------------------------------------------------------------------------
       1          0.00000             0.00000            0.00000
       2          0.00000            11.46020            0.08622
       3          0.00000             3.12774           -0.23106
       4          0.00000           -11.58367           -0.00055
       5          0.00000             2.93808            0.22634
       6          0.00000            10.14329           -0.11418
       7          0.00000            -8.03873           -0.16907
       8          0.00000            -6.11189            0.19892
       9          0.00000            11.02250            0.06701
      10          0.00000             0.00000           -0.24457
      11          0.00000            -3.23173           -0.24875
      12          0.00000            -4.96537           -0.24921
      13          0.00000             0.14096           -0.00689
      14          0.00000             0.09255           -0.00702
      15          0.00000            -0.00000           -0.00727
      16          0.00000            -0.37779            0.00170
      17          0.00000             0.17592            0.00685
      18          0.00000             0.28214           -0.00520
      19          0.00000            -0.32399           -0.00411
      20          0.00000            -0.11241            0.00735
      21          0.00000             0.38181            0.00022
      22          0.00000            -0.09459           -0.00765
      23          0.00000            -0.38007            0.00277
      24          0.00000            -0.00000            0.00000
```

```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
=============================================================================

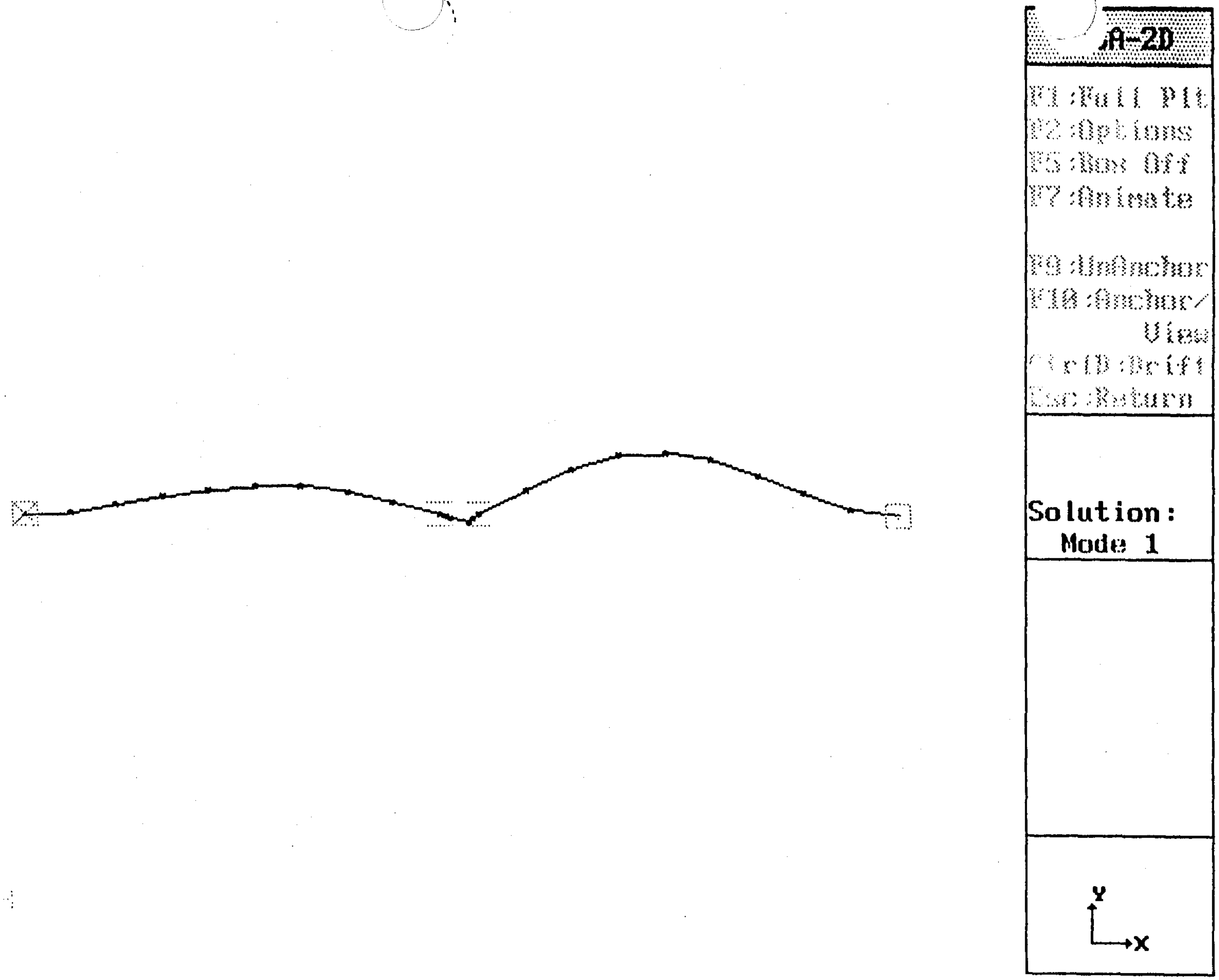
 Mode Shape 11
-----------------------------------------------------------------------------

     Node          Global X             Global Y             Rotation
-----------------------------------------------------------------------------
        1           0.00000             -0.00000             -0.00000
        2           0.00000             -0.25078             -0.00022
        3           0.00000              0.09889              0.00448
        4           0.00000              0.12064             -0.00420
        5           0.00000             -0.23419              0.00020
        6           0.00000              0.13669              0.00399
        7           0.00000              0.08368             -0.00459
        8           0.00000             -0.22949              0.00104
        9           0.00000              0.16272              0.00330
       10           0.00000             -0.00000             -0.00588
       11           0.00000             -0.08124             -0.00647
       12           0.00000             -0.12698             -0.00665
       13           0.00000             -5.23401              0.26578
       14           0.00000             -3.38645              0.26471
       15           0.00000              0.00000              0.25628
       16           0.00000              8.99656             -0.14467
       17           0.00000            -10.95015             -0.07377
       18           0.00000              3.17646              0.23055
       19           0.00000              7.38280             -0.18422
       20           0.00000            -11.47176             -0.02364
       21           0.00000              5.49324              0.21043
       22           0.00000              5.18858             -0.21563
       23           0.00000            -12.34592              0.00698
       24           0.00000             -0.00000              0.00000
```

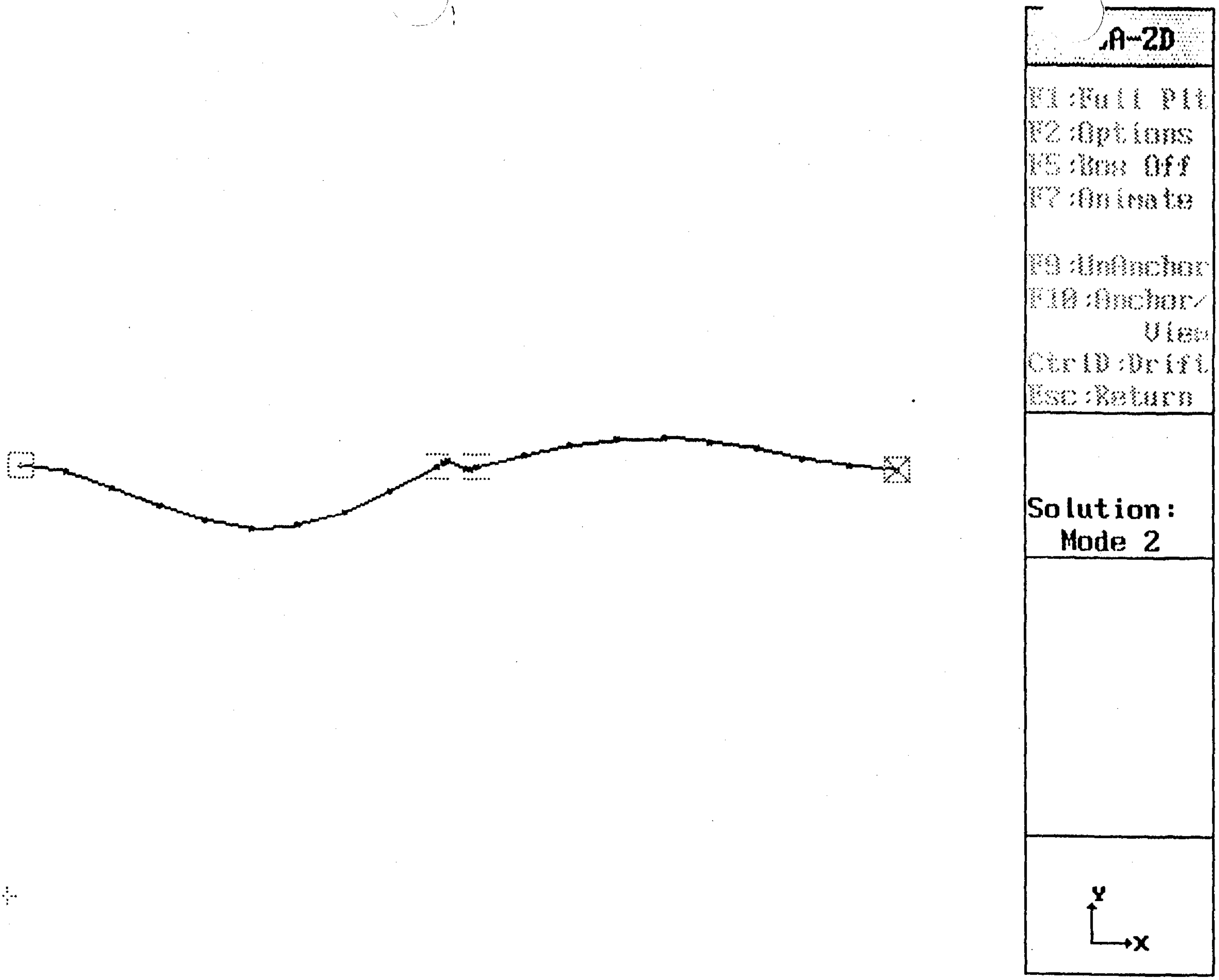
```
LIGO BEAM TUBE -- NATURAL PERIOD MODEL
130' LENGTH, FIXED SUPPORTS @ BOTH ENDS
==========================================================================

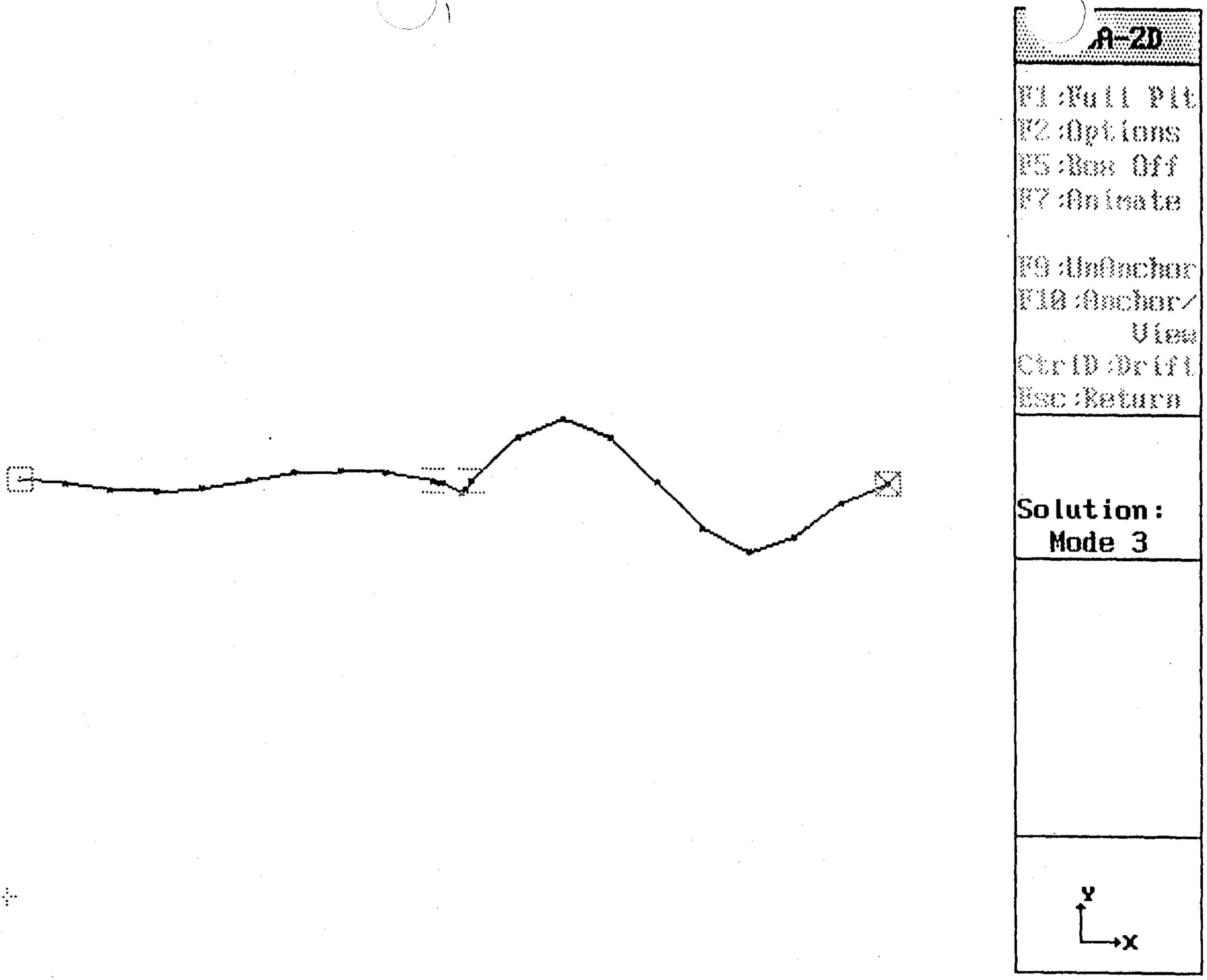
 Mode Shape 12
--------------------------------------------------------------------------

     Node         Global X             Global Y            Rotation
--------------------------------------------------------------------------
        1          0.00000             -0.00000            -0.00000
        2          0.00000            -12.37033            -0.00724
        3          0.00000              5.18207             0.21753
        4          0.00000              5.51670            -0.21197
        5          0.00000            -11.49780             0.02336
        6          0.00000              7.37389             0.18609
        7          0.00000              3.21788            -0.23224
        8          0.00000            -10.99832             0.07428
        9          0.00000              9.02324             0.14636
       10          0.00000              0.00000            -0.25951
       11          0.00000             -3.46391            -0.26843
       12          0.00000             -5.33760            -0.26955
       13          0.00000              0.08469            -0.00406
       14          0.00000              0.05598            -0.00420
       15          0.00000             -0.00000            -0.00445
       16          0.00000             -0.19864             0.00254
       17          0.00000              0.21137             0.00193
       18          0.00000             -0.04489            -0.00471
       19          0.00000             -0.16037             0.00347
       20          0.00000              0.22861             0.00075
       21          0.00000             -0.10133            -0.00431
       22          0.00000             -0.11030             0.00425
       23          0.00000              0.24794            -0.00007
       24          0.00000              0.00000            -0.00000
```

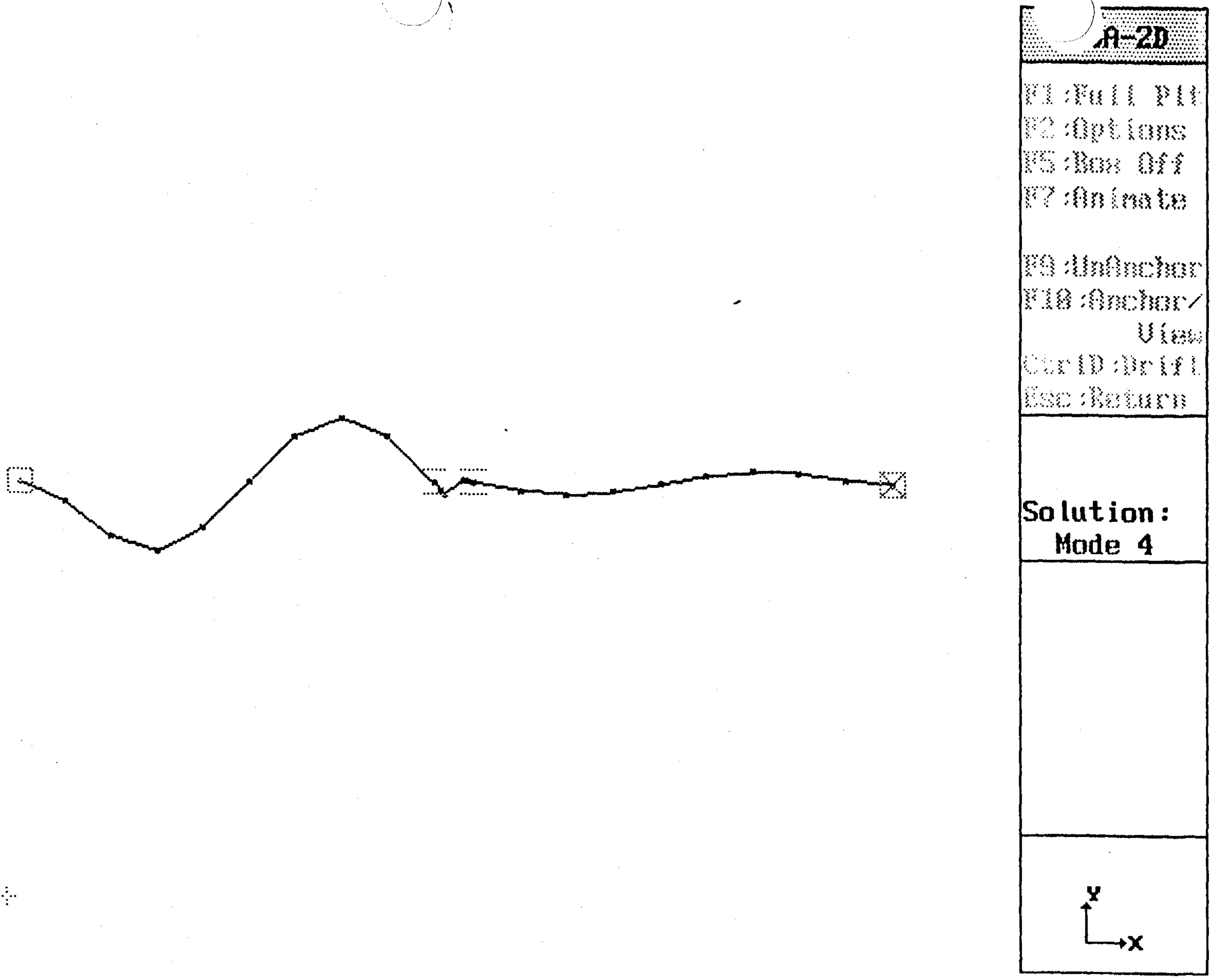


Solution:
Mode 1

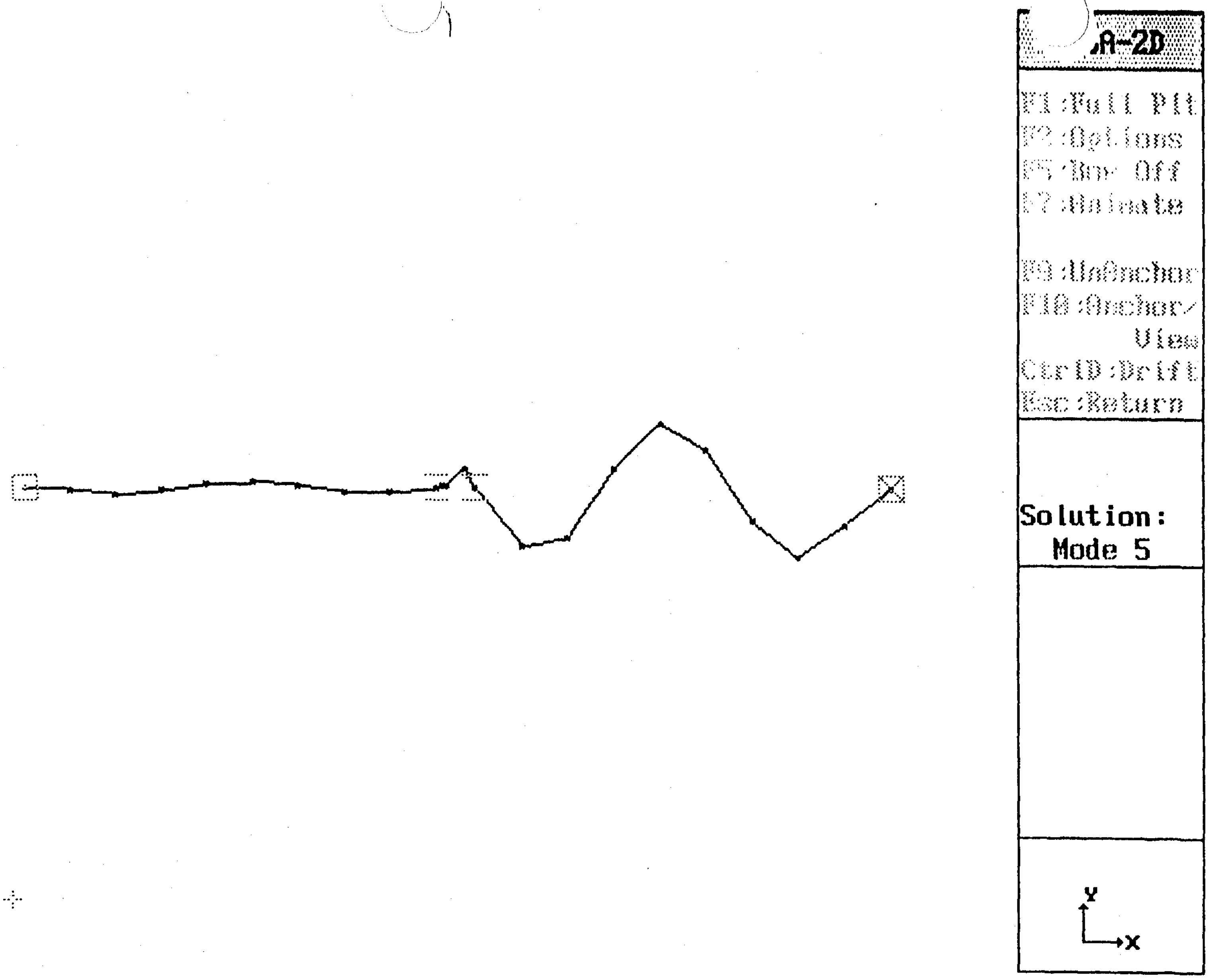

A-2D
F1 :Full Plt
F2 :Options
F5 :Box Off
F7 :Animate
F9 :UnAnchor
F10 :Anchor/
View
CtrlD :Drift
Esc :Return
Solution:
Mode 2
y
x



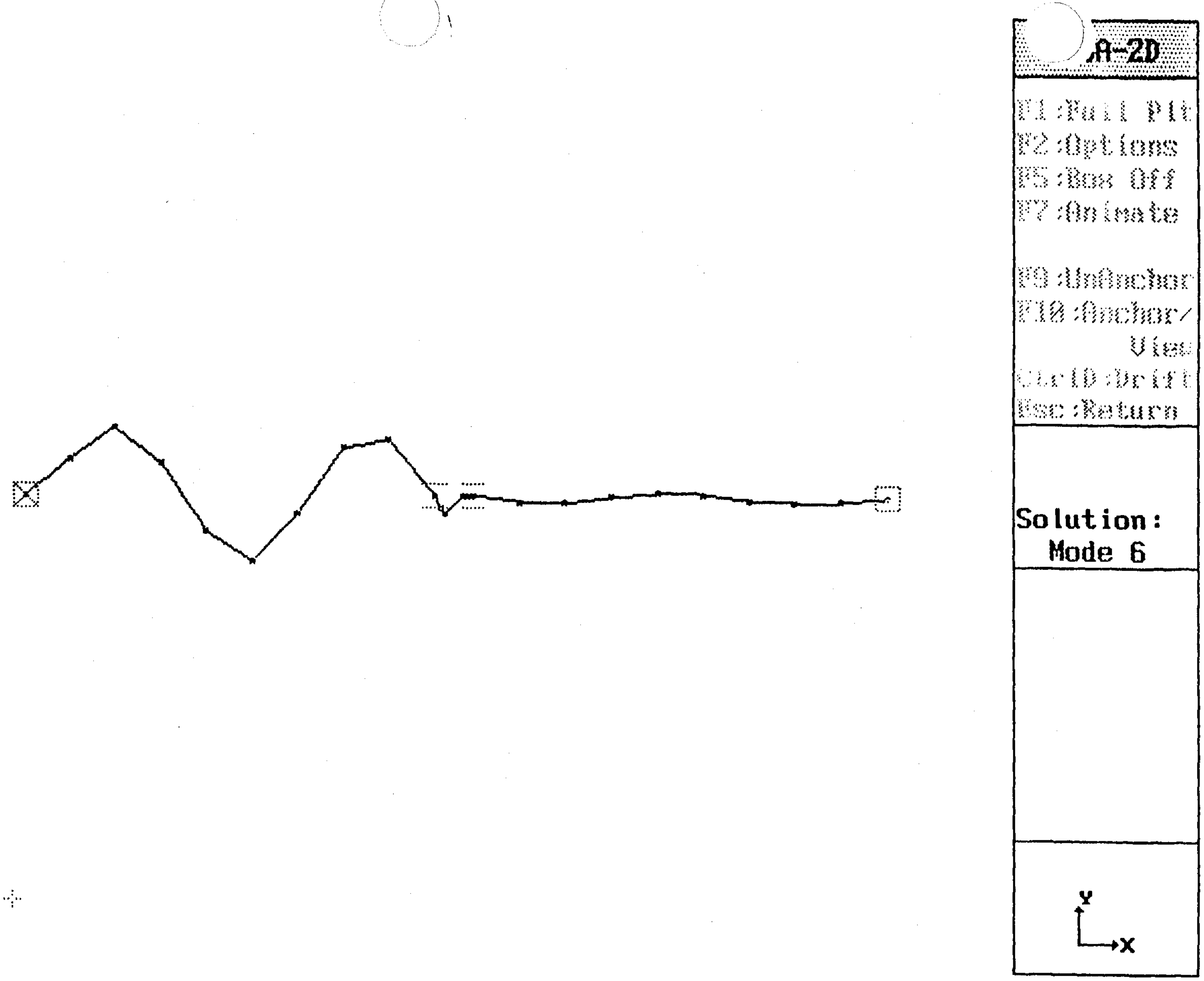
Solution: Mode 3



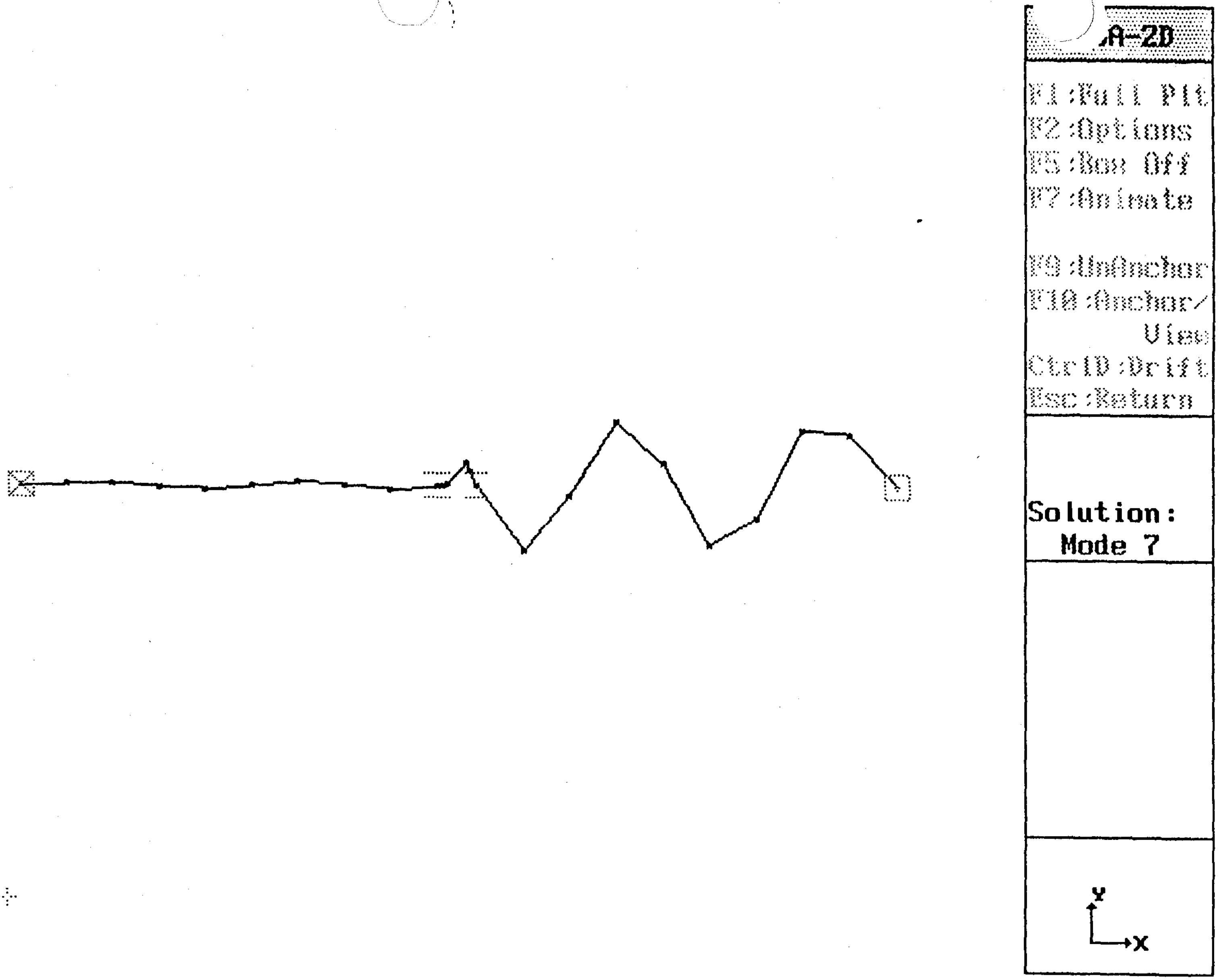
Solution:
Mode 4



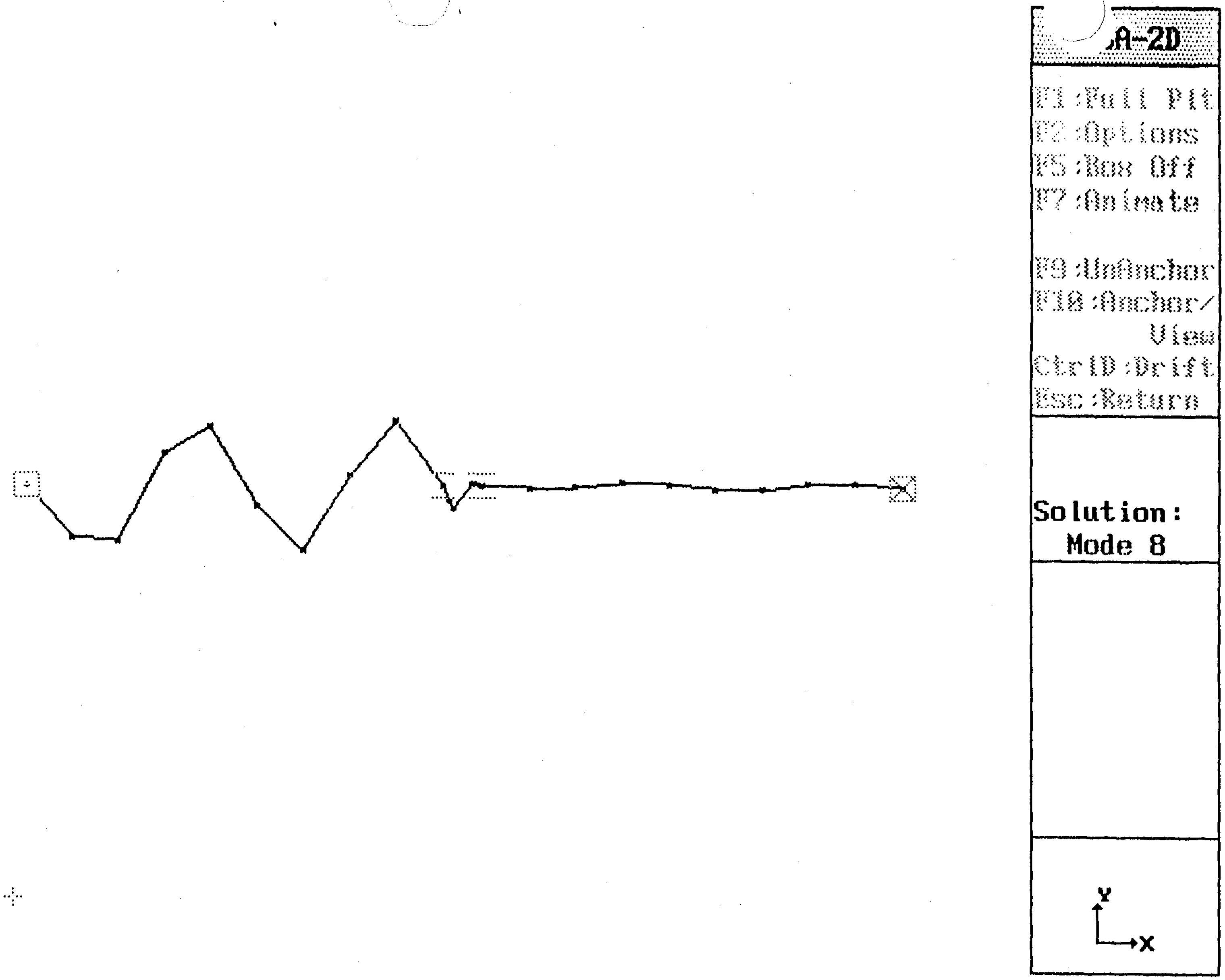
Solution:
Mode 5

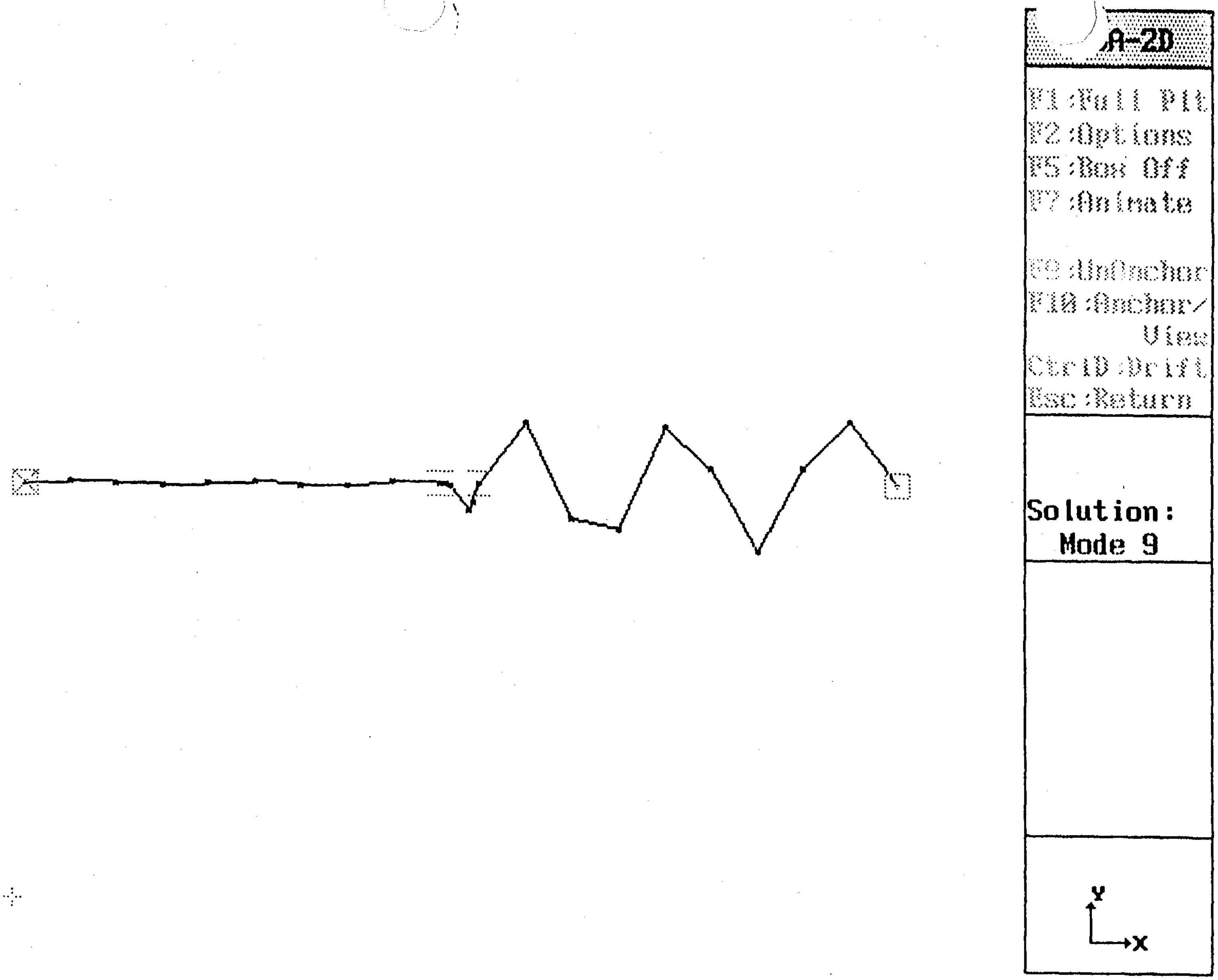


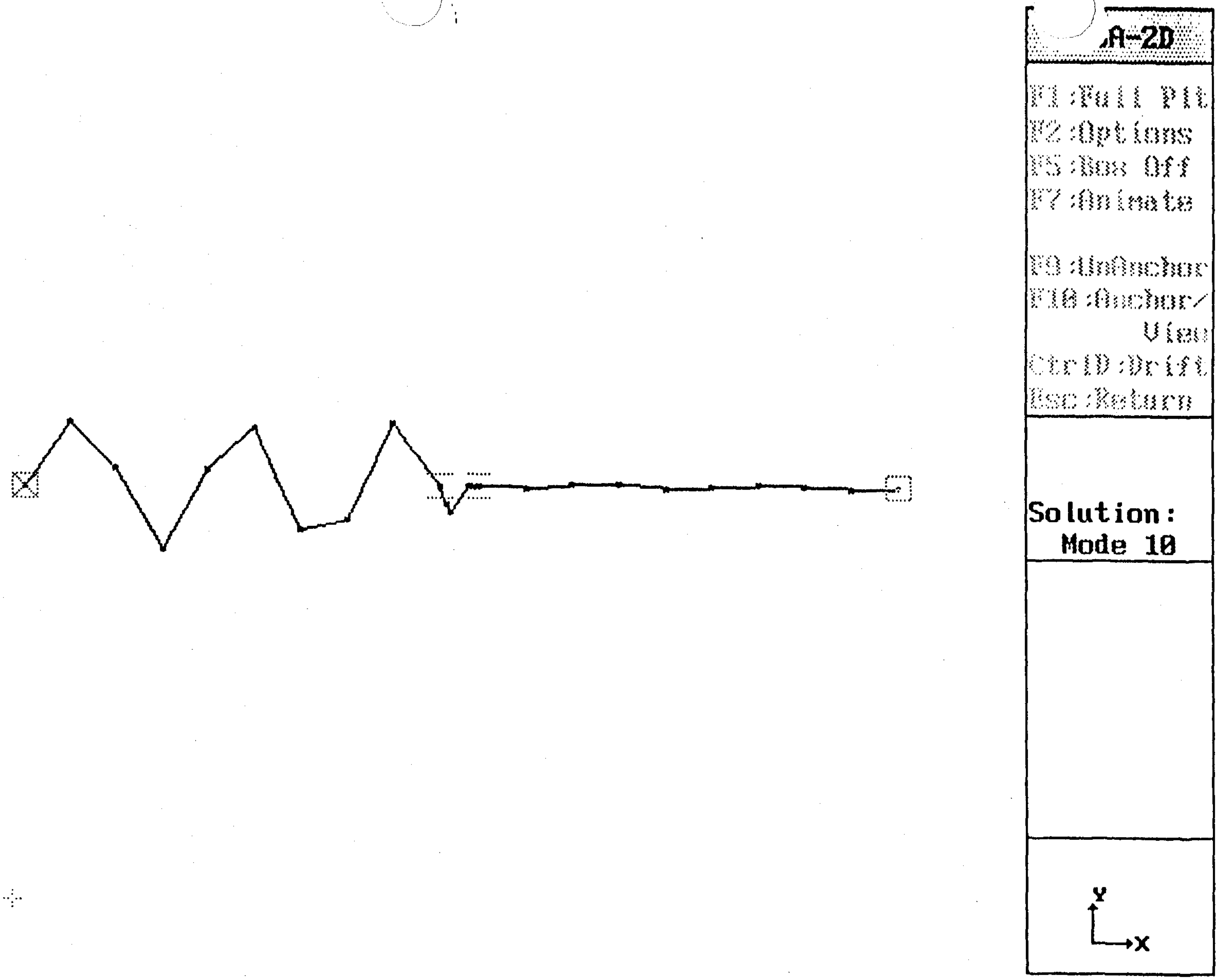
Solution:
Mode 6

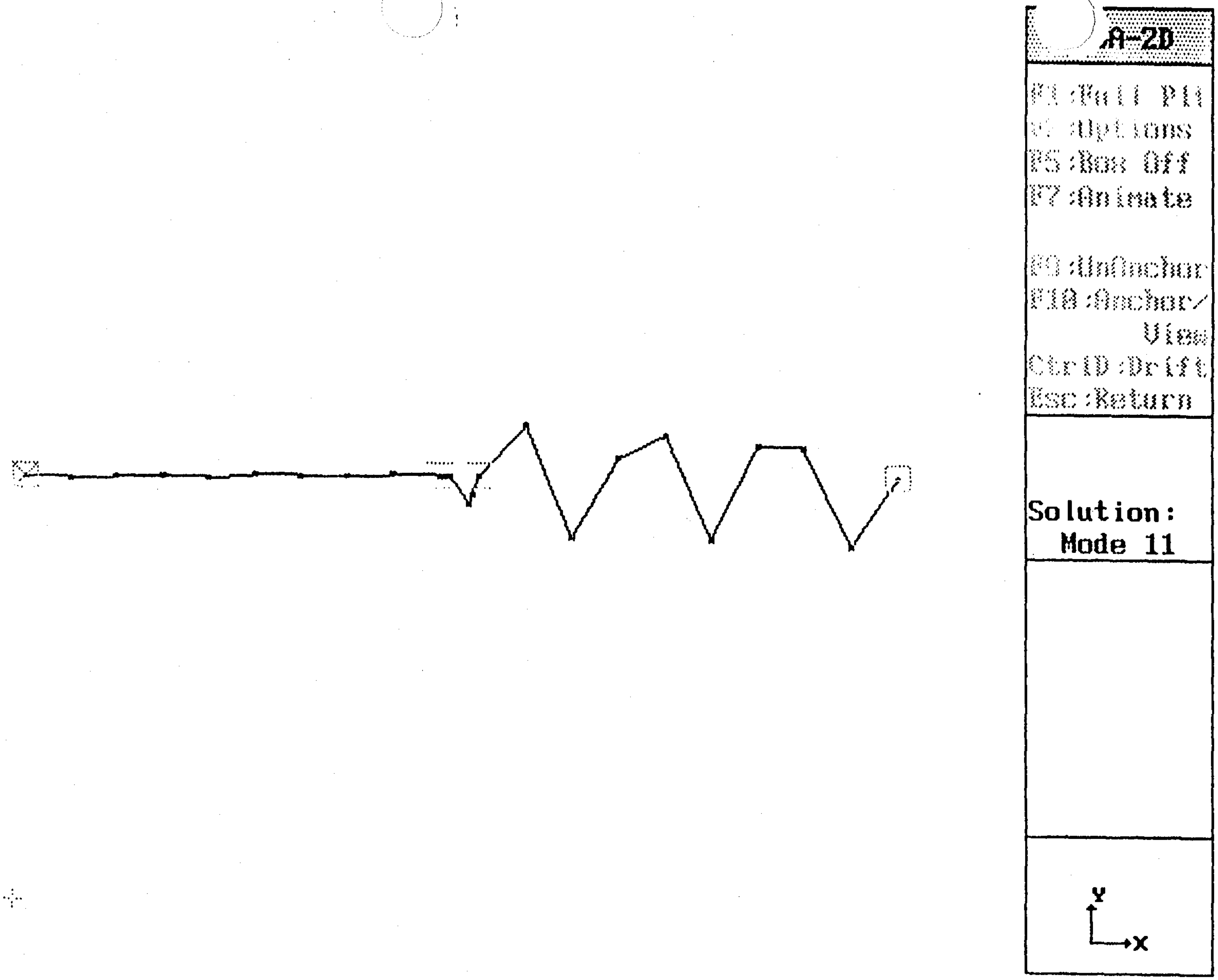


Solution:
Mode 7

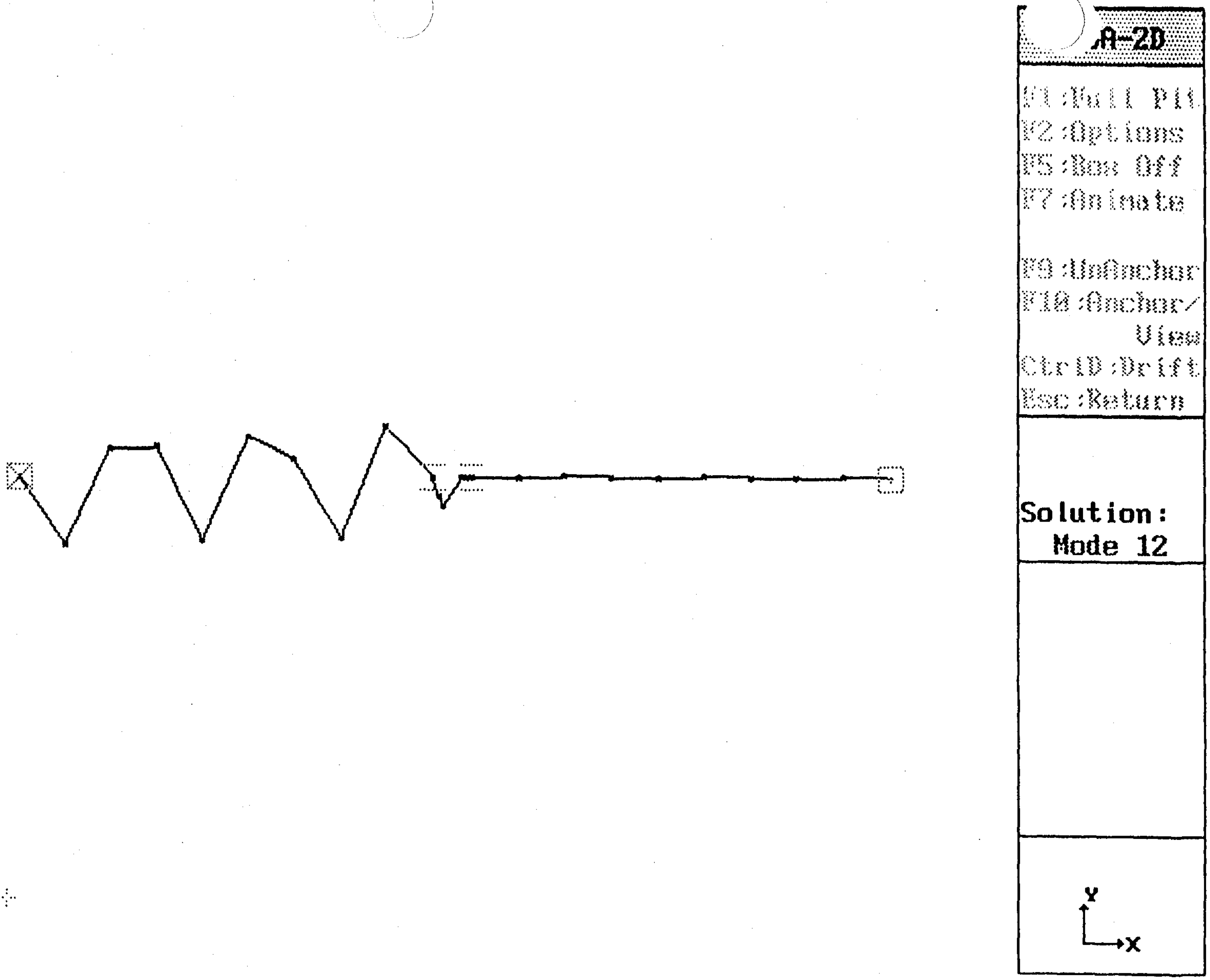

A-2D
F1:Full Plt
F2:Options
F5:Box Off
F7:Animate
F9:UnAnchor
F10:Anchor/
View
CtrlD:Drift
Esc:Return
Solution:
Mode 8
y
x


A-2D
F1:Full Plt
F2:Options
F5:Box Off
F7:Animate
F9:UnAnchor
F10:Anchor/View
CtrlD:Drift
Esc:Return
Solution:
Mode 9
y
x


A-2D
F1 :Full Plt
F2 :Options
F5 :Box Off
F7 :Animate
F9 :UnAnchor
F10 :Anchor/
View
CtrlD :Drift
Esc :Return
Solution:
Mode 10
y
x



Solution:
Mode 11



Solution:
Mode 12

INTRODUCTION

THE BEAM TUBE SECTIONS ARE DESIGNED PER ASME SECTION VIII DIV 1. RISA2D IS USED TO DETERMINE REACTIONS AND MOMENTS. THE REACTIONS AND MOMENTS ARE SUPPERIMPOSED WITH THE OTHER LOAD CASES. THE FOLLOWING LOAD CASES WILL BE INVESTIGATED

CASE:	
1	DEAD LOAD
2	DEAD LOAD + INSULATION (WET)
3	SNOW
4	WIND
5	SEISMIC - HORIZONTAL
6	SEISMIC - AXIAL
7	VACUUM
8	DIFFERENTIAL SETTLEMENT OF SUPPORTS
9	BAKE OUT @ 302°
10	MAXIMUM OPERATING TEMPERATURE OF 100°F
11	MINIMUM OPERATING TEMPERATURE OF -16°F

14 COMBINATIONS OF THE CASES WERE INVESTIGATED. THE COMBINATIONS ARE LISTED ON SUMMARY SHEETS WHICH ARE AT THE END OF EACH CALCULATION SET.

<table>
<tr><td rowspan="3">SUBJECT
BEAM TUBE DESIGN
STRESSES & REACTIONS</td><td colspan="2">CBI OFFICE NOE-C</td><td colspan="2">REVISION</td><td>REFERENCE NO.
930312</td></tr>
<tr><td>MADE BY
KLH</td><td>CHKD BY
WJC</td><td>MADE BY</td><td>CHKD BY</td><td>SHT 1 OF 4</td></tr>
<tr><td>DATE
[illegible]</td><td>DATE
4-4-94</td><td>DATE</td><td>DATE</td><td>6.1</td></tr>
</table>

CASE 3 LIVINGSTON

(NORMAL) $R_{FIX} = 7.029$ K

$R_{FIX} = 6.95$ K

TYPICAL $R_{GUIDE} = \left.\begin{matrix} 2.39 \\ 2.42 \end{matrix}\right\} = 4.81$

END $R_{GUIDE} \left.\begin{matrix} 3.468 \\ 0.180 \end{matrix}\right\} 3.648$

$M_{MAX} = 43.66$

M_{TYP} 43.48

$\theta_{55-56} = 0.00035 + .0007 = .00042$ RAD $= 0.024°$

$\theta_{72-73} = 0.00041 - 0.00043 = 0.00084 = 0.048°$

TYP $\theta_{59-60} = 0.00041 + .00042 = 0.00083 = 0.048°$

$\Delta_{25} = 0.079''$

$\Delta_{29} = 0.076$

$\Delta_{34} = 0.079$

$\Delta_{42} = 0.076$

SUBJECT	CBI OFFICE	REVISION		REFERENCE NO.
RISA2D Results Used for Beam Tube Design	1100-C			930212
	MADE BY: RJW	CHKD BY: WJC	MADE BY	CHKD BY	SHT 3 OF 4
	DATE: 2MAR94	DATE: 4-4-94	DATE	DATE	6.3

Printed In USA

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CASES WITH DIFFERENTIAL SETTLEMENT

CASE 1A - SETTLEMENT @ FIXED SUPPORT

RISA 2D RUN WITH 1" DIFFERENTIAL SETTLEMENT DOWN

NOTE: DIFFERENTIAL SETTLEMENT MAY BE UP - SIGNS REVERSE

NODE 40 FIXED SUPPORT = -2.37^k

$$\left.\begin{matrix}31\\36\end{matrix}\right\}\text{GUIDE SUPPORT}\left\{\begin{matrix}= -1.25\\= 2.45\end{matrix}\right\} = 1.2^k$$

$$\left.\begin{matrix}44\\49\end{matrix}\right\}\text{GUIDE SUPPORT}\left\{\begin{matrix}= 2.47\\= -1.26\end{matrix}\right\} = 1.21^k$$

$$\left.\begin{matrix}\theta_{33} = 0.00007\\ \theta_{34} = -0.00196\end{matrix}\right\} = 0.00203 = 0.116^\circ$$

$$M_{MAX} @ 40 = 71.36^{'k}$$

CASE 1B - SETTLEMENT @ GUIDED SUPPORT

$$\text{NODE}\ \left.\begin{matrix}31\\36\end{matrix}\right\}\text{GUIDED}\left\{\begin{matrix}= -0.560^k\\= -0.537\end{matrix}\right\} = -1.10^k$$

27 FIXED = 1.23

40 FIXED = 1.23

$$\left.\begin{matrix}\theta_{33} = 0.00167\\ \theta_{34} = -0.00167\end{matrix}\right\} = 0.00334\ RAD = 0.191^\circ$$

$$M_{MAX} @ 27 = 35.79^{k\text{-}ft}$$

CASE 1A CONTROLS FOR SUPPORT REACTIONS & MAXIMUM MOMENT
CASE 1B CONTROLS FOR EXPANSION JOINT ROTATION

RUN BEAM TUBE DESIGN W/ CASE 1A FOR DIFFERENTIAL SETTLEMENT
TO YIELD HIGHEST STRESSES & REACTIONS

SUBJECT	OFFICE		REVISION		REFERENCE NO.
RISA 2D RESULTS USED FOR BEAM TUBE DESIGN :	CBI HOU-1				93021Z
	MADE BY RSW	CHKD BY WK	MADE BY	CHKD BY	SHT 4 OF 4
	DATE 7 MAR 94	DATE 4-4-94	DATE	DATE	6.4

Printed In USA

GO 64 REV SEP 84

- INPUT VARIABLES

Tube outside diameter, Do = 49.004 in
Beam Tube section length, L = 19.812 m = 65.000 ft
Beam Tube Span length, Lsp = 18.9484 m = 62.167 ft
Tube thickness, t = 0.127 in
Insulation Density, Deni = 24 kg/m = 16.127 lbs/ft

Vacuum Stiffener thickness, ts = 0.1875 in
Vacuum Stiffener width, ws = 1.75 in
Vacuum Stiffener spacing, Ls = 29.84 in
Support Stiffener thickness, tss = 0.375 in
Support Stiffener width, wss = 4 in

Mod. of Elast. @ ambient, Ea = 28,300 ksi Table TM-1 @ 70
Mod. of Elast. @ 302 degrees, Eb = 27,000 ksi Table TM-1, Page 664
Coefficient of expansion, e= 9E-06 in/in/F Average from 70 to 300 degrees F

Anchor bolt spacing, Abs = 30 in
C. line height of tube, H = 42.000 in
Support Collar / Saddle width, b = 20.000 in

Expansion Joint O.D., De = 53.75 in
Expansion Joint I.D., Dei = 48.75 in
E.J. Concentricity Error, CE = 0.1875 in
Expansion joint axial spring rate, Kej = 9147.6 lbs/in =8316 * 1.1
Spring rate variation, Eej = 10.0%
Spring Rate, K = 10062 lbs/in = Kej * (1 + Eej)

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 1 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.5

- TUBE WEIGHT & PROPERTIES

Inside Diameter, Di = 48.75 in
Area, A = 19.501 in^2 = PI() * (Do^2 - Di^2) / 4
Section Modulus, S = 237.7 in^3 = PI() * (Do^4 - Di^4) / 32 / Do
Moment of inertia, I= 5823 in^4 = PI() * (Do^4 - Di^4) / 64
Radius of gyration, rg = 17.281 in = (I / A)^0.5

Theoretical # of vacuum stiffeners= 27 = Round(L/Ls*12)
Number of stiffeners used, Ns = 25
True spacing = 31.200 in = L/(Ns)*12

Number of support stiffeners, Nss = 1.5 Per section

Shell weight per section = 4357 lbs = 495 * A/144 * L

Weight per vacuum stiffener = 14.987 lbs = PI() * ((Do+2*ws)^2-Do^2)/4 * Ts * 495 / 12^3
Weight per support stiffener = 71.550 lbs = PI() * ((Do+2*wss)^2-Do^2)/4 * Tss * 495 / 12^3
Stiffener weight per section = 482.01 lbs = Weight Vacuun * Ns + Weight support *Nss
Estimated Baffle wt / section = 27.5 lbs

Total metal weight, DL = 4867 lbs, or
wd = 74.87 lbs/ft

Insulation weight per section = 1048 lbs = Deni * L

DL + Insulation = 5915 lbs, or
wdi = 91.00 lbs/ft

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 2 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.6

- ALLOWABLE STRESS PER ASME SECTION VIII DIV 1 UG 23(b)

- Allowable Stresses @ 300 Degrees F.

Yield Stress, Fy = 19,200 psi Table Y1
Tensile Allowable, Sh = 13000 psi Table 1A
Joint Efficiency, Et = 0.7
Compression Allowable UG 23(b)
A = 0.000648 = 0.125 / (Ro/t)
B = 5900 psi per Figure HA 3, interpolate to 300 degrees F.
Where B = Fa = Fbx = Fby = Fbxy, local buckling stress
See below for column buckling

- Allowable Stresses @ Ambient (100 degrees F)

Yield Stress = 25,000 psi Table Y1
Tensile Allowable, Sa = 16,300 psi Table 1A
Compression Allowable UG 23(b)
A = 0.000648 = 0.125 / (Ro/t)
B = 7800 psi per Figure HA 3, 100 degrees F.
Where B = Fa = Fbx = Fby = Fbxy

- Allowable Stress Increase for Wind and Seismic
  Allowable increase for wind or seismic is 1.20

- Allowable Axial Stress, Column Buckling per AISC

k = 1
L = 746 in = Lsp * 12
r = 17.28069 in = rg

kL / r = 43.16958

Cc = 166.6081 = (2 * PI()^2 * Eb * 1000 / Fy)^0.5

Fa = 10533 psi = $\frac{(1- (kL/r)\wedge 2 / 2 / Cc\wedge 2)*Fy}{(5/3 + 3*(kL/r)/8/Cc - (kL/r)\wedge 3/8/Cc\wedge 3)}$

Fa > B, Thus use B = 5900 psi

SUBJECT LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 3 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.7

- CALCULATE WIND LOAD PER ASCE 7-88 (Livingston, LA)

F = Qz * Gh * Cf * Af — Table 4
Qz = 4.1472 = 0.00256*Kz * (I*V)^2 — Eq 3
Kz = 0.80 , Assume exposure C — Table 6
I = 1.00 — Table 5
V = 45 mph — Figure 1
Gh = 1.32 — Table 8
Cf = 0.739 h / D = 0.0853 — Table 12
h = (Do / 2 +H)/12
D = L
D' / Do = ws / Do = 0.03571
Af = 4.084 Sqft / ft = Do / 12

F = 16.53 lbs / ft
F = 1074 lbs / section

- CALCULATE WIND LOAD PER ASCE 7-88 (Hanford, WA)

F = Qz * Gh * Cf * Af — Table 4
Qz = 4.1472 = 0.00256*Kz * (I*V)^2 — Eq 3
Kz = 0.80 , Assume exposure C — Table 6
I = 1.00 — Table 5
V = 45 mph — Figure 1
Gh = 1.32 — Table 8
Cf = 0.739 h / D = 0.0853 — Table 12
h = (Do / 2 +H)/12
D = L
D' / Do = ws / Do = 0.03571
Af = 4.083667 Sqft / ft = Do / 12

F = 16.53 lbs / ft = ww
F = 1074 lbs / section

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 4 OF 29
	DATE 3/11/94	DATE 4-4-94.	DATE	DATE	6.8

- CALCULATE SEISMIC LOAD PER UBC (Livingston, LA)

V = Z * I * C / Rw * W
Z = 0
I = 1.0
C = 2.75
Rw = 3
C/Rw = 0.916667 > 0.075 use: 0.91667
W = 91.00 lbs/ft = DL + Insulation
V = 0.0500W = 0.05W mimimum per ASCE 7-88, 9.11.2
V = 4.55 Lbs/ft
V = 295.8 Lbs per section

- CALCULATE SEISMIC LOAD PER ASCE 7-88 (Hanford, WA)

V = Z * I * C / Rw * W
Z = 0.2
I = 1.0
C = 2.75
Rw = 3
C/Rw = 0.916667 > 0.075 use: 0.91667
W = 91.00 lbs/ft = DL + Insulation
V = 0.1833W
V = 16.68 Lbs/ft = wseis
V = 1084.4 Lbs per section

- CALCULATE SNOW LOAD PER ASCE 7-88 (Hanford, WA only)

Pf = 15.12 = 0.7 * Ce * Ct * I * Pg Eq 5a
Ce = 0.9 Little shelter assumed Table 18
Ct = 1.2 Unheated Table 19
I = 1 Category 1 Table 20
Pg = 20 psf Figure 6

Ps = 9.828 = Cs * Pf
Cs = 0.65 Angle is 35 degrees, 90-(180-70)/2, Figure 8b

Width = 46.049 in = Do * Sin 70 Per 7.4.3, slope > 70 no load
Snow Load per foot, wsn = 37.71 lbs/ft = Ps * Width
Snow load per section = 2451 lbs

SUBJECT LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 5 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.9

- DETERMINE REACTIONS, STRESSES AND DEFLECTIONS FOR INDIVIDUAL LOAD CASES

  - Nomenclature

Rfx1 = Reaction, fixed support, x direction (horizontal), case 1
Rgy2 = Reaction, guided support, y direction (vertical), case 2
Rfz1 = Reaction, fixed support, z direction (axial), case 1
Mx1 = Moment about the horizontal axis due to vertical loads, Case 1.
My2 = Moment about the vertical axis due to horizontal loads, Case 2.
fa9c = Stress, axial, case 9, compression, (if tension t is used instead of c)

  - Reactions Based on RISA2D

Fixed support = 7.029 kips, per RISA2D
1/2 of guided support = 2.41 kips, per RISA2D
Total, two spans = 11.849 kips, per RISA2D

% Fixed support, Kf = 0.593215 (Percentage of 2 spans)
% Guided support, Kg = 0.406785

  - Moments based on RISA2D

Maximum Moment = 43480 lb-ft, at fixed support
Based on, 91 lbs/ft, DL + Insulation, used in RISA2D

True DL + Insulation = wdi = 91.00
Estimated Moment = 43961 lb-ft = wdi * (Lsp ft)^2 / 8

Moment correction factor, Km = 0.989 = RISA2D moment / Estimated moment

  - Deflections based on RISA2D

Midspan Deflection = 0.079 in
Based on, 91 lbs/ft, DL + Insulation, used in RISA2D

True DL + Insulation = wdi = 91.00
Estimated Deflection = 0.081 in = wdi * Lsp^4 / 185 / Eb / I * 12^3 / 1000

Moment correction factor, Kd = 0.978 = RISA2D deflection / Estimated deflection

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 6 OF 29
	DATE 3/11/94	DATE 4·4·94	DATE	DATE	6.10

- CASE 1: Dead Load Reactions, Stresses and Deflections

FIXED SUPPORT

Rfx1 = 0
Rfy1 = 5774 lbs = Kf * 2 * L * wd
Rfz1 = 0

GUIDED SUPPORT

Rgx1 = 0
Rgy1 = 3959 lbs = Kg * 2 * L * wd

MOMENTS & BENDING STRESS

Mx1 = 35774 lb-ft = wd * (Lsp)^2 / 8 * Km
fbx1 = 1806 psi = Mx1 * 12 / S

My1 = 0
fby1 = 0 psi = My1 * 12 / S

MIDSPAN DEFLECTION

Dely1 (amb)= 0.062 in = wd * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 2: Dead Load plus Insulation Reaction, Stresses and Deflections

FIXED SUPPORT

Rfx2 = 0
Rfy2 = 7018 lbs = Kf * 2 * L * wdi
Rfz2 = 0

GUIDED SUPPORT

Rgx2 = 0
Rgy2 = 4812 lbs = Kg * 2 * L * wdi

MOMENTS & BENDING STRESS

Mx2 = 43480 lb-ft = wdi * (Lsp)^2 / 8 * Km
fbx2 = 2195 psi = Mx2 * 12 / S

My2 = 0
fby2 = 0 psi = My2 * 12 / S

MIDSPAN DEFLECTION

Dely2 (302)= 0.079 in = wdi * Lsp^4 / 185 / Eb / I * 12^3 / 1000 * Kd

SUBJECT LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	OFFICE: NOE-C		REVISION:	REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 7 OF 29
	DATE 3/11/94	DATE 4.4.94	DATE	DATE	6.11

- CASE 3: Snow Load Reaction, Stresses and Deflections (Hanford, WA)

FIXED SUPPORT

Rfx3 = 0
Rfy3 = 2908 lbs = Kf * 2 * L * wsn
Rfz3 = 0

GUIDED SUPPORT

Rgx3 = 0
Rgy3 = 1994 lbs = Kg * 2 * L * wsn

MOMENTS & BENDING STRESS

Mx3 = 18020 lb-ft = wsn * (Lsp)^2 / 8 * Km
fbx3 = 910 psi = Mx3 * 12 / S

My3 = 0
fby3 = 0 psi = My3 * 12 / S

MIDSPAN DEFLECTION

Dely3 (amb)= 0.031 in = wsn * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 4: Wind Load Reaction, Stresses and Deflections (Livingston, LA)

FIXED SUPPORT

Rfx4 = 1275 lbs = ww * 2 * L * Kf
Rfy4 = 0
Rfz4 = 0

GUIDED SUPPORT

Rgx4 = 874 lbs = ww * 2 * L * Kg
Rgy4 = 0

MOMENTS & BENDING STRESS

Mx4 = 0
fbx4 = 0 psi = Mx4 * 12 / S

My4 = 7896 lb-ft = ww * (Lsp)^2 / 8 * Km
fby4 = 399 psi = My4 * 12 / S

MIDSPAN DEFLECTION

Delx4 (amb)= 0.014 in = ww * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

SUBJECT LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settléments	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 8 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.12

- DETERMINE REACTIONS, STRESSES AND DEFLECTIONS FOR INDIVIDUAL LOAD CASES

- Nomenclature

Rfx1 = Reaction, fixed support, x direction (horizontal), case 1
Rgy2 = Reaction, guided support, y direction (vertical), case 2
Rfz1 = Reaction, fixed support, z direction (axial), case 1
Mx1 = Moment about the horizontal axis due to vertical loads, Case 1.
My2 = Moment about the vertical axis due to horizontal loads, Case 2.
fa9c = Stress, axial, case 9, compression, (if tension t is used instead of c)

- Reactions Based on RISA2D

Fixed support = 7.029 kips, per RISA2D
1/2 of guided support = 2.41 kips, per RISA2D
Total, two spans = 11.849 kips, per RISA2D

% Fixed support, Kf = 0.593215 (Percentage of 2 spans)
% Guided support, Kg = 0.406785

- Moments based on RISA2D

Maximum Moment = 43480 lb-ft, at fixed support
Based on, 91 lbs/ft, DL + Insulation, used in RISA2D

True DL + Insulation = wdi = 91.00
Estimated Moment = 43961 lb-ft = wdi * (Lsp ft)^2 / 8

Moment correction factor, Km = 0.989 = RISA2D moment / Estimated moment

- Deflections based on RISA2D

Midspan Deflection = 0.079 in
Based on, 91 lbs/ft, DL + Insulation, used in RISA2D

True DL + Insulation = wdi = 91.00
Estimated Deflection = 0.081 in = wdi * Lsp^4 / 185 / Eb / I * 12^3 / 1000

Moment correction factor, Kd = 0.978 = RISA2D deflection / Estimated deflection

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 6 OF 29
	DATE 3/11/94	DATE 4·4·94	DATE	DATE	6.10

- CASE 1: Dead Load Reactions, Stresses and Deflections

FIXED SUPPORT

Rfx1 = 0
Rfy1 = 5774 lbs = Kf * 2 * L * wd
Rfz1 = 0

GUIDED SUPPORT

Rgx1 = 0
Rgy1 = 3959 lbs = Kg * 2 * L * wd

MOMENTS & BENDING STRESS

Mx1 = 35774 lb-ft = wd * (Lsp)^2 / 8 * Km
fbx1 = 1806 psi = Mx1 * 12 / S

My1 = 0
fby1 = 0 psi = My1 * 12 / S

MIDSPAN DEFLECTION

Dely1 (amb)= 0.062 in = wd * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 2: Dead Load plus Insulation Reaction, Stresses and Deflections

FIXED SUPPORT

Rfx2 = 0
Rfy2 = 7018 lbs = Kf * 2 * L * wdi
Rfz2 = 0

GUIDED SUPPORT

Rgx2 = 0
Rgy2 = 4812 lbs = Kg * 2 * L * wdi

MOMENTS & BENDING STRESS

Mx2 = 43480 lb-ft = wdi * (Lsp)^2 / 8 * Km
fbx2 = 2195 psi = Mx2 * 12 / S

My2 = 0
fby2 = 0 psi = My2 * 12 / S

MIDSPAN DEFLECTION

Dely2 (302)= 0.079 in = wdi * Lsp^4 / 185 / Eb / I * 12^3 / 1000 * Kd

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 7 OF 29
	DATE 3/11/94	DATE 4.4.94	DATE	DATE	6.11

- CASE 3: Snow Load Reaction, Stresses and Deflections (Hanford, WA)

FIXED SUPPORT

Rfx3 = 0
Rfy3 = 2908 lbs = Kf * 2 * L * wsn
Rfz3 = 0

GUIDED SUPPORT

Rgx3 = 0
Rgy3 = 1994 lbs = Kg * 2 * L * wsn

MOMENTS & BENDING STRESS

Mx3 = 18020 lb-ft = wsn * (Lsp)^2 / 8 * Km
fbx3 = 910 psi = Mx3 * 12 / S

My3 = 0
fby3 = 0 psi = My3 * 12 / S

MIDSPAN DEFLECTION

Dely3 (amb)= 0.031 in = wsn * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 4: Wind Load Reaction, Stresses and Deflections (Livingston, LA)

FIXED SUPPORT

Rfx4 = 1275 lbs = ww * 2 * L * Kf
Rfy4 = 0
Rfz4 = 0

GUIDED SUPPORT

Rgx4 = 874 lbs = ww * 2 * L * Kg
Rgy4 = 0

MOMENTS & BENDING STRESS

Mx4 = 0
fbx4 = 0 psi = Mx4 * 12 / S

My4 = 7896 lb-ft = ww * (Lsp)^2 / 8 * Km
fby4 = 399 psi = My4 * 12 / S

MIDSPAN DEFLECTION

Delx4 (amb)= 0.014 in = ww * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 5: Seismic Reaction, Stresses and Deflections (Hanford, WA), X Direction (Horizontal)

FIXED SUPPORT

Rfx5 = 1287 lbs = wseis * 2 * L * Kf
Rfy5 = 0
Rfz5 = 0

GUIDED SUPPORT

Rgx5 = 882 lbs = wseis * 2 * L * Kg
Rgy5 = 0

MOMENTS & BENDING STRESS

Mx5 = 0
fbx5 = 0 psi = Mx5 * 12 / S

My5 = 7971 lb-ft = wseis * (Lsp)^2 / 8 * Km
fby5 = 402 psi = My5 * 12 / S

MIDSPAN DEFLECTION

Delx5 (amb)= 0.014 in = wseis * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 6: Seismic Reaction, Stresses and Deflections (Hanford, WA), Z Direction (Axial)

FIXED SUPPORT

Rfx6 = 0
Rfy6 = 0
Rfz6 = 2169 lbs = wseis * 2 * L

GUIDED SUPPORT

Rgx6 = 0
Rgy6 = 0

MOMENTS & BENDING STRESS

Mx6 = 0
fbx6 = 0 psi = Mx5 * 12 / S

My6 = 0
fby6 = 0 psi = My6 * 12 / S

MIDSPAN DEFLECTION

Dely6 (amb)= 0.000 in

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJc	MADE BY	CHKD BY	SHT 9 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.13

- CASE 7: Vacuum

Bellows effective area = 2062.9 sq in = PI()*((De+Dei)/2)^2/4
Tube pressure area = 1866.55 sq in = PI()*((Di))^2/4
Bellows pressure area = 196.35 sq in =Bellows effective - tube area
Axial force, Pzp = 2886 lbs = 14.7*Bellows pressure area, pos.=tension

Axial Stress due to vacuum, fav7 = 148.0 psi = Pzp / A, pos. = tension

FIXED SUPPORT
Rfx7 = 0 lbs
Rfy7 = 0
Rfz7 = 0

GUIDED SUPPORT
Rgx7 = 0 lbs
Rgy7 = 0

fbx7 = fby7 = 0

Dely7 = 0

- CASE 8: Differential Settlement of Fixed Support

  - Reactions Based on RISA2D with 1" differential settlement

Fixed support = -2.37 kips, per RISA2D
1/2 of guided support = 2.47 kips, per RISA2D
Based on, 1 lbs/ft, DL, used in RISA2D

FIXED SUPPORTS
Rfx8 = -2447 lbs = (RISA2D fixed) - DL * 2 * L * Kf
Rfy8 = -2447 lbs = (RISA2D fixed) - DL * 2 * L * Kf
GUIDED SUPPORTS
Rgx8 = 4887 lbs = 2 * (RISA2D guided) - DL * 2 * L * Kg
Rgy8 = 4887 lbs = 2 * (RISA2D guided) - DL * 2 * L * Kg

  - Moments based on RISA2D with 1" differential settlement

Maximum Moment = 71360 lb-ft, at fixed support
Based on, 1 lbs/ft, DL + Insulation, used in RISA2D

Mx8 = My8 = 70882 lb-ft = (RISA2D Moment) - DL * Lsp^2 / 8 * Km
fbx8 = fby8 = 3579 psi = Mx8 * 12 / S

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 11 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.15

- CASE 9: Expansion Joint Forces at 302 Degrees F.

Maximum Bellows spring rate, K = 10062 lbs/in = Kej * (1 + Eej)
Est. temp. change above 70, Tch = 232 degrees Fahrenheit
Thermal growth hot, x = 3.257 in = e * 2 * L * 12 * Tch
Longitudinal Comp. force, Pbc = 32776 lbs = K * x
fa9c = -1681 psi = Pbc / A, stress on tube, neg is comp

FIXED SUPPORT
Rfx9 = 0 lbs
Rfy9 = 0
Rfz9 = 5959 lbs = 2 * Eej * Kej * x

GUIDED SUPPORT
Rgx9 = 0
Rgy9 = 167.8 lbs = Rfz9 * H / Lsp / 12 /2

fbx9 = fby9 = 0
Delx9 = Dely9 = 0

- CASE 10: Expansion Joint Forces at 100 Degrees F.

Maximum Bellows spring rate, K = 10062 lbs/in = Kej * (1 + Eej)
Est. temp. change above 70, Tch = 30 degrees Fahrenheit
Thermal growth hot, xw = 0.421 in = e * 2 * L * 12 * Tch
Longitudinal Comp. force, Pbc = 4238 lbs = K * xw
fa10c = -217 psi = Pbc / A, stress on tube, neg is comp

FIXED SUPPORT
Rfx10 = 0 lbs
Rfy10 = 0
Rfz10 = 771 lbs = 2 * Eej * Kej * xw

GUIDED SUPPORT
Rgx10 = 0
Rgy10 = 21.7 lbs = Rfz10 * H / Lsp / 12 /2

fbx10 = fby10 = 0
Delx10 = Dely10 = 0

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 12 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.16

- CASE 11: Expansion Joint Forces at -16 Degrees F.

Maximum Bellows spring rate, K = 10062 lbs/in = Kej * (1 + Eej)
Est. temp. change below 70, Tchc = 86 degrees Fahrenheit
Thermal shrinkage, xs = -1.207 in = e * 2 * L * 12 * Tchc
Longitudinal Tension force, Pbt = 12150 lbs = K * xs
fa11t = 623 psi = -Pbt / A Positive is tension

FIXED SUPPORT
Rfx11 = 0 lbs
Rfy11 = 0
Rfz11 = 2209 lbs = -2 * Eej * Kej * xs

GUIDED SUPPORT
Rgx11 = 0
Rgy11 = 62.2 lbs = Rfz11 * H / Lsp / 12 /2

fbx11 = fby11 = 0
Delx11 = Dely11 = 0

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 13 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.17

- LOAD COMBINATIONS FOR MAXIMUM REACTIONS, STRESS AND DEFLECTIONS

COMBINATION 1 - DL + Insulation + Vacuum + 302 F (Case 2 + 7 + 9)

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx7 + Rfx9 (laterial)
Ry = 7018 lbs = Rfy2 + Rfy7 + Rfy9 (Vertical)
Rz = 5959 lbs = Rfz2 + Rfz7 + Rfz9 (axial)
Rmax per bolt = 3509 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3509 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx7 + Rgx9
Ry = 4980 lbs = Rgy2 + Rgy7 + Rgy9 (Vertical)
Rmax per bolt = 2490 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2490 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = Delx2 + Delx7 + Delx9
Delta y (302) = 0.079 in = Dely2 + Dely7 + Dely9
Max Delta = 0.079 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -1533 psi, fav7 + fa9c , neg = compression
fbx = 2195 psi = fbx2 + fbx7 + fbx9
fby = 0 psi = fby2 + fby7 + fby9

Md = 7966 in-lbs = fac * A * (Max Delta + CE)
fd = 33.5 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.260
fbx / Fbx = 0.372
fby / Fby = 0.000
fd / Fbxy = 0.006
SUM = 0.638 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJL	MADE BY	CHKD BY	SHT 14 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.18

COMBINATION 2 - DL + Insulation + Settlement + Vacuum + 302 F (Case 2+7+8+9)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx7 +x8 * Rfx8 + Rfx9
Ry = 5601 lbs = Rfy2 + Rfy7+ y8 * Rfy8 + Rfy9
Rz = 5959 lbs = Rfz2 + Rfz7 + Rfz9
Rmax per bolt = 2800 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2800 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx7 + x8*Rgx8 + Rgx9
Ry = 7810 lbs = Rgy2 + Rgy7 + y8*Rgy8 + Rgy9
Rmax per bolt = 3905 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3905 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.369 in = Dely2 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -1533 psi, fav7 + fa9c , neg = compression
fbx = 4267 psi = fbx2 + fbx7 + y8 * fbx8 + fbx9
fby = 0 psi = fby2 + fby7 + x8 * fby8 + fby9

Md = 22910 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 96.4 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.260
fbx / Fbx = 0.723
fby / Fby = 0.000
fd / Fbxy = 0.016
SUM = 0.999 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 15 OF 29
	DATE 3/11/94	DATE 4.4.94	DATE	DATE	6.19

COMBINATION 3 - DL + Insul + Seis x + Dif settle + Vac + 302 F (Case 2+5+7+8+9)

SETTLEMENT WITH COMBINATION
Delta x, x8 = 0 in Maxset = 0.788 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.788 in

FIXED SUPPORTS
Rx = 1287 lbs = Rfx2 + Rfx5 + Rfx7 +x8 * Rfx8 + Rfx9
Ry = 5089 lbs = Rfy2 + Rfy5 + Rfy7+ y8 * Rfy8 + Rfy9
Rz = 5959 lbs = Rfz2 + Rfz5 + Rfz7 + Rfz9
Rmax per bolt = 4346 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 743 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS
Rx = 882 lbs = Rgx2 + Rgx5 + Rgx7 + x8*Rgx8 + Rgx9
Ry = 8831 lbs = Rgy2 + Rgy5 + Rgy7 + y8*Rgy8 + Rgy9
Rmax per bolt = 5651 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3180 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION
Delta x (302) = 0.014 in = Delx5 + 0.5 * x8
Delta y (302) = 0.473 in = Dely2 + 0.5 * y8
Max Delta = 0.473 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES
fac = -1533 psi, fav7 + fa9c , neg = compression
fbx = 5015 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx9
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby9

Md = 29157 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 122.7 psi = Md / S

COMBINED STRESS (compression)
fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3

fac / Fa = 0.216
fbx / Fbx = 0.708
fby / Fby = 0.057
fd / Fbxy = 0.017
SUM = 0.999 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 16 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.20

COMBINATION 4 - DL + Insul + Seis z + Dif settle + Vac + 302 F (Case 2+5+7+8+9)

SETTLEMENT WITH COMBINATION
Delta x, x8 = 0 in Maxset = 0.756 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.756 in

FIXED SUPPORTS
Rx = 0 lbs = Rfx2 + Rfx6 + Rfx7 +x8 * Rfx8 + Rfx9
Ry = 5168 lbs = Rfy2 + Rfy6 + Rfy7+ y8 * Rfy8 + Rfy9
Rz = 8128 lbs = Rfz2 + Rfz6 + Rfz7 + Rfz9
Rmax per bolt = 2584 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2584 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS
Rx = 0 lbs = Rgx2 + Rgx6 + Rgx7 + x8*Rgx8 + Rgx9
Ry = 8675 lbs = Rgy2 + Rgy6 + Rgy7 + y8*Rgy8 + Rgy9
Rmax per bolt = 4337 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 4337 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION
Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.457 in = Dely27 + 0.5 * y8
Max Delta = 0.457 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES
fac = -1644 psi, fav7 + fa9c - Rfz6 / A , neg = compression
fbx = 4901 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx9
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby9

Md = 30247 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 127.3 psi = Md / S

COMBINED STRESS (compression)
fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3

fac / Fa = 0.232
fbx / Fbx = 0.692
fby / Fby = 0.057
fd / Fbxy = 0.018
SUM = 0.999 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 17 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.21

COMBINATION 5 - DL + Wind + Dif Set + 100 F (Case 1 + 4 + 8 + 10)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 0.965 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.965 in

FIXED SUPPORTS

Rx = 1275 lbs = Rfx1 + Rfx4 +x8 * Rfx8 + Rfx10
Ry = 3413 lbs = Rfy1 + Rfy4+ y8 * Rfy8 + Rfy10
Rz = 771 lbs = Rfz1 + Rfz4 + Rfz10
Rmax per bolt = 3491 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = -78 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 874 lbs = Rgx1 + Rgx4 + x8*Rgx8 + Rgx10
Ry = 8697 lbs = Rgy1 + Rgy4 + y8*Rgy8 + Rgy10
Rmax per bolt = 5572 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3125 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.014 in = Delx4 + 0.5 * x8
Delta y (302) = 0.545 in = Dely1 + 0.5 * y8
Max Delta = 0.545 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -217 psi, fav4 + fa10c , neg = compression
fbx = 5260 psi = fbx1 + fbx4 + y8 * fbx8 + fbx10
fby = 399 psi = fby1 + fby4 + x8 * fby8 + fby10

Md = 4885 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 20.6 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.037
fbx / Fbx = 0.891
fby / Fby = 0.068
fd / Fbxy = 0.003
SUM = 0.999 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 18 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.22

COMBINATION 6 - DL + Insulation + Vacuum + 100 F (Case 2 + 7 + 10)

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx7 + Rfx10 (laterial)
Ry = 7018 lbs = Rfy2 + Rfy7 + Rfy10 (Vertical)
Rz = 771 lbs = Rfz2 + Rfz7 + Rfz10 (axial)
Rmax per bolt = 3509 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3509 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx7 + Rgx10
Ry = 4834 lbs = Rgy2 + Rgy7 + Rgy10 (Vertical)
Rmax per bolt = 2417 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2417 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = Delx2 + Delx7 + Delx10
Delta y (302) = 0.079 in = Dely2 + Dely7 + Dely10
Max Delta = 0.079 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -69 psi, fav7 + fa10c , neg = compression
fbx = 2195 psi = fbx2 + fbx7 + fbx10
fby = 0 psi = fby2 + fby7 + fby10

Md = 360 in-lbs = fac * A * (Max Delta + CE)
fd = 1.5 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.012
fbx / Fbx = 0.372
fby / Fby = 0.000
fd / Fbxy = 0.000
SUM = 0.384 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJc	MADE BY	CHKD BY	SHT 19 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.23

COMBINATION 7 - DL + Insulation + Settlement + Vacuum + 100 F (Case 2+7+8+10)

SETTLEMENT WITH COMBINATION
Delta x, x8 = 0 in Maxset = 1.012 = (x8^2 + y8^2)^0.5
Delta y, y8= 1.012 in

FIXED SUPPORTS
Rx = 0 lbs = Rfx2 + Rfx7 +x8 * Rfx8 + Rfx10
Ry = 4541 lbs = Rfy2 + Rfy7+ y8 * Rfy8 + Rfy10
Rz = 771 lbs = Rfz2 + Rfz7 + Rfz10
Rmax per bolt = 2271 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2271 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS
Rx = 0 lbs = Rgx2 + Rgx7 + x8*Rgx8 + Rgx10
Ry = 9780 lbs = Rgy2 + Rgy7 + y8*Rgy8 + Rgy10
Rmax per bolt = 4890 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 4890 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION
Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.585 in = Dely2 + 0.5 * y8
Max Delta = 0.585 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES
fac = -69 psi, fav7 + fa10c , neg = compression
fbx = 5817 psi = fbx2 + fbx7 + y8 * fbx8 + fbx10
fby = 0 psi = fby2 + fby7 + x8 * fby8 + fby10

Md = 1622 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 6.8 psi = Md / S

COMBINED STRESS (compression)
fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.012
fbx / Fbx = 0.986
fby / Fby = 0.000
fd / Fbxy = 0.001
SUM = 0.999 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 20 OF 29
	DATE 3/1.1/94	DATE 4-4-94	DATE	DATE	6.24

COMBINATION 8 - DL + Insul + Seis x + Dif settle + Vac + 100 F (Case 2+5+7+8+10)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 1.229 = (x8^2 + y8^2)^0.5
Delta y, y8= 1.229 in

FIXED SUPPORTS

Rx = 1287 lbs = Rfx2 + Rfx5 + Rfx7 +x8 * Rfx8 + Rfx10
Ry = 4010 lbs = Rfy2 + Rfy5 + Rfy7+ y8 * Rfy8 + Rfy10
Rz = 771 lbs = Rfz2 + Rfz5 + Rfz7 + Rfz10
Rmax per bolt = 3806 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 204 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 882 lbs = Rgx2 + Rgx5 + Rgx7 + x8*Rgx8 + Rgx10
Ry = 10840 lbs = Rgy2 + Rgy5 + Rgy7 + y8*Rgy8 + Rgy10
Rmax per bolt = 6655 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 4185 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.014 in = Delx5 + 0.5 * x8
Delta y (302) = 0.694 in = Dely2 + 0.5 * y8
Max Delta = 0.694 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -69 psi, fav7 + fa10c , neg = compression
fbx = 6594 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx10
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby10

Md = 1915 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 8.1 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3

fac / Fa = 0.010
fbx / Fbx = 0.931
fby / Fby = 0.057
fd / Fbxy = 0.001
SUM = 0.999 < 1.00 Tube is adequate

SUBJECT LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 21 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	. 6.25

COMBINATION 9 - DL + Insul + Seis z + Dif settle + Vac + 100 F (Case 2+5+7+8+10)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in   Maxset = 1.195 = (x8^2 + y8^2)^0.5
Delta y, y8= 1.195 in

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx6 + Rfx7 +x8 * Rfx8 + Rfx10
Ry = 4093 lbs = Rfy2 + Rfy6 + Rfy7+ y8 * Rfy8 + Rfy10
Rz = 2939 lbs = Rfz2 + Rfz6 + Rfz7 + Rfz10
Rmax per bolt = 2047 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2047 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx6 + Rgx7 + x8*Rgx8 + Rgx10
Ry = 10674 lbs = Rgy2 + Rgy6 + Rgy7 + y8*Rgy8 + Rgy10
Rmax per bolt = 5337 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 5337 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.677 in = Dely27 + 0.5 * y8
Max Delta = 0.677 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -181 psi, fav7 + fa10c - Rfz6 / A , neg = compression
fbx = 6472 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx10
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby10

Md = 4867 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 20.5 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3

fac / Fa = 0.026
fbx / Fbx = 0.914
fby / Fby = 0.057
fd / Fbxy = 0.003
SUM = 0.999 < 1.00   Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 22 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.26

COMBINATION 10 - DL + snow + Dif Set + -16 F (Case 1 + 3 + 8 + 11)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 1.044 = (x8^2 + y8^2)^0.5
Delta y, y8= 1.044 in

FIXED SUPPORTS

Rx = 0 lbs = Rfx1 + Rfx3 +x8 * Rfx8 + Rfx11
Ry = 6128 lbs = Rfy1 + Rfy3+ y8 * Rfy8 + Rfy11
Rz = 2209 lbs = Rfz1 + Rfz3 + Rfz11
Rmax per bolt = 3064 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3064 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx1 + Rgx3 + x8*Rgx8 + Rgx11
Ry = 11118 lbs = Rgy1 + Rgy3 + y8*Rgy8 + Rgy11
Rmax per bolt = 5559 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 5559 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.615 in = Dely1 + Dely3 +0.5 * y8
Max Delta = 0.615 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fat = 623 psi, fa11t , pos = tension
fbx = 6452 psi = fbx1 + fbx3 + y8 * fbx8 + fbx11
fby = 0 psi = fby1 + fby3 + x8 * fby8 + fby11

Md = 14962 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 63.0 psi = Md / S

COMBINED STRESS

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3
Tension Allowable = 9100 psi = Sh * Et, for tension from page 3

	COMPRESSION		TENSION		
fa(c or t) / Fa =	-0.106		0.068		
fbx / Fbx =	1.094		0.709		
fby / Fby =	0.000		0.000		
fd / Fbxy =	0.011		0.007		
SUM =	0.999	< 1.00	0.784	< 1.00	Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJc	MADE BY	CHKD BY	SHT 23 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.27

COMBINATION 11 - DL + wind +Dif set -16 F (Case 1 + 4 + 8 + 11)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 1.186 = (x8^2 + y8^2)^0.5
Delta y, y8= 1.186 in

FIXED SUPPORTS

Rx = 1275 lbs = Rfx1 + Rfx4 +x8 * Rfx8 + Rfx11
Ry = 2872 lbs = Rfy1 + Rfy4+ y8 * Rfy8 + Rfy11
Rz = 2209 lbs = Rfz1 + Rfz4 + Rfz11
Rmax per bolt = 3220 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = -348 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 874 lbs = Rgx1 + Rgx4 + x8*Rgx8 + Rgx11
Ry = 9818 lbs = Rgy1 + Rgy4 + y8*Rgy8 + Rgy11
Rmax per bolt = 6132 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3685 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.014 in =Delx4 + 0.5 * x8
Delta y (302) = 0.655 in = Dely1 + 0.5 * y8
Max Delta = 0.655 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fat = 623 psi, fa11t , pos = tension
fbx = 6051 psi = fbx1 + fbx4 + y8 * fbx8 + fbx11
fby = 399 psi = fby1 + fby4 + x8 * fby8 + fby11

Md = 16688 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 70.2 psi = Md / S

COMBINED STRESS

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3
Tension Allowable = 9100 psi = Sh * Et, for tension from page 3

	COMPRESSION		TENSION		
fa(c or t) / Fa =	-0.106		0.068		
fbx / Fbx =	1.026		0.665		
fby / Fby =	0.068		0.044		
fd / Fbxy =	0.012		0.008		
SUM =	0.999	< 1.00	0.785	< 1.00	Tube is adequate

COMBINATION 12 - DL + Insulation + Settlement + Vacuum + 100 F (Case 2+7+8+11)

SETTLEMENT WITH COMBINATION
Delta x, x8 = 0 in Maxset = 1.224 = (x8^2 + y8^2)^0.5
Delta y, y8= 1.224 in

FIXED SUPPORTS
Rx = 0 lbs = Rfx2 + Rfx7 +x8 * Rfx8 + Rfx11
Ry = 4023 lbs = Rfy2 + Rfy7+ y8 * Rfy8 + Rfy11
Rz = 2209 lbs = Rfz2 + Rfz7 + Rfz11
Rmax per bolt = 2011 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2011 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS
Rx = 0 lbs = Rgx2 + Rgx7 + x8*Rgx8 + Rgx11
Ry = 10856 lbs = Rgy2 + Rgy7 + y8*Rgy8 + Rgy11
Rmax per bolt = 5428 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 5428 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION
Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.691 in = Dely2 + 0.5 * y8
Max Delta = 0.691 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES
fat = 771 psi, fav7 + fa11t , pos = tension
fbx = 6576 psi = fbx2 + fbx7 + y8 * fbx8 + fbx11
fby = 0 psi = fby2 + fby7 + x8 * fby8 + fby11

Md = 21223 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 89.3 psi = Md / S

COMBINED STRESS
fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3
Tension Allowable = 9100 psi = Sh * Et, for tension from page 3

	COMPRESSION		TENSION		
fa(c or t) / Fa =	-0.131		0.085		
fbx / Fbx =	1.115		0.723		
fby / Fby =	0.000		0.000		
fd / Fbxy =	0.015		0.010		
SUM =	0.999	< 1.00	0.817	< 1.00	Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 25 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.29

COMBINATION 13 - DL + Insul + Seis x + Dif settle + Vac + -15 F (Case 2+5+7+8+11)

SETTLEMENT WITH COMBINATION
Delta x, x8 = 0 in Maxset = 1.438 = (x8^2 + y8^2)^0.5
Delta y, y8= 1.438 in

FIXED SUPPORTS
Rx = 1287 lbs = Rfx2 + Rfx5 + Rfx7 +x8 * Rfx8 + Rfx11
Ry = 3499 lbs = Rfy2 + Rfy5 + Rfy7+ y8 * Rfy8 + Rfy11
Rz = 2209 lbs = Rfz2 + Rfz5 + Rfz7 + Rfz11
Rmax per bolt = 3551 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = -52 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS
Rx = 882 lbs = Rgx2 + Rgx5 + Rgx7 + x8*Rgx8 + Rgx11
Ry = 11902 lbs = Rgy2 + Rgy5 + Rgy7 + y8*Rgy8 + Rgy11
Rmax per bolt = 7186 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 4716 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION
Delta x (302) = 0.014 in = Delx5 + 0.5 * x8
Delta y (302) = 0.798 in = Dely2 + 0.5 * y8
Max Delta = 0.798 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES
fat = 771 psi, fav7 + fa11t , pos = tension
fbx = 7342 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx11
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby11

Md = 24441 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 102.8 psi = Md / S

COMBINED STRESS
fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3
Tension Allowable = 10920 psi = 1.2*Sh * Et, from page 3

	COMPRESSION		TENSION		
fa(c or t) / Fa =	-0.109		0.071		
fbx / Fbx =	1.037		0.672		
fby / Fby =	0.057		0.037		
fd / Fbxy =	0.015		0.009		
SUM =	0.999	< 1.00	0.789	< 1.00	Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 26 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	v.30

COMBINATION 14 - DL + Insul + Seis z + Dif settle + Vac + -16 F (Case 2+5+7+8+11)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 1.411 = (x8^2 + y8^2)^0.5
Delta y, y8= 1.411 in

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx6 + Rfx7 +x8 * Rfx8 + Rfx11
Ry = 3565 lbs = Rfy2 + Rfy6 + Rfy7+ y8 * Rfy8 + Rfy11
Rz = 4378 lbs = Rfz2 + Rfz6 + Rfz7 + Rfz11
Rmax per bolt = 1782 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 1782 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx6 + Rgx7 + x8*Rgx8 + Rgx11
Ry = 11770 lbs = Rgy2 + Rgy6 + Rgy7 + y8*Rgy8 + Rgy11
Rmax per bolt = 5885 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 5885 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.785 in = Dely27 + 0.5 * y8
Max Delta = 0.785 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fat = 660 psi, fav7 + fa11t - Rfz6 / A , pos = tension
fbx = 7245 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx11
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby11

Md = 20568 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 86.5 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3
Tension Allowable = 10920 psi = 1.2*Sh * Et, from page 3

	COMPRESSION		TENSION		
fa(c or t) / Fa =	-0.093		0.060		
fbx / Fbx =	1.023		0.663		
fby / Fby =	0.057		0.037		
fd / Fbxy =	0.012		0.008		
SUM =	0.999	< 1.00	0.769	< 1.00	Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 27 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.31

- CHECK RIM BENDING PER ROARK & YOUNG 4th Ed, TABLE XIII CASE 13

Mo = (p / 2 / landa^2) * (A / (A + t*c + 2 * t / landa)

p = 14.7 psi, internal pressure
Landa = 0.7277 = (3 * (1-0.3^2)/(((Do+t)/2)^2 * t^2))^0.25
A = 1.5 sq in = tss * wss
t = 0.127 in = t
c = 0.375 in = tss

Mo = 10.976 in lbs / in

Stress = 4083 psi = 6 * M / t^2 < 3 * S = 17700 psi

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 28 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.32

- SUMMARY - Vertical Differential Misalignment Only

	Fixed supports (lbs)			Guided Support (lbs)		Settlement (in)		Unity	
Combination	Rx	Ry	Rz	Rx	Ry	x	y	Comp	Tension
1	0	7018	5959	0	4980	0	0	0.638	
2	0	5601	5959	0	7810	0	0.579	0.999	
3	1287	5089	5959	882	8831	0	0.788	0.999	
4	0	5168	8128	0	8675	0	0.756	0.999	
5	1275	3413	771	874	8697	0	0.965	0.999	
6	0	7018	771	0	4834	0	0	0.384	
7	0	4541	771	0	9780	0	1.012	0.999	
8	1287	4010	771	882	10840	0	1.229	0.999	
9	0	4093	2939	0	10674	0	1.195	0.999	
10	0	6128	2209	0	11118	0	1.044	0.999	0.784
11	1275	2872	2209	874	9818	0	1.186	0.999	0.785
12	0	4023	2209	0	10856	0	1.224	0.999	0.817
13	1287	3499	2209	882	11902	0	1.438	0.999	0.789
14	0	3565	4378	0	11770	0	1.411	0.999	0.769

COMBINATIONS

1 - DL + Insulation + Vacuum + 302 F (Case 2 + 7 + 9)
2 - DL + Insulation + Settlement + Vacuum + 302 F (Case 2+7+8+9)
3 - DL + Insul + Seis x + Dif settle + Vac + 302 F (Case 2+5+7+8+9)
4 - DL + Insul + Seis z + Dif settle + Vac + 302 F (Case 2+5+7+8+9)

5 - DL + Wind + Dif Set + 100 F (Case 1 + 4 + 8 + 10)
6 - DL + Insulation + Vacuum + 100 F (Case 2 + 7 + 10)
7 - DL + Insulation + Settlement + Vacuum + 100 F (Case 2+7+8+10)
8 - DL + Insul + Seis x + Dif settle + Vac + 100 F (Case 2+5+7+8+10)
9 - DL + Insul + Seis z + Dif settle + Vac + 100 F (Case 2+5+7+8+10)

10 - DL + snow + Dif Set + -16 F (Case 1 + 3 + 8 + 11)
11 - DL + wind +Dif set -16 F (Case 1 + 4 + 8 + 11)
12 - DL + Insulation + Settlement + Vacuum + 100 F (Case 2+7+8+11)
13 - DL + Insul + Seis x + Dif settle + Vac + -15 F (Case 2+5+7+8+11)
14 - DL + Insul + Seis z + Dif settle + Vac + -16 F (Case 2+5+7+8+11)

SUBJECT

LIGO - BEAM TUBE DESIGN
Configuration 3, K = 8316 + 20%
Maximum Differential Settlements

OFFICE: NOE-C
REVISION:
REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY	
RJW	WJC			SHT 29 OF 29
DATE 3/11/94	DATE 4·4·94	DATE	DATE	0.33

- INPUT VARIABLES

Tube outside diameter, Do = 49.004 in
Beam Tube section length, L = 19.812 m = 65.000 ft
Beam Tube Span length, Lsp = 18.9484 m = 62.167 ft
Tube thickness, t = 0.127 in
Insulation Density, Deni = 24 kg/m = 16.127 lbs/ft

Vacuum Stiffener thickness, ts = 0.1875 in
Vacuum Stiffener width, ws = 1.75 in
Vacuum Stiffener spacing, Ls = 29.84 in
Support Stiffener thickness, tss = 0.375 in
Support Stiffener width, wss = 4 in

Mod. of Elast. @ ambient, Ea = 28,300 ksi Table TM-1 @ 70
Mod. of Elast. @ 302 degrees, Eb = 27,000 ksi Table TM-1, Page 664
Coefficient of expansion, e= 9E-06 in/in/F Average from 70 to 300 degrees F

Anchor bolt spacing, Abs = 30 in
C. line height of tube, H = 42.000 in
Support Collar / Saddle width, b = 20.000 in

Expansion Joint O.D., De = 53.75 in
Expansion Joint I.D., Dei = 48.75 in
E.J. Concentricity Error, CE = 0.1875 in
Expansion joint axial spring rate, Kej = 9147.6 lbs/in = 8316 * 1.1
Spring rate variation, Eej = 10.0%
Spring Rate, K = 10062 lbs/in = Kej * (1 + Eej)

SUBJECT

LIGO - BEAM TUBE DESIGN
Configuration 3, K = 8316 + 20%
Vertical Differential Settlement = 0.579"

OFFICE: NOE-C
REVISION:
REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY	
RJW	WJC			SHT 1 OF 29
DATE	DATE	DATE	DATE	
3/11/94	4-5-94			6.34

- ALLOWABLE STRESS PER ASME SECTION VIII DIV 1 UG 23(b)

- Allowable Stresses @ 300 Degrees F.

Yield Stress, Fy =	19,200 psi	Table Y1
Tensile Allowable, Sh =	13000 psi	Table 1A
Joint Efficiency, Et =	0.7	
Compression Allowable		UG 23(b)

A = 0.000648 = 0.125 / (Ro/t)
B = 5900 psi per Figure HA 3, interpolate to 300 degrees F.
Where B = Fa = Fbx = Fby = Fbxy, local buckling stress
See below for column buckling

- Allowable Stresses @ Ambient (100 degrees F)

Yield Stress =	25,000 psi	Table Y1
Tensile Allowable, Sa =	16,300 psi	Table 1A
Compression Allowable		UG 23(b)

A = 0.000648 = 0.125 / (Ro/t)
B = 7800 psi per Figure HA 3, 100 degrees F.
Where B = Fa = Fbx = Fby = Fbxy

- Allowable Stress Increase for Wind and Seismic
  Allowable increase for wind or seismic is 1.20

- Allowable Axial Stress, Column Buckling per AISC

k = 1
L = 746 in = Lsp * 12
r = 17.28069 in = rg

kL / r = 43.16958

Cc = 166.6081 = (2 * PI()^2 * Eb * 1000 / Fy)^0.5

Fa = 10533 psi = (1- (kL/r)^2 / 2 / Cc^2)*Fy / (5/3 + 3*(kL/r)/8/Cc - (kL/r)^3/8/Cc^3)

Fa > B, Thus use B = 5900 psi

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 3 OF 29
	DATE 3/11/94	DATE 4.5.94	DATE	DATE	6.36

- CALCULATE WIND LOAD PER ASCE 7-88 (Livingston, LA)

F = Qz * Gh * Cf * Af	Table 4
Qz = 4.1472 = 0.00256*Kz * (I*V)^2	Eq 3
Kz = 0.80 , Assume exposure C	Table 6
I = 1.00	Table 5
V = 45 mph	Figure 1
Gh = 1.32	Table 8
Cf = 0.739 h / D = 0.0853	Table 12
h = (Do / 2 +H)/12	
D = L	
D' / Do = ws / Do = 0.03571	
Af = 4.084 Sqft / ft = Do / 12	
F = 16.53 lbs / ft	
F = 1074 lbs / section	

- CALCULATE WIND LOAD PER ASCE 7-88 (Hanford, WA)

F = Qz * Gh * Cf * Af	Table 4
Qz = 4.1472 = 0.00256*Kz * (I*V)^2	Eq 3
Kz = 0.80 , Assume exposure C	Table 6
I = 1.00	Table 5
V = 45 mph	Figure 1
Gh = 1.32	Table 8
Cf = 0.739 h / D = 0.0853	Table 12
h = (Do / 2 +H)/12	
D = L	
D' / Do = ws / Do = 0.03571	
Af = 4.083667 Sqft / ft = Do / 12	
F = 16.53 lbs / ft = ww	
F = 1074 lbs / section	

- CALCULATE SEISMIC LOAD PER UBC (Livingston, LA)

V = Z * I * C / Rw * W
Z = 0
I = 1.0
C = 2.75
Rw = 3
C/Rw = 0.916667 > 0.075 use: 0.91667
W = 91.00 lbs/ft = DL + Insulation
V = 0.0500W = 0.05W mimimum per ASCE 7-88, 9.11.2
V = 4.55 Lbs/ft
V = 295.8 Lbs per section

- CALCULATE SEISMIC LOAD PER ASCE 7-88 (Hanford, WA)

V = Z * I * C / Rw * W
Z = 0.2
I = 1.0
C = 2.75
Rw = 3
C/Rw = 0.916667 > 0.075 use: 0.91667
W = 91.00 lbs/ft = DL + Insulation
V = 0.1833W
V = 16.68 Lbs/ft = wseis
V = 1084.4 Lbs per section

- CALCULATE SNOW LOAD PER ASCE 7-88 (Hanford, WA only)

Pf =	15.12	= 0.7 * Ce * Ct * I * Pg	Eq 5a
Ce =	0.9	Little shelter assumed	Table 18
Ct =	1.2	Unheated	Table 19
I =	1	Category 1	Table 20
Pg =	20	psf	Figure 6

Ps = 9.828 = Cs * Pf
Cs = 0.65 Angle is 35 degrees, 90-(180-70)/2, Figure 8b

Width = 46.049 in = Do * Sin 70 Per 7.4.3, slope > 70 no load
Snow Load per foot, wsn = 37.71 lbs/ft = Ps * Width
Snow load per section = 2451 lbs

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 5 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.38

- DETERMINE REACTIONS, STRESSES AND DEFLECTIONS FOR INDIVIDUAL LOAD CASES

- Nomenclature

Rfx1 = Reaction, fixed support, x direction (horizontal), case 1
Rgy2 = Reaction, guided support, y direction (vertical), case 2
Rfz1 = Reaction, fixed support, z direction (axial), case 1
Mx1 = Moment about the horizontal axis due to vertical loads, Case 1.
My2 = Moment about the vertical axis due to horizontal loads, Case 2.
fa9c = Stress, axial, case 9, compression, (if tension t is used instead of c)

- Reactions Based on RISA2D

Fixed support = 7.029 kips, per RISA2D
1/2 of guided support = 2.41 kips, per RISA2D
Total, two spans = 11.849 kips, per RISA2D

% Fixed support, Kf = 0.593215 (Percentage of 2 spans)
% Guided support, Kg = 0.406785

- Moments based on RISA2D

Maximum Moment = 43480 lb-ft, at fixed support
Based on, 91 lbs/ft, DL + Insulation, used in RISA2D

True DL + Insulation = wdi = 91.00
Estimated Moment = 43961 lb-ft = wdi * (Lsp ft)^2 / 8

Moment correction factor, Km = 0.989 = RISA2D moment / Estimated moment

- Deflections based on RISA2D

Midspan Deflection = 0.079 in
Based on, 91 lbs/ft, DL + Insulation, used in RISA2D

True DL + Insulation = wdi = 91.00
Estimated Deflection = 0.081 in = wdi * Lsp^4 / 185 / Eb / I * 12^3 / 1000

Moment correction factor, Kd = 0.978 = RISA2D deflection / Estimated deflection

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 6 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.79

- CASE 1: Dead Load Reactions, Stresses and Deflections

FIXED SUPPORT
Rfx1 = 0
Rfy1 = 5774 lbs = Kf * 2 * L * wd
Rfz1 = 0

GUIDED SUPPORT
Rgx1 = 0
Rgy1 = 3959 lbs = Kg * 2 * L * wd

MOMENTS & BENDING STRESS
Mx1 = 35774 lb-ft = wd * (Lsp)^2 / 8 * Km
fbx1 = 1806 psi = Mx1 * 12 / S

My1 = 0
fby1 = 0 psi = My1 * 12 / S

MIDSPAN DEFLECTION
Dely1 (amb)= 0.062 in = wd * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 2: Dead Load plus Insulation Reaction, Stresses and Deflections

FIXED SUPPORT
Rfx2 = 0
Rfy2 = 7018 lbs = Kf * 2 * L * wdi
Rfz2 = 0

GUIDED SUPPORT
Rgx2 = 0
Rgy2 = 4812 lbs = Kg * 2 * L * wdi

MOMENTS & BENDING STRESS
Mx2 = 43480 lb-ft = wdi * (Lsp)^2 / 8 * Km
fbx2 = 2195 psi = Mx2 * 12 / S

My2 = 0
fby2 = 0 psi = My2 * 12 / S

MIDSPAN DEFLECTION
Dely2 (302)= 0.079 in = wdi * Lsp^4 / 185 / Eb / I * 12^3 / 1000 * Kd

SUBJECT

LIGO - BEAM TUBE DESIGN
Configuration 3, K = 8316 + 20%
Vertical Differential Settlement = 0.579"

OFFICE: NOE-C
REVISION:
REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY	
RJW	WJC			SHT 7 OF 29
DATE	DATE	DATE	DATE	
3/11/94	4-5-94			6.40

- CASE 3: Snow Load Reaction, Stresses and Deflections (Hanford, WA)

FIXED SUPPORT

Rfx3 = 0
Rfy3 = 2908 lbs = Kf * 2 * L * wsn
Rfz3 = 0

GUIDED SUPPORT

Rgx3 = 0
Rgy3 = 1994 lbs = Kg * 2 * L * wsn

MOMENTS & BENDING STRESS

Mx3 = 18020 lb-ft = wsn * (Lsp)^2 / 8 * Km
fbx3 = 910 psi = Mx3 * 12 / S

My3 = 0
fby3 = 0 psi = My3 * 12 / S

MIDSPAN DEFLECTION

Dely3 (amb)= 0.031 in = wsn * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 4: Wind Load Reaction, Stresses and Deflections (Livingston, LA)

FIXED SUPPORT

Rfx4 = 1275 lbs = ww * 2 * L * Kf
Rfy4 = 0
Rfz4 = 0

GUIDED SUPPORT

Rgx4 = 874 lbs = ww * 2 * L * Kg
Rgy4 = 0

MOMENTS & BENDING STRESS

Mx4 = 0
fbx4 = 0 psi = Mx4 * 12 / S

My4 = 7896 lb-ft = ww * (Lsp)^2 / 8 * Km
fby4 = 399 psi = My4 * 12 / S

MIDSPAN DEFLECTION

Delx4 (amb)= 0.014 in = ww * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 5: Seismic Reaction, Stresses and Deflections (Hanford, WA), X Direction (Horizontal)

FIXED SUPPORT

Rfx5 = 1287 lbs = wseis * 2 * L * Kf
Rfy5 = 0
Rfz5 = 0

GUIDED SUPPORT

Rgx5 = 882 lbs = wseis * 2 * L * Kg
Rgy5 = 0

MOMENTS & BENDING STRESS

Mx5 = 0
fbx5 = 0 psi = Mx5 * 12 / S

My5 = 7971 lb-ft = wseis * (Lsp)^2 / 8 * Km
fby5 = 402 psi = My5 * 12 / S

MIDSPAN DEFLECTION

Delx5 (amb)= 0.014 in = wseis * Lsp^4 / 185 / Ea / I * 12^3 / 1000 * Kd

- CASE 6: Seismic Reaction, Stresses and Deflections (Hanford, WA), Z Direction (Axial)

FIXED SUPPORT

Rfx6 = 0
Rfy6 = 0
Rfz6 = 2169 lbs = wseis * 2 * L

GUIDED SUPPORT

Rgx6 = 0
Rgy6 = 0

MOMENTS & BENDING STRESS

Mx6 = 0
fbx6 = 0 psi = Mx5 * 12 / S

My6 = 0
fby6 = 0 psi = My6 * 12 / S

MIDSPAN DEFLECTION

Dely6 (amb)= 0.000 in

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 9 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.42

- CASE 7: Vacuum

Bellows effective area = 2062.9 sq in = PI()*((De+Dei)/2)^2/4
Tube pressure area = 1866.55 sq in = PI()*((Di))^2/4
Bellows pressure area = 196.35 sq in =Bellows effective - tube area
Axial force, Pzp = 2886 lbs = 14.7*Bellows pressure area, pos.=tension

Axial Stress due to vacuum, fav7 = 148.0 psi = Pzp / A, pos. = tension

FIXED SUPPORT
Rfx7 = 0 lbs
Rfy7 = 0
Rfz7 = 0

GUIDED SUPPORT
Rgx7 = 0 lbs
Rgy7 = 0

fbx7 = fby7 = 0

Dely7 = 0

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 10 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	v.43

- CASE 8: Differential Settlement of Fixed Support

  - Reactions Based on RISA2D with 1" differential settlement

Fixed support = -2.37 kips, per RISA2D
1/2 of guided support = 2.47 kips, per RISA2D
Based on, 1 lbs/ft, DL, used in RISA2D

FIXED SUPPORTS
Rfx8 = -2447 lbs = (RISA2D fixed) - DL * 2 * L * Kf
Rfy8 = -2447 lbs = (RISA2D fixed) - DL * 2 * L * Kf
GUIDED SUPPORTS
Rgx8 = 4887 lbs = 2 * (RISA2D guided) - DL * 2 * L * Kg
Rgy8 = 4887 lbs = 2 * (RISA2D guided) - DL * 2 * L * Kg

  - Moments based on RISA2D with 1" differential settlement

Maximum Moment = 71360 lb-ft, at fixed support
Based on, 1 lbs/ft, DL + Insulation, used in RISA2D

Mx8 = My8 = 70882 lb-ft = (RISA2D Moment) - DL * Lsp^2 / 8 * Km
fbx8 = fby8 = 3579 psi = Mx8 * 12 / S

SUBJECT LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 11 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.44

- CASE 9: Expansion Joint Forces at 302 Degrees F.

Maximum Bellows spring rate, K = 10062 lbs/in = Kej * (1 + Eej)
Est. temp. change above 70, Tch = 232 degrees Fahrenheit
Thermal growth hot, x = 3.257 in = e * 2 * L * 12 * Tch
Longitudinal Comp. force, Pbc = 32776 lbs = K * x
fa9c = -1681 psi = Pbc / A, stress on tube, neg is comp

FIXED SUPPORT
Rfx9 = 0 lbs
Rfy9 = 0
Rfz9 = 5959 lbs = 2 * Eej * Kej * x

GUIDED SUPPORT
Rgx9 = 0
Rgy9 = 167.8 lbs = Rfz9 * H / Lsp / 12 /2

fbx9 = fby9 = 0
Delx9 = Dely9 = 0

- CASE 10: Expansion Joint Forces at 100 Degrees F.

Maximum Bellows spring rate, K = 10062 lbs/in = Kej * (1 + Eej)
Est. temp. change above 70, Tch = 30 degrees Fahrenheit
Thermal growth hot, xw = 0.421 in = e * 2 * L * 12 * Tch
Longitudinal Comp. force, Pbc = 4238 lbs = K * xw
fa10c = -217 psi = Pbc / A, stress on tube, neg is comp

FIXED SUPPORT
Rfx10 = 0 lbs
Rfy10 = 0
Rfz10 = 771 lbs = 2 * Eej * Kej * xw

GUIDED SUPPORT
Rgx10 = 0
Rgy10 = 21.7 lbs = Rfz10 * H / Lsp / 12 /2

fbx10 = fby10 = 0
Delx10 = Dely10 = 0

SUBJECT
LIGO - BEAM TUBE DESIGN
Configuration 3, K = 8316 + 20%
Vertical Differential Settlement = 0.579"

OFFICE: NOE-C
REVISION:
REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY	
RJW	WJC			SHT 12 OF 29
DATE	DATE	DATE	DATE	
3/11/94	4-5-94			6.45

- CASE 11: Expansion Joint Forces at -16 Degrees F.

Maximum Bellows spring rate, K = 10062 lbs/in = Kej * (1 + Eej)
Est. temp. change below 70, Tchc = 86 degrees Fahrenheit
Thermal shrinkage, xs = -1.207 in = e * 2 * L * 12 * Tchc
Longitudinal Tension force, Pbt = 12150 lbs = K * xs
fa11t = 623 psi = -Pbt / A Positive is tension

FIXED SUPPORT
Rfx11 = 0 lbs
Rfy11 = 0
Rfz11 = 2209 lbs = -2 * Eej * Kej * xs

GUIDED SUPPORT
Rgx11 = 0
Rgy11 = 62.2 lbs = Rfz11 * H / Lsp / 12 /2

fbx11 = fby11 = 0
Delx11 = Dely11 = 0

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 13 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.46

- LOAD COMBINATIONS FOR MAXIMUM REACTIONS, STRESS AND DEFLECTIONS

COMBINATION 1 - DL + Insulation + Vacuum + 302 F (Case 2 + 7 + 9)

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx7 + Rfx9 (laterial)
Ry = 7018 lbs = Rfy2 + Rfy7 + Rfy9 (Vertical)
Rz = 5959 lbs = Rfz2 + Rfz7 + Rfz9 (axial)
Rmax per bolt = 3509 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3509 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx7 + Rgx9
Ry = 4980 lbs = Rgy2 + Rgy7 + Rgy9 (Vertical)
Rmax per bolt = 2490 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2490 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = Delx2 + Delx7 + Delx9
Delta y (302) = 0.079 in = Dely2 + Dely7 + Dely9
Max Delta = 0.079 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -1533 psi, fav7 + fa9c , neg = compression
fbx = 2195 psi = fbx2 + fbx7 + fbx9
fby = 0 psi = fby2 + fby7 + fby9

Md = 7966 in-lbs = fac * A * (Max Delta + CE)
fd = 33.5 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.260
fbx / Fbx = 0.372
fby / Fby = 0.000
fd / Fbxy = 0.006
SUM = 0.638 < 1.00 Tube is adequate

<table>
<tr><td rowspan="3">SUBJECT
LIGO - BEAM TUBE DESIGN
Configuration 3, K = 8316 + 20%
Vertical Differential Settlement = 0.579"</td><td colspan="2">OFFICE: NOE-C</td><td colspan="2">REVISION:</td><td>REFERENCE NO.
930212</td></tr>
<tr><td>MADE BY
RJW</td><td>CHKD BY
WJC</td><td>MADE BY</td><td>CHKD BY</td><td>SHT 14 OF 29</td></tr>
<tr><td>DATE
3/11/94</td><td>DATE
4-5-94</td><td>DATE</td><td>DATE</td><td>6.47</td></tr>
</table>

COMBINATION 2 - DL + Insulation + Settlement + Vacuum + 302 F (Case 2+7+8+9)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx7 +x8 * Rfx8 + Rfx9
Ry = 5601 lbs = Rfy2 + Rfy7+ y8 * Rfy8 + Rfy9
Rz = 5959 lbs = Rfz2 + Rfz7 + Rfz9
Rmax per bolt = 2800 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2800 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx7 + x8*Rgx8 + Rgx9
Ry = 7810 lbs = Rgy2 + Rgy7 + y8*Rgy8 + Rgy9
Rmax per bolt = 3905 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3905 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.369 in = Dely2 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -1533 psi, fav7 + fa9c , neg = compression
fbx = 4267 psi = fbx2 + fbx7 + y8 * fbx8 + fbx9
fby = 0 psi = fby2 + fby7 + x8 * fby8 + fby9

Md = 22910 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 96.4 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.260
fbx / Fbx = 0.723
fby / Fby = 0.000
fd / Fbxy = 0.016
SUM = 0.999 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 15 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.48

COMBINATION 3 - DL + Insul + Seis x + Dif settle + Vac + 302 F (Case 2+5+7+8+9)

SETTLEMENT WITH COMBINATION
Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS
Rx = 1287 lbs = Rfx2 + Rfx5 + Rfx7 +x8 * Rfx8 + Rfx9
Ry = 5601 lbs = Rfy2 + Rfy5 + Rfy7+ y8 * Rfy8 + Rfy9
Rz = 5959 lbs = Rfz2 + Rfz5 + Rfz7 + Rfz9
Rmax per bolt = 4602 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 999 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS
Rx = 882 lbs = Rgx2 + Rgx5 + Rgx7 + x8*Rgx8 + Rgx9
Ry = 7810 lbs = Rgy2 + Rgy5 + Rgy7 + y8*Rgy8 + Rgy9
Rmax per bolt = 5140 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2670 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION
Delta x (302) = 0.014 in = Delx5 + 0.5 * x8
Delta y (302) = 0.369 in = Dely2 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES
fac = -1533 psi, fav7 + fa9c , neg = compression
fbx = 4267 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx9
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby9

Md = 22910 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 96.4 psi = Md / S

COMBINED STRESS (compression)
fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3

fac / Fa = 0.216
fbx / Fbx = 0.603
fby / Fby = 0.057
fd / Fbxy = 0.014
SUM = 0.890 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 16 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.49

COMBINATION 4 - DL + Insul + Seis z + Dif settle + Vac + 302 F (Case 2+5+7+8+9)

SETTLEMENT WITH COMBINATION
Delta x, x8 = 0 in   Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS
Rx = 0 lbs = Rfx2 + Rfx6 + Rfx7 +x8 * Rfx8 + Rfx9
Ry = 5601 lbs = Rfy2 + Rfy6 + Rfy7+ y8 * Rfy8 + Rfy9
Rz = 8128 lbs = Rfz2 + Rfz6 + Rfz7 + Rfz9
Rmax per bolt = 2800 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2800 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS
Rx = 0 lbs = Rgx2 + Rgx6 + Rgx7 + x8*Rgx8 + Rgx9
Ry = 7810 lbs = Rgy2 + Rgy6 + Rgy7 + y8*Rgy8 + Rgy9
Rmax per bolt = 3905 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3905 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION
Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.369 in = Dely27 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES
fac = -1644 psi, fav7 + fa9c - Rfz6 / A , neg = compression
fbx = 4267 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx9
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby9

Md = 24573 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 103.4 psi = Md / S

COMBINED STRESS (compression)
fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3

fac / Fa = 0.232
fbx / Fbx = 0.603
fby / Fby = 0.057
fd / Fbxy = 0.015
SUM = 0.906 < 1.00   Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 17 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.50

COMBINATION 5 - DL + Wind + Dif Set + 100 F (Case 1 + 4 + 8 + 10)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS

Rx = 1275 lbs = Rfx1 + Rfx4 +x8 * Rfx8 + Rfx10
Ry = 4357 lbs = Rfy1 + Rfy4+ y8 * Rfy8 + Rfy10
Rz = 771 lbs = Rfz1 + Rfz4 + Rfz10
Rmax per bolt = 3963 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 394 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 874 lbs = Rgx1 + Rgx4 + x8*Rgx8 + Rgx10
Ry = 6811 lbs = Rgy1 + Rgy4 + y8*Rgy8 + Rgy10
Rmax per bolt = 4629 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2182 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.014 in = Delx4 + 0.5 * x8
Delta y (302) = 0.352 in = Dely1 + 0.5 * y8
Max Delta = 0.352 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -217 psi, fav4 + fa10c , neg = compression
fbx = 3878 psi = fbx1 + fbx4 + y8 * fbx8 + fbx10
fby = 399 psi = fby1 + fby4 + x8 * fby8 + fby10

Md = 3249 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 13.7 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.037
fbx / Fbx = 0.657
fby / Fby = 0.068
fd / Fbxy = 0.002
SUM = 0.764 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 18 OF 29
	DATE 3/11/94	DATE 4-1-94	DATE	DATE	6.51

COMBINATION 6 - DL + Insulation + Vacuum + 100 F (Case 2 + 7 + 10)

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx7 + Rfx10 (laterial)
Ry = 7018 lbs = Rfy2 + Rfy7 + Rfy10 (Vertical)
Rz = 771 lbs = Rfz2 + Rfz7 + Rfz10 (axial)
Rmax per bolt = 3509 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3509 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx7 + Rgx10
Ry = 4834 lbs = Rgy2 + Rgy7 + Rgy10 (Vertical)
Rmax per bolt = 2417 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2417 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = Delx2 + Delx7 + Delx10
Delta y (302) = 0.079 in = Dely2 + Dely7 + Dely10
Max Delta = 0.079 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -69 psi, fav7 + fa10c , neg = compression
fbx = 2195 psi = fbx2 + fbx7 + fbx10
fby = 0 psi = fby2 + fby7 + fby10

Md = 360 in-lbs = fac * A * (Max Delta + CE)
fd = 1.5 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.012
fbx / Fbx = 0.372
fby / Fby = 0.000
fd / Fbxy = 0.000
SUM = 0.384 < 1.00 Tube is adequate

SUBJECT LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY VNC	MADE BY	CHKD BY	SHT 19 OF 29
	DATE 3/11/94	DATE 45-94	DATE	DATE	6.52

COMBINATION 7 - DL + Insulation + Settlement + Vacuum + 100 F (Case 2+7+8+10)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx7 +x8 * Rfx8 + Rfx10
Ry = 5601 lbs = Rfy2 + Rfy7+ y8 * Rfy8 + Rfy10
Rz = 771 lbs = Rfz2 + Rfz7 + Rfz10
Rmax per bolt = 2800 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2800 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx7 + x8*Rgx8 + Rgx10
Ry = 7664 lbs = Rgy2 + Rgy7 + y8*Rgy8 + Rgy10
Rmax per bolt = 3832 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3832 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.369 in = Dely2 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -69 psi, fav7 + fa10c , neg = compression
fbx = 4267 psi = fbx2 + fbx7 + y8 * fbx8 + fbx10
fby = 0 psi = fby2 + fby7 + x8 * fby8 + fby10

Md = 1036 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 4.4 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3

fac / Fa = 0.012
fbx / Fbx = 0.723
fby / Fby = 0.000
fd / Fbxy = 0.001
SUM = 0.736 < 1.00 Tube is adequate

COMBINATION 8 - DL + Insul + Seis x + Dif settle + Vac + 100 F (Case 2+5+7+8+10)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in   Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS

Rx = 1287 lbs = Rfx2 + Rfx5 + Rfx7 +x8 * Rfx8 + Rfx10
Ry = 5601 lbs = Rfy2 + Rfy5 + Rfy7+ y8 * Rfy8 + Rfy10
Rz = 771 lbs = Rfz2 + Rfz5 + Rfz7 + Rfz10
Rmax per bolt = 4602 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 999 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 882 lbs = Rgx2 + Rgx5 + Rgx7 + x8*Rgx8 + Rgx10
Ry = 7664 lbs = Rgy2 + Rgy5 + Rgy7 + y8*Rgy8 + Rgy10
Rmax per bolt = 5067 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2597 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.014 in = Delx5 + 0.5 * x8
Delta y (302) = 0.369 in = Dely2 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fac = -69 psi, fav7 + fa10c , neg = compression
fbx = 4267 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx10
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby10

Md = 1036 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 4.4 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3

fac / Fa = 0.010
fbx / Fbx = 0.603
fby / Fby = 0.057
fd / Fbxy = 0.001
SUM = 0.670 < 1.00   Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 21 OF 27
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.54

COMBINATION 9 - DL + Insul + Seis z + Dif settle + Vac + 100 F (Case 2+5+7+8+10)

SETTLEMENT WITH COMBINATION
Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS
Rx = 0 lbs = Rfx2 + Rfx6 + Rfx7 +x8 * Rfx8 + Rfx10
Ry = 5601 lbs = Rfy2 + Rfy6 + Rfy7+ y8 * Rfy8 + Rfy10
Rz = 2939 lbs = Rfz2 + Rfz6 + Rfz7 + Rfz10
Rmax per bolt = 2800 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2800 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS
Rx = 0 lbs = Rgx2 + Rgx6 + Rgx7 + x8*Rgx8 + Rgx10
Ry = 7664 lbs = Rgy2 + Rgy6 + Rgy7 + y8*Rgy8 + Rgy10
Rmax per bolt = 3832 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3832 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION
Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.369 in = Dely27 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES
fac = -181 psi, fav7 + fa10c - Rfz6 / A , neg = compression
fbx = 4267 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx10
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby10

Md = 2699 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 11.4 psi = Md / S

COMBINED STRESS (compression)
fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3

fac / Fa = 0.026
fbx / Fbx = 0.603
fby / Fby = 0.057
fd / Fbxy = 0.002
SUM = 0.687 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 22 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.55.

COMBINATION 10 - DL + snow + Dif Set + -16 F (Case 1 + 3 + 8 + 11)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS

Rx = 0 lbs = Rfx1 + Rfx3 +x8 * Rfx8 + Rfx11
Ry = 7266 lbs = Rfy1 + Rfy3+ y8 * Rfy8 + Rfy11
Rz = 2209 lbs = Rfz1 + Rfz3 + Rfz11
Rmax per bolt = 3633 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3633 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx1 + Rgx3 + x8*Rgx8 + Rgx11
Ry = 8846 lbs = Rgy1 + Rgy3 + y8*Rgy8 + Rgy11
Rmax per bolt = 4423 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 4423 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.383 in = Dely1 + Dely3 +0.5 * y8
Max Delta = 0.383 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fat = 623 psi, fa11t , pos = tension
fbx = 4788 psi = fbx1 + fbx3 + y8 * fbx8 + fbx11
fby = 0 psi = fby1 + fby3 + x8 * fby8 + fby11

Md = 9313 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 39.2 psi = Md / S

COMBINED STRESS

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3
Tension Allowable = 9100 psi = Sh * Et, for tension from page 3

	COMPRESSION		TENSION	
fa(c or t) / Fa =	-0.106		0.068	
fbx / Fbx =	0.812		0.526	
fby / Fby =	0.000		0.000	
fd / Fbxy =	0.007		0.004	
SUM =	0.713	< 1.00	0.599	< 1.00 Tube is adequate

SUBJECT

LIGO - BEAM TUBE DESIGN
Configuration 3, K = 8316 + 20%
Vertical Differential Settlement = 0.579"

OFFICE: NOE-C
REVISION:
REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY	
RJW	WJC			SHT 23 OF 29
DATE	DATE	DATE	DATE	
3/11/94	4-5-94			6.56.

COMBINATION 11 - DL + wind +Dif set -16 F (Case 1 + 4 + 8 + 11)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS

Rx = 1275 lbs = Rfx1 + Rfx4 +x8 * Rfx8 + Rfx11
Ry = 4357 lbs = Rfy1 + Rfy4+ y8 * Rfy8 + Rfy11
Rz = 2209 lbs = Rfz1 + Rfz4 + Rfz11
Rmax per bolt = 3963 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 394 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 874 lbs = Rgx1 + Rgx4 + x8*Rgx8 + Rgx11
Ry = 6851 lbs = Rgy1 + Rgy4 + y8*Rgy8 + Rgy11
Rmax per bolt = 4649 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2202 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.014 in =Delx4 + 0.5 * x8
Delta y (302) = 0.352 in = Dely1 + 0.5 * y8
Max Delta = 0.352 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fat = 623 psi, fa11t , pos = tension
fbx = 3878 psi = fbx1 + fbx4 + y8 * fbx8 + fbx11
fby = 399 psi = fby1 + fby4 + x8 * fby8 + fby11

Md = 9313 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 39.2 psi = Md / S

COMBINED STRESS

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3
Tension Allowable = 9100 psi = Sh * Et, for tension from page 3

	COMPRESSION	TENSION
fa(c or t) / Fa =	-0.106	0.068
fbx / Fbx =	0.657	0.426
fby / Fby =	0.068	0.044
fd / Fbxy =	0.007	0.004
SUM =	0.626 < 1.00	0.543 < 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 24 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.57

COMBINATION 12 - DL + Insulation + Settlement + Vacuum + 100 F (Case 2+7+8+11)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx7 +x8 * Rfx8 + Rfx11
Ry = 5601 lbs = Rfy2 + Rfy7+ y8 * Rfy8 + Rfy11
Rz = 2209 lbs = Rfz2 + Rfz7 + Rfz11
Rmax per bolt = 2800 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2800 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx7 + x8*Rgx8 + Rgx11
Ry = 7704 lbs = Rgy2 + Rgy7 + y8*Rgy8 + Rgy11
Rmax per bolt = 3852 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3852 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.369 in = Dely2 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fat = 771 psi, fav7 + fa11t , pos = tension
fbx = 4267 psi = fbx2 + fbx7 + y8 * fbx8 + fbx11
fby = 0 psi = fby2 + fby7 + x8 * fby8 + fby11

Md = 11525 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 48.5 psi = Md / S

COMBINED STRESS

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 5900 psi for compression from page 3
Tension Allowable = 9100 psi = Sh * Et, for tension from page 3

	COMPRESSION		TENSION		
fa(c or t) / Fa =	-0.131		0.085		
fbx / Fbx =	0.723		0.469		
fby / Fby =	0.000		0.000		
fd / Fbxy =	0.008		0.005		
SUM =	0.601	< 1.00	0.559	< 1.00	Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 25 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	v.58

COMBINATION 13 - DL + Insul + Seis x + Dif settle + Vac + -15 F (Case 2+5+7+8+11)

SETTLEMENT WITH COMBINATION
Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS
Rx = 1287 lbs = Rfx2 + Rfx5 + Rfx7 +x8 * Rfx8 + Rfx11
Ry = 5601 lbs = Rfy2 + Rfy5 + Rfy7+ y8 * Rfy8 + Rfy11
Rz = 2209 lbs = Rfz2 + Rfz5 + Rfz7 + Rfz11
Rmax per bolt = 4602 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 999 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS
Rx = 882 lbs = Rgx2 + Rgx5 + Rgx7 + x8*Rgx8 + Rgx11
Ry = 7704 lbs = Rgy2 + Rgy5 + Rgy7 + y8*Rgy8 + Rgy11
Rmax per bolt = 5087 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2617 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION
Delta x (302) = 0.014 in = Delx5 + 0.5 * x8
Delta y (302) = 0.369 in = Dely2 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES
fat = 771 psi, fav7 + fa11t , pos = tension
fbx = 4267 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx11
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby11

Md = 11525 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 48.5 psi = Md / S

COMBINED STRESS
fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3
Tension Allowable = 10920 psi = 1.2*Sh * Et, from page 3

	COMPRESSION		TENSION	
fa(c or t) / Fa =	-0.109		0.071	
fbx / Fbx =	0.603		0.391	
fby / Fby =	0.057		0.037	
fd / Fbxy =	0.007		0.004	
SUM =	0.558	< 1.00	0.503	< 1.00 Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 26 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6,59

COMBINATION 14 - DL + Insul + Seis z + Dif settle + Vac + -16 F (Case 2+5+7+8+11)

SETTLEMENT WITH COMBINATION

Delta x, x8 = 0 in Maxset = 0.579 = (x8^2 + y8^2)^0.5
Delta y, y8= 0.579 in

FIXED SUPPORTS

Rx = 0 lbs = Rfx2 + Rfx6 + Rfx7 +x8 * Rfx8 + Rfx11
Ry = 5601 lbs = Rfy2 + Rfy6 + Rfy7+ y8 * Rfy8 + Rfy11
Rz = 4378 lbs = Rfz2 + Rfz6 + Rfz7 + Rfz11
Rmax per bolt = 2800 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 2800 lbs = Ry/2 - Rx * H / Abs

GUIDED SUPPORTS

Rx = 0 lbs = Rgx2 + Rgx6 + Rgx7 + x8*Rgx8 + Rgx11
Ry = 7704 lbs = Rgy2 + Rgy6 + Rgy7 + y8*Rgy8 + Rgy11
Rmax per bolt = 3852 lbs = Ry/2 + Rx * H / Abs
Rmin per bolt = 3852 lbs = Ry/2 - Rx * H / Abs

MIDSPAN DEFLECTION

Delta x (302) = 0.000 in = 0.5 * x8
Delta y (302) = 0.369 in = Dely27 + 0.5 * y8
Max Delta = 0.369 in = (Delta x ^2 + Delta y ^2)^0.5

TUBE STRESSES

fat = 660 psi, fav7 + fa11t - Rfz6 / A , pos = tension
fbx = 4267 psi = fbx2 + fbx5 + fbx7 + y8 * fbx8 + fbx11
fby = 402 psi = fby2 + fby5 + fby7 + x8 * fby8 + fby11

Md = 9863 in-lbs = fac * A * (Max(Max Delta or maxset) + CE)
fd = 41.5 psi = Md / S

COMBINED STRESS (compression)

fat/Fa + fbx/Fbx + fby/Fby +fd/Fbxy < = 1.00
Where B=Fa=Fbx=Fby=Fbxy= 7080 psi = 1.2 * B from page 3
Tension Allowable = 10920 psi = 1.2*Sh * Et, from page 3

	COMPRESSION		TENSION		
fa(c or t) / Fa =	-0.093		0.060		
fbx / Fbx =	0.603		0.391		
fby / Fby =	0.057		0.037		
fd / Fbxy =	0.006		0.004		
SUM =	0.572	< 1.00	0.492	< 1.00	Tube is adequate

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 27 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.60

- CHECK RIM BENDING PER ROARK & YOUNG 4th Ed, TABLE XIII CASE 13

Mo = (p / 2 / landa^2) * (A / (A + t*c + 2 * t / landa)

p = 14.7 psi, internal pressure
Landa = 0.7277 = (3 * (1-0.3^2)/(((Do+t)/2)^2 * t^2))^0.25
A = 1.5 sq in = tss * wss
t = 0.127 in = t
c = 0.375 in = tss

Mo = 10.976 in lbs / in

Stress = 4083 psi = 6 * M / t^2 < 3 * S = 17700 psi

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 28 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.61

- SUMMARY - Vertical Differential Misalignment Only

Combination	Fixed supports (lbs)			Guided Support (lbs)		Settlement (in)		Unity	
	Rx	Ry	Rz	Rx	Ry	x	y	Comp	Tension
1	0	7018	5959	0	4980	0	0	0.638	
2	0	5601	5959	0	7810	0	0.579	0.999	
3	1287	5601	5959	882	7810	0	0.579	0.890	
4	0	5601	8128	0	7810	0	0.579	0.906	
5	1275	4357	771	874	6811	0	0.579	0.764	
6	0	7018	771	0	4834	0	0	0.384	
7	0	5601	771	0	7664	0	0.579	0.736	
8	1287	5601	771	882	7664	0	0.579	0.670	
9	0	5601	2939	0	7664	0	0.579	0.687	
10	0	7266	2209	0	8846	0	0.579	0.713	0.599
11	1275	4357	2209	874	6851	0	0.579	0.626	0.543
12	0	5601	2209	0	7704	0	0.579	0.601	0.559
13	1287	5601	2209	882	7704	0	0.579	0.558	0.503
14	0	5601	4378	0	7704	0	0.579	0.572	0.492

COMBINATIONS

1 - DL + Insulation + Vacuum + 302 F (Case 2 + 7 + 9)
2 - DL + Insulation + Settlement + Vacuum + 302 F (Case 2+7+8+9)
3 - DL + Insul + Seis x + Dif settle + Vac + 302 F (Case 2+5+7+8+9)
4 - DL + Insul + Seis z + Dif settle + Vac + 302 F (Case 2+5+7+8+9)

5 - DL + Wind + Dif Set + 100 F (Case 1 + 4 + 8 + 10)
6 - DL + Insulation + Vacuum + 100 F (Case 2 + 7 + 10)
7 - DL + Insulation + Settlement + Vacuum + 100 F (Case 2+7+8+10)
8 - DL + Insul + Seis x + Dif settle + Vac + 100 F (Case 2+5+7+8+10)
9 - DL + Insul + Seis z + Dif settle + Vac + 100 F (Case 2+5+7+8+10)

10 - DL + snow + Dif Set + -16 F (Case 1 + 3 + 8 + 11)
11 - DL + wind +Dif set -16 F (Case 1 + 4 + 8 + 11)
12 - DL + Insulation + Settlement + Vacuum + 100 F (Case 2+7+8+11)
13 - DL + Insul + Seis x + Dif settle + Vac + -15 F (Case 2+5+7+8+11)
14 - DL + Insul + Seis z + Dif settle + Vac + -16 F (Case 2+5+7+8+11)

SUBJECT	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Vertical Differential Settlement = 0.579"	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 29 OF 29
	DATE 3/11/94	DATE 4-5-94	DATE	DATE	6.62

STRESS INPUT FOR 2U RUNS

2U CASE #1

DL + INSULATION + VACUUM + 0.0" DIF SETTLE + 302°
BEAM TUBE DESIGN COMBINATION 1 (Pg 14)

$f_a = 1533$ psi
$f_b = 2195$
$f_d = \underline{33.5}$
3762 psi

2U CASE #2

DL + INSULATION + VACUUM + AXIAL SEISMIC + 0.0" SETTLE + 302°
NOTE: AXIAL SEISMIC CAUSES HIGHER TOTAL STRESS THAN LATERAL SEISMIC. CAN BE SEEN BY COMPARING COMBINATION 3 & 4
BEAM TUBE COMBINATION 4 W/O 0.579" SETTLEMENT (Pg 17 & 11)

$f_a = 1644$ psi
$f_{b_x} = 2195 \quad = 4267 - (y_B)(S_{b_x B}) = 4267 - .579(3579)$
$f_{b_y} = 402$
$f_b = \underline{103}$
4344 psi

2U CASE #3

DL + INS + VACUUM + 0.579 SETTLEMENT + 302°
BEAM TUBE DESIGN COMBINATION 2 (Pg 15)

$f_a = 1533$
$f_b = 4267$
$f_d = \underline{96}$
5896 psi

SUBJECT	CBI OFFICE	REVISION		REFERENCE NO.
Longitudinal Stress Values for API 2U Beam Tube Factor of Safety Determination	NO8-C			930212
	MADE BY RJW / CHKD BY WJC	MADE BY	CHKD BY	SHT 1 OF 3
	DATE 10MAR94 / DATE 4-5-94	DATE	DATE	7.1

2U CASE #4

DL + INS + VACUUM + 0.0 SETTLE + 100°

BEAM TUBE DESIGN COMBINATION 6 (pg 19)

$f_a = 69$

$f_b = 2195$

$f_d = \underline{\quad 1}$

2265 psi

2U CASE #5

DL + INS + VACUUM + AXIAL SEISMIC + 100°

BEAM TUBE DESIGN COMBINATION 9 − ($y8 \times f_{bx} 8$) (pg 21 & 11)

$f_a = 181$

$f_{bx} = 2195 = 4267 - .579(3579)$

$f_{by} = 402$

$f_d = \underline{\quad 11}$

2789 psi

2U CASE #6

DL + INS + VACUUM + 0.25 SETTLEMENT + 100°

BEAM TUBE DESIGN COMBINATION 6 + $0.25 \times f_{bx} 8$ (pg 19 & 11)

$f_a = 69$

$f_{bx} = 3090 = 2195 + 0.25(3579)$

$f_d = \underline{\quad 2}$

3161 psi

2U CASE #7

DL + INS + VACUUM + .579 SETTLE + 100

BEAM TUBE DESIGN COMBINATION 7 pg 20

$f_a = 69$

$f_b = 4267$

$f_d = \underline{\quad 4}$

4340 psi

SUBJECT Longitudinal Stress Values for API 2U Beam Tube Factor of Safety Determination	CBI OFFICE NO8-C		REVISION		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 2 OF 3
	DATE 10 MAR 94	DATE 4-5-94	DATE	DATE	7.2

2U CASE #8

DL + INS + VACUUM + AXIAL SEISMIC + 0.579 SETTLE + 100°
BEAM TUBE DESIGN COMBINATION 9 (pg 22)

$f_a = 181$ psi
$f_{b_x} = 4267$
$f_{b_y} = 402$
$f_d = 11$
4861

2U CASE #9

DL + INS + VACUUM + 1" SETTLEMENT + 100° (DURING ADJUSTMENT)
BEAM TUBE DESIGN COMBINATION 7 (pg

$f_a = 69$ psc
$f_{b_x} = 5817$
$f_{b_y} = 0$
$f_d = 7$
5893 psi

SUBJECT	CBI OFFICE		REVISION		REFERENCE NO.
Longitudinal Stress Values for API 2U Beam Tube Factor of Safety Determination	NOE-C				930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 3 OF 3
	DATE 10MAR94	DATE 4-5-94	DATE	DATE	7.3

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GO 64 REV SEP 84

SUMMARY OF RESULTS – ANALYSIS OF BEAM TUBE CONTROLLING LOAD COMBINATIONS
PER API BULLETIN 2U, "STABILITY DESIGN OF CYLINDRICAL SHELLS"

The table below summarizes the results of the analysis of the LIGO beam tube utilizing API Bulletin 2U, "Bulletin on Stability Design of Cylindrical Shells", 1st Edition (May 1987). API Bulletin 2U provides stability criteria for measuring the structural adequacy against buckling of circular cylindrical members, either stiffened or unstiffened, when subjected to axial load, bending and external pressure acting independently or in combination.

API Bulletin 2U, unlike the ASME Code, considers the interaction between compressive axial and hoop stresses in evaluating the susceptability of a stiffened cylinder to local buckling between stiffeners. It is for this reason that the beam tube was evaluated per the API Bulletin 2U provisions.

These results are discussed further in the section on the design of the beam tube.

API Bul 2U Case No	300F Bake	100F Oper'ng	Vacuum	Axial Seismic	Suppt Settl'mt	Tube Axial Stress, psi	Tube Hoop Stress, psi	API Bul 2U Factor of Safety Actual	API Bul 2U Factor of Safety Recommended
1	**Yes**	—	**Yes**	—	—	- 3,762	- 2,836	**1.88**	**2.00**
2	**Yes**	—	**Yes**	**Yes**	—	- 4,344	- 2,836	**1.78**	**1.50**
3	**Yes**	—	**Yes**	—	**Yes, 0.579"**	- 5,896	- 2,836	**1.55**	**1.50**
4	—	**Yes**	**Yes**	—	—	- 2,266	- 2,836	**2.25**	**2.00**
5	—	**Yes**	**Yes**	**Yes**	—	- 2,789	- 2,836	**2.19**	**1.50**
6	—	**Yes**	**Yes**	—	**Yes, 0.250"**	- 3,161	- 2,836	**2.14**	**2.00**
7	—	**Yes**	**Yes**	—	**Yes, 0.579"**	- 4,340	- 2,836	**1.99**	**2.00**
8	—	**Yes**	**Yes**	**Yes**	**Yes, 0.579"**	- 4,681	- 2,836	**1.91**	**1.50**
9	—	**Yes**	**Yes**	—	**Yes, 1.000"**	- 5,893	- 2,836	**1.77**	**1.50**

2.4

SUBJECT	CBI OFFICE Noe-c		REVISION		REFERENCE NO. 930212
	MADE BY WJC	CHKD BY RJW	MADE BY	CHKD BY	SHT 1 OF 1
	DATE 3-17-94	DATE 18 MAR 94	DATE	DATE	

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE

						Ring Stiffener		
Lr =	30.00	in.	b =	0.00	in.	tw =	0.1875	in.
R =	24.439	in.	Fy =	19,200	psi	Ar =	0.3280	sq.in.
t =	0.127	in.	E =	27,000,000	psi	Zr =	0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43		Ir =	0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)				Rr =	25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)				Le=[1.56(Rt)^.5]+tw =	2.936	in.

Nx =	477.77	#/in.	No =	360.18	#/in.
=	3,762	psi (Axial)	=	2,836	psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx = 0.630		if	Mx =< 1.5	(eq. 4-3)
Cx = [0.904/(Mx)^2] + 0.1013(Mx)^2 =	2.941	if	1.5 < Mx < 1.73	
Cx = 0.605		if	Mx > 1.73	

Mx = 17.03 ==========> **Cx = 0.605**

axL = 0.207		if	R/t >= 610	(eq. 4-4)
axL = 169c/(195 + R/t) < 0.9 =	0.436	if	R/t < 610	

R/t = 192 ==========> **axL = 0.436**

c = 2.64		if	Mx =< 1.5	(eq. 4-5)
c = 3.13/(Mx)^0.42 =	0.952	if	1.5 < Mx =< 15	
c = 1.0		if	Mx > 15	

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 37,029 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:

FxcL = FxeL = 37,029 psi eq. 4-6

FxcL = 233(Fy)/(166 + R/t) =< Fy =	12,481 psi	if	R/t < 300	(eq. 4-7)
FxcL = 0.5(Fy) = 9,600 psi		if	R/t >= 300	

R/t = 192 ==========> **FxcL = 12,481 psi**

SUBJECT	OFFICE: NOE		REVISION	REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 300F Bakeout + Vacuum, No Seismic No Support Settlement	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 6
	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.5

Section 4.1.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k = Nx/No = 0
e = 0.449

y = 1.0 if Mx =< 1.26
y = 1.58 - 0.46 Mx = -6.25 if 1.26 < Mx =< 3.42
y = 0.0 if Mx >= 3.42
Mx = 17.03 ====> **y = 0.000**

PeL = [1.27 (E) (t/R)^2]/[A^1.18 + 0.5]= 34.8387 if Mx > 1.5 & A < 2.5
PeL = [0.92 (E) (t/R)^2]/A = 42.3001 if 2.5 < A < 0.208 R/t
PeL = 0.836(Cp)^-1.061 (E)(t/R)^3 = 44.7594 if 0.208 < Cp < 2.85
PeL = 0.275 (E)(t/R)^3 = 1.0420 if Cp > 2.85
PeL = 42.3001

A = Mx - 1.17 + 1.068k = 15.859
Mx = 17.03
k = 0
0.208 R/t = 40.02526
Cp = A/(R/t) = 0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,512 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10) FhcL = n (FheL) (eq. 4-11)

n = 1.0 if d =< 0.55
n = 0.45/d + 0.18 = 1.51 if 0.55 < d =< 1.6
n = 1.31/(1 + 1.15d) = 0.94 if 1.6 < d < 6.25
n = 1/d = 2.95 if d >= 6.25

d = FreL/Fy = 0.3392 (eq. 5-3)
n = 1.000

FrcL = n (FreL) = 6,512 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 33.840 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 300F Bakeout + Vacuum, No Seismic No Support Settlement	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 2 OF 6
	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.6

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE

						Ring Stiffener		
Lr =	30.00	in.	b =	0.00	in.	tw =	0.1875	in.
R =	24.439	in.	Fy =	19,200	psi	Ar =	0.3280	sq.in.
t =	0.127	in.	E =	27,000,000	psi	Zr =	0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43		Ir =	0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)				Rr =	25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)				Le=[1.56(Rt)^.5]+tw =	2.936	in.

Nx =	477.77	#/in.	No =	360.18	#/in.
=	3,762	psi (Axial)	=	2,836	psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx = 0.630		if	Mx =< 1.5	(eq. 4-3)
Cx = [0.904/(Mx)^2] + 0.1013(Mx)^2 =	2.941	if	1.5 < Mx < 1.73	
Cx = 0.605		if	Mx > 1.73	

Mx = 17.03 ==========> **Cx = 0.605**

axL = 0.207		if	R/t >= 610	(eq. 4-4)
axL = 169c/(195 + R/t) < 0.9 =	0.436	if	R/t < 610	

R/t = 192 ==========> **axL = 0.436**

c = 2.64		if	Mx =< 1.5	(eq. 4-5)
c = 3.13/(Mx)^0.42 =	0.952	if	1.5 < Mx =< 15	
c = 1.0		if	Mx > 15	

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 37,029 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:

FxcL = FxeL = 37,029 psi eq. 4-6

FxcL = 233(Fy)/(166 + R/t) =< Fy =	12,481	psi	if	R/t < 300	(eq. 4-7)
FxcL = 0.5(Fy) = 9,600 psi			if	R/t >= 300	

R/t = 192 ==========> **FxcL = 12,481 psi**

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	DATE 3/9/94	DATE 18 MAR 94	DATE	DATE	7.5

Section 4.1.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k = Nx/No = 0
e = 0.449

y = 1.0 if Mx =< 1.26
y = 1.58 - 0.46 Mx = -6.25 if 1.26 < Mx =< 3.42
y = 0.0 if Mx >= 3.42
Mx = 17.03 ====> **y = 0.000**

PeL = [1.27 (E) (t/R)^2]/[A^1.18 + 0.5]= 34.8387 if Mx > 1.5 & A < 2.5
PeL = [0.92 (E) (t/R)^2]/A = 42.3001 if 2.5 < A < 0.208 R/t
PeL = 0.836(Cp)^-1.061 (E)(t/R)^3 = 44.7594 if 0.208 < Cp < 2.85
PeL = 0.275 (E)(t/R)^3 = 1.0420 if Cp > 2.85
PeL = 42.3001

A = Mx - 1.17 + 1.068k = 15.859
Mx = 17.03
k = 0
0.208 R/t = 40.02526
Cp = A/(R/t) = 0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,512 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10) FhcL = n (FheL) (eq. 4-11)

n = 1.0 if d =< 0.55
n = 0.45/d + 0.18 = 1.51 if 0.55 < d =< 1.6
n = 1.31/(1 + 1.15d) = 0.94 if 1.6 < d < 6.25
n = 1/d = 2.95 if d >= 6.25

d = FreL/Fy = 0.3392 (eq. 5-3)
n = 1.000

FrcL = n (FreL) = 6,512 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 33.840 psi (eq. 4-12)

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	DATE 3/9/94	DATE 18 MAR 94	DATE	DATE	7.6

Section 4.2 General Instability of Ring Stiffened Cylinders

Section 4.2.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 (eq. 4-13)

A'r = Ar/[Lr) t] = 0.0861

Ar = ring area = 0.328 sq.in.
Lr = ring spacing = 30 in.

b. Imperfection Factors

axG =	0.72		if A'r >= 0.2
axG =	[3.6 - 5.0(axL)] (A'r) + axL =	0.558	if 0.06 < A'r < 0.2
axG =	axL = 0.436209		if A'r =< 0.06
axG =	**0.558**	axL from eq. 4-4 with c = 1.0	

(eq. 4-14)

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 = 49,397 psi (eq. 4-13)

c. Inelastic Buckling Stresses

FxcG = n (FxeG) (eq. 4-15)

n =	1.0		if d =< 0.55	d = FxeG/Fy =	2.5728
n =	0.45/d + 0.18 =	0.35	if 0.55 < d =< 1.6		
n =	1.31/(1 + 1.15d) =	0.33	if 1.6 < d < 6.25	**n =**	**0.331**
n =	1/d = 0.39		if d >= 6.25		

(eq. 5-3)

FxcG = n (FxeG) = 16,346 psi (eq. 4-15)

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	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.7

Section 4.2.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Buckling Stresses With or Without End Pressure

FreG or FheG = (acG)(PeG)(Ro)(KoG)/t (eq. 4-16)

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.531994 (eq. 11-9)

Ar =	0.328	sq.in.
Le=[1.56(Rt)^.5]+tw =	2.935797	in.
k=	0	

$$PeG = \frac{(E)(t/R)(Lg)^4}{[N^2 + k(Lg)^2 - 1]\,[N^2 + (Lg)^2]^2} + \frac{(E)(Ier)(N^2 - 1)}{(Lr)(Rc)^2(R)}$$ (eq. 4-17)

lamda G (Lg) = (pi)(R)/Lb = 2.559194

Lb = 30 in.

k = 0

Ier = Ir + (Ar)(Zr)^2 (Le)(t)/[(Ar) + (Le)(t)] + (Le)(t)^3/12 = 0.233 in.^4 (eq. 4-18)

Ir =	0.08374	in.^4
Ar =	0.328	sq.in.
Zr =	0.9385	in.
t =	0.127	in.
Rr =	25.3767	in.

Le = 1.1(Dt)^0.5 =	2.741 in.		if Mx > 1.56
Le = Lr =	30.000 in.		if Mx=< 1.56
Mx =	17.03	====>	**Le = 2.741 in.**

N = 4 use N that gives PeG min. 2< N

PeG = 988.937 psi (eq. 4-17)

b. Imperfection Factors

aoG = 0.8

FreG or FheG = (aoG)(PeG)(Ro)(KoG)/t = 81,201 psi (eq. 4-16)

c. Inelastic Buckling Stresses

FrcG = n (FreG) (eq. 4-19) FhcG = n (FheG) (eq. 4-20)

n =	1.0		if d =< 0.55	d = FreG/Fy = 4.2292
n =	0.45/d + 0.18 =	0.286	if 0.55 < d =< 1.6	
n =	1.31/(1 + 1.15d) =	0.223	if 1.6 < d < 6.25	**n = 0.223**
n =	1/d =	0.236	if d >= 6.25	

(eq. 5-3)

FrcG = n (FreG) = 18,141 psi (eq. 4-10)

d. Failure Pressures

poG = (n)(aoG)(peG) = 176.752 psi (eq. 4-12)

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	DATE 3/9/94	DATE 10 MAR 94	DATE / DATE	7.9

SECTION 6 PREDICTED SHELL BUCKLING STRESSES FOR COMBINED LOADS

Section 6.3 Axial Compression, Bending and Hoop Compression

(Ra)^2 - c (Ra)(Rh) + (Rh)^2 = 1.0 (eq. 6-3)

Ra = Flcj / Fxcj Rh = Focj / Frcj

a. Unstiffened and Ring Stiffened Cylinders (all buckling modes)

c = (Fxcj + Frcj) / Fy - 1.0 (eq. 6-4)

Local Buckling

c = [FxcL + FrcL] / Fy - 1 = -0.01078

Let FlcL = (FocL) (k) (KxL/KoL) = 1.3265 (FocL)

Ra = FlcL / FxcL = 0.000106 (FocL)

KxL = 1.0

Rh = FocL / FrcL = 0.000154 (FocL)

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.
k = Nx/No = 1.326
e = 0.280

Solve eq. 6-3 for FocL

FocL = 5,341 psi (eq. 6-3)

FlcL= (FocL) (k) (KxL/KoL) = 7,085 psi

General Instability

c = [FxcG + FrcG] / Fy - 1 = 0.796234

KxG = 1.0

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.3104 (eq. 11-9)
(If KoG < 0 then ring is in tension and the interaction equation is not applicable. Then FlcG = FxcG)

k = Nx / No = 1.326
Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.

Let FlcG = (FocG) (k) (KxG/KoG) = 4.273774 (FocG)

Ra = FlcG / FxcG : 0.000261 (FocG)

Rh = FocG / FrcG 5.51E-05 (FocG)

Solve eq. 6-3 for FocG

FocG = 4,085 psi (eq. 6-3)

FlcG= (FocG) (k) (KxG/KoG) = 17,459 psi

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	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 5 OF 6
	DATE 3/9/94	DATE 12MAR94	DATE	DATE	7.9

SECTION 9 ALLOWABLE STRESSES

Section 9.1 Allowable Stresses For Shell Buckling Mode

Section 9.1.5 Axial Compression and Hoop Compression and Axial Compression, Bending and Hoop Compression

Fa = Fb = FicL / FS

(eq. 9-7)

Fo = FocL / FS

Factor of Safety (FS) = 1.88

Fa = Fb =	3,769	psi	=	478.61	#/in.	Nx =	477.77	#/in.
Fc =	2,841	psi	=	360.81	#/in.	No =	360.18	#/in.

SECTION 11 STRESS CALCULATIONS

Section 11.3 Hoop Stresses

Section 11.3(b)2 Stress in a Ring Stiffener

Ring Stiffener Stress = (p * Ro / t) * (1.00 - 0.30 * (Nx / No)) * (Le * t) / (Ar + Le * t) (Eq 11-8)

Solving Eq 11-8,

==> Ring Stiffener Stress = 1,941 psi

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	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 6 OF 6
	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.10

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE

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R =	24.439	in.	Fy =	19,200	psi	Ar =	0.3280	sq.in.
t =	0.127	in.	E =	27,000,000	psi	Zr =	0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43		Ir =	0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)				Rr =	25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)				Le=[1.56(Rt)^.5]+tw =	2.936	in.

Nx =	551.69	#/in.	No =	360.18	#/in.
=	4,344	psi (Axial)	=	2,836	psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx = 0.630		if	Mx =< 1.5	(eq. 4-3)
Cx = [0.904/(Mx)^2] + 0.1013(Mx)^2 =	2.941	if	1.5 < Mx < 1.73	
Cx = 0.605		if	Mx > 1.73	

Mx = 17.03 ==========> **Cx = 0.605**

axL = 0.207		if	R/t >= 610	(eq. 4-4)
axL = 169c/(195 + R/t) < 0.9 =	0.436	if	R/t < 610	

R/t = 192 ==========> **axL = 0.436**

c = 2.64		if	Mx =< 1.5	(eq. 4-5)
c = 3.13/(Mx)^0.42 =	0.952	if	1.5 < Mx =< 15	
c = 1.0		if	Mx > 15	

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 37,029 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:

FxcL = FxeL = 37,029 psi eq. 4-6

FxcL = 233(Fy)/(166 + R/t) =< Fy =	12,481 psi	if	R/t < 300	(eq. 4-7)
FxcL = 0.5(Fy) = 9,600 psi		if	R/t >= 300	

R/t = 192 ==========> FxcL = 12,481 psi

SUBJECT	OFFICE: NOE		REVISION	
					REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 300F Bakeout + Vacuum + Axial Seismic No Support Settlement	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 6
	DATE 3/10/94	DATE 12MAR94	DATE	DATE	7.11

Section 4.1.2 External Pressure (Nx/No = 0 or 0.5)

Use Nx/No = 0
Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL =	1.0		if	Mx >= 3.42
KoL =	1 - e*y =	1.000	if	Mx < 3.42 (eq. 11-7)
Mx =	17.03	==========>	KoL =	**1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]		
A = (Ar)(R/Rr)^2 =	0.304196	sq.in.
Ar =	0.328	sq.in.
Rr =	25.377	in.
Le=[1.56(Rt)^.5]+tw =	2.935797	in.
k = Nx/No =	0	
e =	**0.449**	

y =	1.0		if	Mx =< 1.26
y = 1.58 - 0.46 Mx =		-6.25	if	1.26 < Mx =< 3.42
y =	0.0		if	Mx >= 3.42
Mx =	17.03	====>	y =	**0.000**

PeL =	[1.27 (E) (t/R)^2]/[A^1.18 + 0.5]=	34.8387	if Mx > 1.5 & A < 2.5
PeL =	[0.92 (E) (t/R)^2]/A =	42.3001	if 2.5 < A < 0.208 R/t
PeL =	0.836(Cp)^-1.061 (E)(t/R)^3 =	44.7594	if 0.208 < Cp < 2.85
PeL =	0.275 (E)(t/R)^3 =	1.0420	if Cp > 2.85
PeL =	**42.3001**		

A = Mx - 1.17 + 1.068k =	15.859
Mx =	17.03
k =	0
0.208 R/t =	40.02526
Cp = A/(R/t) =	0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,512 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10)   FhcL = n (FheL) (eq. 4-11)

n =	1.0		if d =< 0.55
n =	0.45/d + 0.18 =	1.51	if 0.55 < d =< 1.6
n =	1.31/(1 + 1.15d) =	0.94	if 1.6 < d < 6.25
n =	1/d = 2.95		if d >= 6.25

d = FreL/Fy =	0.3392
n =	**1.000**

(eq. 5-3)

FrcL = n (FreL) = 6,512 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 33,840 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 2 OF 6
300F Bakeout + Vacuum + Axial Seismic No Support Settlement	DATE 3/10/94	DATE 18MAR94	DATE	DATE	7.12

Section 4.2 General Instability of Ring Stiffened Cylinders

Section 4.2.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 (eq. 4-13)

A'r = Ar/[Lr) t] = 0.0861

Ar = ring area = 0.328 sq.in.
Lr = ring spacing = 30 in.

b. Imperfection Factors

axG =	0.72		if A'r >= 0.2
axG =	[3.6 - 5.0(axL)] (A'r) + axL =	0.558	if 0.06 < A'r < 0.2
axG =	axL = 0.436209		if A'r =< 0.06
axG =	**0.558**	axL from eq. 4-4 with c = 1.0	

(eq. 4-14)

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 = 49,397 psi (eq. 4-13)

c. Inelastic Buckling Stresses

FxcG = n (FxeG) (eq. 4-15)

n =	1.0		if d =< 0.55	d = FxeG/Fy = 2.5728
n =	0.45/d + 0.18 =	0.35	if 0.55 < d =< 1.6	
n =	1.31/(1 + 1.15d) =	0.33	if 1.6 < d < 6.25	**n = 0.331**
n =	1/d = 0.39		if d >= 6.25	

(eq. 5-3)

FxcG = n (FxeG) = 16,346 psi (eq. 4-15)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 300F Bakeout + Vacuum + Axial Seismic No Support Settlement	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 3 OF 6
	DATE 3/10/94	DATE 18MAR94	DATE	DATE	7.13

Section 4.2.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Buckling Stresses With or Without End Pressure

FreG or FheG = (acG)(PeG)(Ro)(KoG)/t (eq. 4-16)

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.531994 (eq. 11-9)

Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k= 0

PeG = (E)(t/R)(Lg)^4 / [N^2 + k(Lg)^2 - 1] [N^2 + (Lg)^2]^2 + (E)(Ier)(N^2 - 1) / (Lr)(Rc)^2(R) (eq. 4-17)

lamda G (Lg) = (pi)(R)/Lb = 2.559194

Lb = 30 in.

k = 0

Ier = Ir + (Ar)(Zr)^2 (Le)(t)/[(Ar) + (Le)(t)] + (Le)(t)^3/12 = 0.233 in.^4 (eq. 4-18)

Ir = 0.08374 in.^4
Ar = 0.328 sq.in.
Zr = 0.9385 in.
t = 0.127 in.
Rr = 25.3767 in.

Le = 1.1(Dt)^0.5 = 2.741 in. if Mx > 1.56
Le = Lr = 30.000 in. if Mx=< 1.56
Mx = 17.03 ====> **Le = 2.741 in.**

N = 4 use N that gives PeG min. 2< N

PeG = 988.937 psi (eq. 4-17)

b. Imperfection Factors

aoG = 0.8

FreG or FheG = (aoG)(PeG)(Ro)(KoG)/t = 81,201 psi (eq. 4-16)

c. Inelastic Buckling Stresses

FrcG = n (FreG) (eq. 4-19)

FhcG = n (FheG) (eq. 4-20)

n =	1.0		if d =< 0.55	d = FreG/Fy = 4.2292
n =	0.45/d + 0.18 =	0.286	if 0.55 < d =< 1.6	
n =	1.31/(1 + 1.15d) =	0.223	if 1.6 < d < 6.25	**n = 0.223**
n =	1/d = 0.236		if d >= 6.25	

(eq. 5-3)

FrcG = n (FreG) = 18,141 psi (eq. 4-10)

d. Failure Pressures

poG = (n)(aoG)(peG) = 176.752 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
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	DATE 3/10/94	DATE 10 MAR 94	DATE	DATE	7.14

SECTION 6 PREDICTED SHELL BUCKLING STRESSES FOR COMBINED LOADS

Section 6.3 Axial Compression, Bending and Hoop Compression

(Ra)^2 - c (Ra)(Rh) + (Rh)^2 = 1.0 (eq. 6-3)

Ra = Ficj / Fxcj   Rh = Focj / Frcj

a. Unstiffened and Ring Stiffened Cylinders (all buckling modes)

c = (Fxcj + Frcj) / Fy - 1.0 (eq. 6-4)

Local Buckling

c = [FxcL + FrcL] / Fy - 1 = -0.01078

Let FicL = (FocL) (k) (KxL/KoL) = 1.5317 (FocL)

Ra = FicL / FxcL = 0.000123 (FocL)

Rh = FocL / FrcL = 0.000154 (FocL)

KxL = 1.0

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.
k = Nx/No = 1.532
e = 0.252

Solve eq. 6-3 for FocL

FocL = 5,074 psi (eq. 6-3)

FicL= (FocL) (k) (KxL/KoL) = 7,771 psi

General Instability

c = [FxcG + FrcG] / Fy - 1 = 0.796234

KxG = 1.0

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.2786 (eq. 11-9)
(If KoG < 0 then ring is in tension and the interaction equation is not applicable. Then FicG = FxcG)

k = Nx / No = 1.532
Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.

Let FicG = (FocG) (k) (KxG/KoG) = 5.497063 (FocG)

Ra = FicG / FxcG : 0.000336 (FocG)

Rh = FocG / FrcG 5.51E-05 (FocG)

Solve eq. 6-3 for FocG

FocG = 3,141 psi (eq. 6-3)

FicG= (FocG) (k) (KxG/KoG) = 17,268 psi

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	DATE 3/10/94	DATE 18 MAR 94	DATE	DATE	7.15

SECTION 9 ALLOWABLE STRESSES

Section 9.1 Allowable Stresses For Shell Buckling Mode

Section 9.1.5 Axial Compression and Hoop Compression and Axial Compression, Bending and Hoop Compression

Fa = Fb = FicL / FS

(eq. 9-7)

Fo = FocL / FS

Factor of Safety (FS) = 1.78

Fa = Fb = 4,366 psi = 554.47 #/in.   Nx = 551.69 #/in.

Fc = 2,850 psi = 362.00 #/in.   No = 360.18 #/in.

SECTION 11 STRESS CALCULATIONS

Section 11.3 Hoop Stresses

Section 11.3(b)2 Stress in a Ring Stiffener

Ring Stiffener Stress = (p * Ro / t) * (1.00 - 0.30 * (Nx / No)) * (Le * t) / (Ar + Le * t)   (Eq 11-8)

Solving Eq 11-8,

==> Ring Stiffener Stress = 1,742 psi

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	DATE 3/10/94	DATE 11 MAR 94	DATE	DATE	7.16

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE

						Ring Stiffener		
Lr =	30.00	in.	b =	0.00	in.	tw =	0.1875	in.
R =	24.439	in.	Fy =	19,200	psi	Ar =	0.3280	sq.in.
t =	0.127	in.	E =	27,000,000	psi	Zr =	0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43		Ir =	0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)				Rr =	25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)				Le=[1.56(Rt)^.5]+tw =	2.936	in.

Nx =	748.79	#/in.	No =	360.18	#/in.
=	5,896	psi (Axial)	=	2,836	psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx =	0.630		if	Mx =< 1.5	(eq. 4-3)
Cx =	[0.904/(Mx)^2] + 0.1013(Mx)^2 =	2.941	if	1.5 < Mx < 1.73	
Cx =	0.605		if	Mx > 1.73	

Mx = 17.03 ==========> **Cx = 0.605**

axL =	0.207		if	R/t >= 610	(eq. 4-4)
axL =	169c/(195 + R/t) < 0.9 =	0.436	if	R/t < 610	

R/t = 192 ==========> **axL = 0.436**

c =	2.64		if	Mx =< 1.5	(eq. 4-5)
c =	3.13/(Mx)^0.42 =	0.952	if	1.5 < Mx =< 15	
c =	1.0		if	Mx > 15	

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 37,029 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:

FxcL = FxeL = 37,029 psi eq. 4-6

FxcL =	233(Fy)/(166 + R/t) =< Fy =	12,481 psi	if	R/t < 300	(eq. 4-7)
FxcL =	0.5(Fy) =	9,600 psi	if	R/t >= 300	

R/t = 192 ==========> FxcL = 12,481 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 300F Bakeout + Vacuum, No Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 6
	DATE 3/9/94	DATE 10MAR94	DATE	DATE	7.17

Section 4.1.2 **External Pressure (Nx/No = 0 or 0.5)**

Use Nx/No = 0
Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k = Nx/No = 0
e = 0.449

y = 1.0 if Mx =< 1.26
y = 1.58 - 0.46 Mx = -6.25 if 1.26 < Mx =< 3.42
y = 0.0 if Mx >= 3.42
Mx = 17.03 =====> **y = 0.000**

PeL = [1.27 (E) (t/R)^2]/[A^1.18 + 0.5]= 34.8387 if Mx > 1.5 & A < 2.5
PeL = [0.92 (E) (t/R)^2]/A = 42.3001 if 2.5 < A < 0.208 R/t
PeL = 0.836(Cp)^-1.061 (E)(t/R)^3 = 44.7594 if 0.208 < Cp < 2.85
PeL = 0.275 (E)(t/R)^3 = 1.0420 if Cp > 2.85
PeL = 42.3001

A = Mx - 1.17 + 1.068k = 15.859
Mx = 17.03
k = 0
0.208 R/t = 40.02526
Cp = A/(R/t) = 0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,512 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10) FhcL = n (FheL) (eq. 4-11)

n = 1.0 if d =< 0.55
n = 0.45/d + 0.18 = 1.51 if 0.55 < d =< 1.6
n = 1.31/(1 + 1.15d) = 0.94 if 1.6 < d < 6.25
n = 1/d = 2.95 if d >= 6.25

d = FreL/Fy = 0.3392 (eq. 5-3)
n = 1.000

FrcL = n (FreL) = 6,512 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 33.840 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 300F Bakeout + Vacuum, No Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 2 OF 6
	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.18

Section 4.2 General Instability of Ring Stiffened Cylinders

Section 4.2.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 (eq. 4-13)

A'r = Ar/[Lr) t] = 0.0861

Ar = ring area = 0.328 sq.in.
Lr = ring spacing = 30 in.

b. Imperfection Factors

axG = 0.72		if A'r >= 0.2	
axG = [3.6 - 5.0(axL)] (A'r) + axL =	0.558	if 0.06 < A'r < 0.2	(eq. 4-14)
axG = axL = 0.436209		if A'r =< 0.06	
axG = 0.558	axL from eq. 4-4 with c = 1.0		

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 = 49,397 psi (eq. 4-13)

c. Inelastic Buckling Stresses

FxcG = n (FxeG) (eq. 4-15)

n =	1.0		if d =< 0.55	d = FxeG/Fy = 2.5728	
n =	0.45/d + 0.18 =	0.35	if 0.55 < d =< 1.6		(eq. 5-3)
n =	1.31/(1 + 1.15d) =	0.33	if 1.6 < d < 6.25	**n = 0.331**	
n =	1/d = 0.39		if d >= 6.25		

FxcG = n (FxeG) = 16,346 psi (eq. 4-15)

SUBJECT	OFFICE: NOE		REVISION	REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 300F Bakeout + Vacuum, No Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 3 OF 6
	DATE 3/9/94	DATE 10MAR94	DATE	DATE	7.19

Section 4.2.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Buckling Stresses With or Without End Pressure

FreG or FheG = (acG)(PeG)(Ro)(KoG)/t (eq. 4-16)

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.531994 (eq. 11-9)

Ar =	0.328	sq.in.
Le=[1.56(Rt)^.5]+tw =	2.935797	in.
k=	0	

PeG = (E)(t/R)(Lg)^4 / [N^2 + k(Lg)^2 - 1] [N^2 + (Lg)^2]^2 + (E)(Ier)(N^2 - 1) / (Lr)(Rc)^2(R) (eq. 4-17)

lamda G (Lg) = (pi)(R)/Lb = 2.559194 Lb = 30 in.

k = 0

Ier = Ir + (Ar)(Zr)^2 (Le)(t)/[(Ar) + (Le)(t)] + (Le)(t)^3/12 = 0.233 in.^4 (eq. 4-18)

Ir = 0.08374 in.^4
Ar = 0.328 sq.in.
Zr = 0.9385 in.
t = 0.127 in.
Rr = 25.3767 in.

Le = 1.1(Dt)^0.5 =		2.741	in.	if Mx > 1.56
Le = Lr =		30.000	in.	if Mx=< 1.56
Mx =	17.03	====>	**Le =**	**2.741 in.**

N = 4 use N that gives PeG min. 2< N

PeG = 988.937 psi (eq. 4-17)

b. Imperfection Factors

aoG = 0.8

FreG or FheG = (aoG)(PeG)(Ro)(KoG)/t = 81,201 psi (eq. 4-16)

c. Inelastic Buckling Stresses

FrcG = n (FreG) (eq. 4-19) FhcG = n (FheG) (eq. 4-20)

n = 1.0		if d =< 0.55	d = FreG/Fy =	4.2292
n = 0.45/d + 0.18 =	0.286	if 0.55 < d =< 1.6		
n = 1.31/(1 + 1.15d) =	0.223	if 1.6 < d < 6.25	**n =**	**0.223**
n = 1/d = 0.236		if d >= 6.25		

(eq. 5-3)

FrcG = n (FreG) = 18,141 psi (eq. 4-10)

d. Failure Pressures

poG = (n)(aoG)(peG) = 176.752 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 300F Bakeout + Vacuum, No Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 4 OF 6
	DATE 3/9/94	DATE 10 MAR 94	DATE	DATE	7.20

SECTION 6 PREDICTED SHELL BUCKLING STRESSES FOR COMBINED LOADS

Section 6.3 Axial Compression, Bending and Hoop Compression

(Ra)^2 - c (Ra)(Rh) + (Rh)^2 = 1.0 (eq. 6-3)

Ra = Flcj / Fxcj   Rh = Focj / Frcj

a. Unstiffened and Ring Stiffened Cylinders (all buckling modes)

c = (Fxcj + Frcj) / Fy - 1.0 (eq. 6-4)

Local Buckling

c = [FxcL + FrcL] / Fy - 1 = -0.01078

Let FlcL = (FocL) (k) (KxL/KoL) = 2.0789 (FocL)

Ra = FlcL / FxcL = 0.000167 (FocL)

Rh = FocL / FrcL = 0.000154 (FocL)

KxL = 1.0

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.
k = Nx/No = 2.079
e = 0.175

Solve eq. 6-3 for FocL

FocL = 4,402 psi (eq. 6-3)

FlcL= (FocL) (k) (KxL/KoL) = 9,152 psi

General Instability

c = [FxcG + FrcG] / Fy - 1 = 0.796234

KxG = 1.0

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.1940 (eq. 11-9)
(If KoG < 0 then ring is in tension and the interaction equation is not applicable. Then FlcG = FxcG)

k = Nx / No = 2.079
Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.

Let FlcG = (FocG) (k) (KxG/KoG) = 10.71595 (FocG)

Ra = FlcG / FxcG : 0.000656 (FocG)

Rh = FocG / FrcG 5.51E-05 (FocG)

Solve eq. 6-3 for FocG

FocG = 1,573 psi (eq. 6-3)

FlcG= (FocG) (k) (KxG/KoG) = 16,859 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 300F Bakeout + Vacuum, No Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJN	MADE BY	CHKD BY	SHT 5 OF 6
	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.21

SECTION 9 ALLOWABLE STRESSES

Section 9.1 Allowable Stresses For Shell Buckling Mode

Section 9.1.5 Axial Compression and Hoop Compression and Axial Compression, Bending and Hoop Compression

Fa = Fb = FicL / FS

(eq. 9-7)

Fo = FocL / FS

Factor of Safety (FS) = 1.55

Fa = Fb =	5,904	psi	=	749.85	#/in.		Nx =	748.79	#/in.
Fc =	2,840	psi	=	360.69	#/in.		No =	360.18	#/in.

SECTION 11 STRESS CALCULATIONS

Section 11.3 Hoop Stresses

Section 11.3(b)2 Stress in a Ring Stiffener

Ring Stiffener Stress = (p * Ro / t) * (1.00 - 0.30 * (Nx / No)) * (Le * t) / (Ar + Le * t) (Eq 11-8)

Solving Eq 11-8,

==> Ring Stiffener Stress = 1,213 psi

<table>
<tr><td rowspan="3">SUBJECT
LIGO Beam Tube -- 49.00" OD x 0.127" Wall
1.75" x 0.1875" Vacuum Stiffener, 30" Spacing
300F Bakeout + Vacuum, No Seismic
Support Settlement of 0.579"</td><td colspan="2">OFFICE: NOE</td><td colspan="2">REVISION</td><td>REFERENCE NO.
930212</td></tr>
<tr><td>MADE BY
WJC</td><td>CHKD
RJW</td><td>MADE BY</td><td>CHKD BY</td><td>SHT 6 OF 6</td></tr>
<tr><td>DATE
3/9/94</td><td>DATE
18 MAR 94</td><td>DATE</td><td>DATE</td><td>7.22</td></tr>
</table>

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 — PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE

						Ring Stiffener		
Lr =	30.00	in.	b =	0.00	in.	tw =	0.1875	in.
R =	24.439	in.	Fy =	25,000	psi	Ar =	0.3280	sq.in.
t =	0.127	in.	E =	28,300,000	psi	Zr =	0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43		Ir =	0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)				Rr =	25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)				Le=[1.56(Rt)^.5]+tw =	2.936	in.

Nx =	287.78	#/in.	No =	360.18	#/in.
=	2,266	psi (Axial)	=	2,836	psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx =	0.630		if	Mx =< 1.5	(eq. 4-3)
Cx =	[0.904/(Mx)^2] + 0.1013(Mx)^2 =	2.941	if	1.5 < Mx < 1.73	
Cx =	0.605		if	Mx > 1.73	

Mx = 17.03 ==========> **Cx = 0.605**

axL =	0.207		if	R/t >= 610	(eq. 4-4)
axL =	169c/(195 + R/t) < 0.9 =	0.436	if	R/t < 610	

R/t = 192 ==========> **axL = 0.436**

c =	2.64		if	Mx =< 1.5	(eq. 4-5)
c =	3.13/(Mx)^0.42 =	0.952	if	1.5 < Mx =< 15	
c =	1.0		if	Mx > 15	

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 38,812 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:

FxcL = FxeL = 38,812 psi eq. 4-6

FxcL =	233(Fy)/(166 + R/t) =< Fy =	16,251 psi	if	R/t < 300	(eq. 4-7)
FxcL =	0.5(Fy) =	12,500 psi	if	R/t >= 300	

R/t = 192 ==========> **FxcL = 16,251 psi**

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic No Support Settlement	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 6
	DATE 3/9/94	DATE 10 MAR 94	DATE	DATE	7.23

Section 4.1.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL =	1.0		if	Mx >= 3.42
KoL =	1 - e*y =	1.000	if	Mx < 3.42 (eq. 11-7)
Mx =	17.03	==========>	KoL =	**1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k = Nx/No = 0
e = 0.449

y =	1.0		if	Mx =< 1.26
y = 1.58 - 0.46 Mx =		-6.25	if	1.26 < Mx =< 3.42
y =	0.0		if	Mx >= 3.42
Mx =	17.03	=====>	y =	**0.000**

PeL = [1.27 (E) (t/R)^2]/[A^1.18 + 0.5]=	36.5161	if Mx > 1.5 & A < 2.5
PeL = [0.92 (E) (t/R)^2]/A =	44.3368	if 2.5 < A < 0.208 R/t
PeL = 0.836(Cp)^-1.061 (E)(t/R)^3 =	46.9145	if 0.208 < Cp < 2.85
PeL = 0.275 (E)(t/R)^3 =	1.0922	if Cp > 2.85
PeL = 44.3368		

A = Mx - 1.17 + 1.068k = 15.859
Mx = 17.03
k = 0
0.208 R/t = 40.02526
Cp = A/(R/t) = 0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,825 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10) FhcL = n (FheL) (eq. 4-11)

n =	1.0		if d =< 0.55
n =	0.45/d + 0.18 =	1.83	if 0.55 < d =< 1.6
n =	1.31/(1 + 1.15d) =	1.00	if 1.6 < d < 6.25
n =	1/d = 3.66		if d >= 6.25

d = FreL/Fy = 0.2730
n = 1.000
(eq. 5-3)

FrcL = n (FreL) = 6,825 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 35,469 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic No Support Settlement	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 2 OF 6
	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.24

Section 4.2 General Instability of Ring Stiffened Cylinders

Section 4.2.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 (eq. 4-13)

A'r = Ar/[Lr) t] = 0.0861

Ar = ring area = 0.328 sq.in.
Lr = ring spacing = 30 in.

b. Imperfection Factors

axG = 0.72		if A'r >= 0.2	
axG = [3.6 - 5.0(axL)] (A'r) + axL =	0.558	if 0.06 < A'r < 0.2	(eq. 4-14)
axG = axL = 0.436209		if A'r =< 0.06	
axG = 0.558	axL from eq. 4-4 with c = 1.0		

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 = 51,775 psi (eq. 4-13)

c. Inelastic Buckling Stresses

FxcG = n (FxeG) (eq. 4-15)

n = 1.0		if d =< 0.55	d = FxeG/Fy = 2.0710	
n = 0.45/d + 0.18 =	0.40	if 0.55 < d =< 1.6		(eq. 5-3)
n = 1.31/(1 + 1.15d) =	0.39	if 1.6 < d < 6.25	**n = 0.387**	
n = 1/d = 0.48		if d >= 6.25		

FxcG = n (FxeG) = 20,057 psi (eq. 4-15)

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	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.25

Section 4.2.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Buckling Stresses With or Without End Pressure

FreG or FheG = (acG)(PeG)(Ro)(KoG)/t (eq. 4-16)

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = **0.531994** (eq. 11-9)

Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k= 0

$$PeG = \frac{(E)(t/R)(Lg)^4}{[N^2 + k(Lg)^2 - 1]\,[N^2 + (Lg)^2]^2} + \frac{(E)(Ier)(N^2 - 1)}{(Lr)(Rc)^2(R)} \quad \text{(eq. 4-17)}$$

lamda G (Lg) = (pi)(R)/Lb = 2.559194 Lb = 30 in.

k = 0

Ier = Ir + (Ar)(Zr)^2 (Le)(t)/[(Ar) + (Le)(t)] + (Le)(t)^3/12 = 0.233 in.^4 (eq. 4-18)

Ir = 0.08374 in.^4
Ar = 0.328 sq.in.
Zr = 0.9385 in.
t = 0.127 in.
Rr = 25.3767 in.

Le = 1.1(Dt)^0.5 = 2.741 in. if Mx > 1.56
Le = Lr = 30.000 in. if Mx=< 1.56
Mx = 17.03 ====> **Le = 2.741 in.**

N = 4 use N that gives PeG min. 2< N

PeG = 1036.55 psi (eq. 4-17)

b. Imperfection Factors

aoG = 0.8

FreG or FheG = (aoG)(PeG)(Ro)(KoG)/t = 85,111 psi (eq. 4-16)

c. Inelastic Buckling Stresses

FrcG = n (FreG) (eq. 4-19) FhcG = n (FheG) (eq. 4-20)

n =	1.0		if d =< 0.55	d = FreG/Fy = 3.4044
n =	0.45/d + 0.18 =	0.312	if 0.55 < d =< 1.6	
n =	1.31/(1 + 1.15d) =	0.267	if 1.6 < d < 6.25	**n = 0.267**
n =	1/d = 0.294		if d >= 6.25	

(eq. 5-3)

FrcG = n (FreG) = 22,684 psi (eq. 4-10)

d. Failure Pressures

poG = (n)(aoG)(peG) = 221.014 psi (eq. 4-12)

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	DATE 3/9/94	DATE 10 MAR 94	DATE	DATE	7.26

SECTION 6 PREDICTED SHELL BUCKLING STRESSES FOR COMBINED LOADS

Section 6.3 Axial Compression, Bending and Hoop Compression

(Ra)^2 - c (Ra)(Rh) + (Rh)^2 = 1.0 (eq. 6-3)

Ra = Ficj / Fxcj Rh = Focj / Frcj

a. Unstiffened and Ring Stiffened Cylinders (all buckling modes)

c = (Fxcj + Frcj) / Fy - 1.0 (eq. 6-4)

Local Buckling

c = [FxcL + FrcL] / Fy - 1 = -0.07693

Let FicL = (FocL) (k) (KxL/KoL) = 0.7990 (FocL)

Ra = FicL / FxcL = 4.92E-05 (FocL)

Rh = FocL / FrcL = 0.000147 (FocL)

KxL = 1.0

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.
k = Nx/No = 0.799
e = 0.354

Solve eq. 6-3 for FocL

FocL = 6,397 psi (eq. 6-3)

FicL= (FocL) (k) (KxL/KoL) = 5,111 psi

General Instability

c = [FxcG + FrcG] / Fy - 1 = 0.709645

KxG = 1.0

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.3920 (eq. 11-9)
(If KoG < 0 then ring is in tension and the interaction equation is not applicable. Then FicG = FxcG)

k = Nx / No = 0.799
Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.

Let FicG = (FocG) (k) (KxG/KoG) = 2.038459 (FocG)

Ra = FicG / FxcG : 0.000102 (FocG)

Rh = FocG / FrcG 4.41E-05 (FocG)

Solve eq. 6-3 for FocG

FocG = 10,487 psi (eq. 6-3)

FicG= (FocG) (k) (KxG/KoG) = 21,377 psi

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	DATE 3/9/94	DATE 10MAR94	DATE	DATE	7.27

SECTION 9 ALLOWABLE STRESSES

Section 9.1 Allowable Stresses For Shell Buckling Mode

Section 9.1.5 Axial Compression and Hoop Compression and Axial Compression, Bending and Hoop Compression

Fa = Fb = FlcL / FS

(eq. 9-7)

Fo = FocL / FS

Factor of Safety (FS) = 2.25

Fa = Fb = 2,272 psi = 288.50 #/in. Nx = 287.78 #/in.

Fc = 2,843 psi = 361.07 #/in. No = 360.18 #/in.

SECTION 11 STRESS CALCULATIONS

Section 11.3 Hoop Stresses

Section 11.3(b)2 Stress in a Ring Stiffener

Ring Stiffener Stress = (p * Ro / t) * (1.00 - 0.30 * (Nx / No)) * (Le * t) / (Ar + Le * t) (Eq 11-8)

Solving Eq 11-8,

==> Ring Stiffener Stress = 2,451 psi

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	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.28

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE

						Ring Stiffener		
Lr =	30.00	in.	b =	0.00	in.	tw =	0.1875	in.
R =	24.439	in.	Fy =	25,000	psi	Ar =	0.3280	sq.in.
t =	0.127	in.	E =	28,300,000	psi	Zr =	0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43		Ir =	0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)				Rr =	25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)				Le=[1.56(Rt)^.5]+tw =	2.936	in.

Nx =	354.20	#/in.	No =	360.18	#/in.
=	2,789	psi (Axial)	=	2,836	psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx = 0.630		if	Mx =< 1.5	(eq. 4-3)
Cx = [0.904/(Mx)^2] + 0.1013(Mx)^2 =	2.941	if	1.5 < Mx < 1.73	
Cx = 0.605		if	Mx > 1.73	

Mx = 17.03 ==========> **Cx = 0.605**

axL = 0.207		if	R/t >= 610	(eq. 4-4)
axL = 169c/(195 + R/t) < 0.9 =	0.436	if	R/t < 610	

R/t = 192 ==========> **axL = 0.436**

c = 2.64		if	Mx =< 1.5	(eq. 4-5)
c = 3.13/(Mx)^0.42 =	0.952	if	1.5 < Mx =< 15	
c = 1.0		if	Mx > 15	

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 38,812 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:

FxcL = FxeL = 38,812 psi eq. 4-6

FxcL = 233(Fy)/(166 + R/t) =< Fy =	16,251	psi	if	R/t < 300	(eq. 4-7)
FxcL = 0.5(Fy) =	12,500	psi	if	R/t >= 300	

R/t = 192 ==========> **FxcL = 16,251 psi**

SUBJECT	OFFICE: NOE		REVISION	REFERENCE NO. 930212
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	DATE 3/9/94	DATE 18MAR94	DATE / DATE	7.29

Section 4.1.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k = Nx/No = 0
e = 0.449

y = 1.0 if Mx =< 1.26
y = 1.58 - 0.46 Mx = -6.25 if 1.26 < Mx =< 3.42
y = 0.0 if Mx >= 3.42
Mx = 17.03 =====> **y = 0.000**

PeL = [1.27 (E) (t/R)^2]/[A^1.18 + 0.5]= 36.5161 if Mx > 1.5 & A < 2.5
PeL = [0.92 (E) (t/R)^2]/A = 44.3368 if 2.5 < A < 0.208 R/t
PeL = 0.836(Cp)^-1.061 (E)(t/R)^3 = 46.9145 if 0.208 < Cp < 2.85
PeL = 0.275 (E)(t/R)^3 = 1.0922 if Cp > 2.85
PeL = 44.3368

A = Mx - 1.17 + 1.068k = 15.859
Mx = 17.03
k = 0
0.208 R/t = 40.02526
Cp = A/(R/t) = 0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,825 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10) FhcL = n (FheL) (eq. 4-11)

n = 1.0 if d =< 0.55
n = 0.45/d + 0.18 = 1.83 if 0.55 < d =< 1.6
n = 1.31/(1 + 1.15d) = 1.00 if 1.6 < d < 6.25
n = 1/d = 3.66 if d >= 6.25

d = FreL/Fy = 0.2730 (eq. 5-3)
n = 1.000

FrcL = n (FreL) = 6,825 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 35.469 psi (eq. 4-12)

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	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.30

Section 4.2 General Instability of Ring Stiffened Cylinders

Section 4.2.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 (eq. 4-13)

A'r = Ar/[Lr) t] = 0.0861

Ar = ring area = 0.328 sq.in.
Lr = ring spacing = 30 in.

b. Imperfection Factors

axG = 0.72		if A'r >= 0.2	(eq. 4-14)
axG = [3.6 - 5.0(axL)] (A'r) + axL =	0.558	if 0.06 < A'r < 0.2	
axG = axL = 0.436209		if A'r =< 0.06	
axG = 0.558	axL from eq. 4-4 with c = 1.0		

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 = 51,775 psi (eq. 4-13)

c. Inelastic Buckling Stresses

FxcG = n (FxeG) (eq. 4-15)

n = 1.0		if d =< 0.55	d = FxeG/Fy =	2.0710	(eq. 5-3)
n = 0.45/d + 0.18 =	0.40	if 0.55 < d =< 1.6			
n = 1.31/(1 + 1.15d) =	0.39	if 1.6 < d < 6.25	**n =**	**0.387**	
n = 1/d = 0.48		if d >= 6.25			

FxcG = n (FxeG) = 20,057 psi (eq. 4-15)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum + Axial Seismic No Support Settlement	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 3 OF 6
	DATE 3/9/94	DATE 10MAR94	DATE	DATE	7.31

Section 4.2.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Buckling Stresses With or Without End Pressure

FreG or FheG = (acG)(PeG)(Ro)(KoG)/t (eq. 4-16)

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.531994 (eq. 11-9)

Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k= 0

$$\text{PeG} = \frac{(E)(t/R)(Lg)^4}{[N^2 + k(Lg)^2 - 1]\,[N^2 + (Lg)^2]^2} + \frac{(E)(Ier)(N^2 - 1)}{(Lr)(Rc)^2(R)} \quad \text{(eq. 4-17)}$$

lamda G (Lg) = (pi)(R)/Lb = 2.559194

Lb = 30 in.

k = 0

Ier = Ir + (Ar)(Zr)^2 (Le)(t)/[(Ar) + (Le)(t)] + (Le)(t)^3/12 = 0.233 in.^4 (eq. 4-18)

Ir = 0.08374 in.^4
Ar = 0.328 sq.in.
Zr = 0.9385 in.
t = 0.127 in.
Rr = 25.3767 in.

Le = 1.1(Dt)^0.5 = 2.741 in. if Mx > 1.56
Le = Lr = 30.000 in. if Mx=< 1.56
Mx = 17.03 ⟹ **Le = 2.741 in.**

N = 4 use N that gives PeG min. 2< N

PeG = 1036.55 psi (eq. 4-17)

b. Imperfection Factors

aoG = 0.8

FreG or FheG = (aoG)(PeG)(Ro)(KoG)/t = 85,111 psi (eq. 4-16)

c. Inelastic Buckling Stresses

FrcG = n (FreG) (eq. 4-19) FhcG = n (FheG) (eq. 4-20)

n = 1.0		if d =< 0.55	d = FreG/Fy =	3.4044
n = 0.45/d + 0.18 =	0.312	if 0.55 < d =< 1.6		
n = 1.31/(1 + 1.15d) =	0.267	if 1.6 < d < 6.25	**n =**	**0.267**
n = 1/d = 0.294		if d >= 6.25		

(eq. 5-3)

FrcG = n (FreG) = 22,684 psi (eq. 4-10)

d. Failure Pressures

poG = (n)(aoG)(peG) = 221.014 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum + Axial Seismic No Support Settlement	MADE BY WJC	CHKD RJN	MADE BY	CHKD BY	SHT 4 OF 6
	DATE 3/9/94	DATE 10MAR94	DATE	DATE	7.32

SECTION 6 PREDICTED SHELL BUCKLING STRESSES FOR COMBINED LOADS

Section 6.3 Axial Compression, Bending and Hoop Compression

(Ra)^2 - c (Ra)(Rh) + (Rh)^2 = 1.0 (eq. 6-3)

Ra = Flcj / Fxcj Rh = Focj / Frcj

a. Unstiffened and Ring Stiffened Cylinders (all buckling modes)

c = (Fxcj + Frcj) / Fy - 1.0 (eq. 6-4)

Local Buckling

c = [FxcL + FrcL] / Fy - 1 = -0.07693

Let FlcL = (FocL) (k) (KxL/KoL) = 0.9834 (FocL)

Ra = FlcL / FxcL = 6.05E-05 (FocL)

Rh = FocL / FrcL = 0.000147 (FocL)

KxL = 1.0

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.
k = Nx/No = 0.983
e = 0.328

Solve eq. 6-3 for FocL

FocL = 6,225 psi (eq. 6-3)

FlcL= (FocL) (k) (KxL/KoL) = 6,121 psi

General Instability

c = [FxcG + FrcG] / Fy - 1 = 0.709645

KxG = 1.0

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.3634 (eq. 11-9)
(If KoG < 0 then ring is in tension and the interaction equation is not applicable. Then FlcG = FxcG)

k = Nx / No = 0.983
Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.

Let FlcG = (FocG) (k) (KxG/KoG) = 2.705832 (FocG)

Ra = FlcG / FxcG : 0.000135 (FocG)

Rh = FocG / FrcG 4.41E-05 (FocG)

Solve eq. 6-3 for FocG

FocG = 7,925 psi (eq. 6-3)

FlcG= (FocG) (k) (KxG/KoG) = 21,443 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum + Axial Seismic No Support Settlement	MADE BY WJC	CHKD	MADE BY	CHKD BY	SHT 5 OF 6
	DATE 3/9/94	DATE 18 MAR94	DATE	DATE	7.33

SECTION 9 ALLOWABLE STRESSES

Section 9.1 Allowable Stresses For Shell Buckling Mode

Section 9.1.5 Axial Compression and Hoop Compression and Axial Compression, Bending and Hoop Compression

Fa = Fb = FicL / FS

(eq. 9-7)

Fo = FocL / FS

Factor of Safety (FS) = 2.19

Fa = Fb = 2,795 psi = 354.98 #/in. Nx = 354.20 #/in.

Fc = 2,842 psi = 360.97 #/in. No = 360.18 #/in.

SECTION 11 STRESS CALCULATIONS

Section 11.3 Hoop Stresses

Section 11.3(b)2 Stress in a Ring Stiffener

Ring Stiffener Stress = (p * Ro / t) * (1.00 - 0.30 * (Nx / No)) * (Le * t) / (Ar + Le * t) (Eq 11-8)

Solving Eq 11-8,

==> Ring Stiffener Stress = 2,273 psi

SUBJECT LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum + Axial Seismic No Support Settlement	OFFICE: NOE MADE BY WJC DATE 3/9/94	CHKD RJW DATE 14MAR94	REVISION MADE BY DATE	CHKD BY DATE
				REFERENCE NO. 930212 SHT 6 OF 6 7.34

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE

									Ring Stiffener	
Lr =	30.00	in.	b =	0.00	in.		tw =		0.1875	in.
R =	24.439	in.	Fy =	25,000	psi		Ar =		0.3280	sq.in.
t =	0.127	in.	E =	28,300,000	psi		Zr =		0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43			Ir =		0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)					Rr =		25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)					Le=[1.56(Rt)^.5]+tw =		2.936	in.

Nx = 401.45 #/in. No = 360.18 #/in.

= 3,161 psi (Axial) = 2,836 psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx =	0.630		if	Mx =< 1.5
Cx =	[0.904/(Mx)^2] + 0.1013(Mx)^2 =	2.941	if	1.5 < Mx < 1.73
Cx =	0.605		if	Mx > 1.73

(eq. 4-3)

Mx = 17.03 ==========> **Cx = 0.605**

axL =	0.207		if	R/t >= 610
axL =	169c/(195 + R/t) < 0.9 =	0.436	if	R/t < 610

(eq. 4-4)

R/t = 192 ==========> **axL = 0.436**

c =	2.64		if	Mx =< 1.5
c =	3.13/(Mx)^0.42 =	0.952	if	1.5 < Mx =< 15
c =	1.0		if	Mx > 15

(eq. 4-5)

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 38,812 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:

FxcL = FxeL = 38,812 psi eq. 4-6

FxcL = 233(Fy)/(166 + R/t) =< Fy =	16,251	psi	if	R/t < 300
FxcL = 0.5(Fy) =	12,500	psi	if	R/t >= 300

(eq. 4-7)

R/t = 192 ==========> FxcL = 16,251 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Settlement of 0.250"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 6
	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.35

Section 4.1.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL = 1.0		if	Mx >= 3.42
KoL = 1 - e*y =	1.000	if	Mx < 3.42 (eq. 11-7)
Mx = 17.03	==========>		**KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]		
A = (Ar)(R/Rr)^2 =	0.304196	sq.in.
Ar =	0.328	sq.in.
Rr =	25.377	in.
Le=[1.56(Rt)^.5]+tw =	2.935797	in.
k = Nx/No =	0	
e = 0.449		

y =	1.0	if	Mx =< 1.26
y = 1.58 - 0.46 Mx =	-6.25	if	1.26 < Mx =< 3.42
y =	0.0	if	Mx >= 3.42
Mx = 17.03	====>		**y = 0.000**

PeL = [1.27 (E) (t/R)^2]/[A^1.18 + 0.5]=	36.5161	if Mx > 1.5 & A < 2.5
PeL = [0.92 (E) (t/R)^2]/A =	44.3368	if 2.5 < A < 0.208 R/t
PeL = 0.836(Cp)^-1.061 (E)(t/R)^3 =	46.9145	if 0.208 < Cp < 2.85
PeL = 0.275 (E)(t/R)^3 =	1.0922	if Cp > 2.85
PeL = 44.3368		

A = Mx - 1.17 + 1.068k =	15.859
Mx =	17.03
k =	0
0.208 R/t =	40.02526
Cp = A/(R/t) =	0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,825 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10) FhcL = n (FheL) (eq. 4-11)

n = 1.0		if d =< 0.55
n = 0.45/d + 0.18 =	1.83	if 0.55 < d =< 1.6
n = 1.31/(1 + 1.15d) =	1.00	if 1.6 < d < 6.25
n = 1/d = 3.66		if d >= 6.25

d = FreL/Fy =	0.2730
n =	**1.000**

(eq. 5-3)

FrcL = n (FreL) = 6,825 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 35.469 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Settlement of 0.250"	MADE BY WJC	CHKD RJH	MADE BY	CHKD BY	SHT 2 OF 6
	DATE 3/9/94	DATE 19 MAR 94	DATE	DATE	7.36

Section 4.2 General Instability of Ring Stiffened Cylinders

Section 4.2.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 (eq. 4-13)

A'r = Ar/[Lr) t] = 0.0861

Ar = ring area = 0.328 sq.in.
Lr = ring spacing = 30 in.

b. Imperfection Factors

axG = 0.72 if A'r >= 0.2

axG = [3.6 - 5.0(axL)] (A'r) + axL = 0.558 if 0.06 < A'r < 0.2

axG = axL = 0.436209 if A'r =< 0.06

axG = 0.558 axL from eq. 4-4 with c = 1.0

(eq. 4-14)

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 = 51,775 psi (eq. 4-13)

c. Inelastic Buckling Stresses

FxcG = n (FxeG) (eq. 4-15)

n = 1.0 if d =< 0.55
n = 0.45/d + 0.18 = 0.40 if 0.55 < d =< 1.6
n = 1.31/(1 + 1.15d) = 0.39 if 1.6 < d < 6.25
n = 1/d = 0.48 if d >= 6.25

d = FxeG/Fy = 2.0710

n = 0.387

(eq. 5-3)

FxcG = n (FxeG) = 20,057 psi (eq. 4-15)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Settlement of 0.250"	MADE BY WJC	CHKD RJN	MADE BY	CHKD BY	SHT 3 OF 6
	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.37

Section 4.2.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Buckling Stresses With or Without End Pressure

FreG or FheG = (acG)(PeG)(Ro)(KoG)/t (eq. 4-16)

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.531994 (eq. 11-9)

Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k= 0

$$PeG = \frac{(E)(t/R)(Lg)^4}{[N^2 + k(Lg)^2 - 1]\,[N^2 + (Lg)^2]^2} + \frac{(E)(Ier)(N^2 - 1)}{(Lr)(Rc)^2(R)}$$ (eq. 4-17)

lamda G (Lg) = (pi)(R)/Lb = 2.559194   Lb = 30 in.

k = 0

Ier = Ir + (Ar)(Zr)^2 (Le)(t)/[(Ar) + (Le)(t)] + (Le)(t)^3/12 = 0.233 in.^4 (eq. 4-18)

Ir = 0.08374 in.^4
Ar = 0.328 sq.in.
Zr = 0.9385 in.
t = 0.127 in.
Rr = 25.3767 in.

Le = 1.1(Dt)^0.5 = 2.741 in. if Mx > 1.56
Le = Lr = 30.000 in. if Mx=< 1.56
Mx = 17.03 ====> **Le = 2.741 in.**

N = 4 use N that gives PeG min. 2< N

PeG = 1036.55 psi (eq. 4-17)

b. Imperfection Factors

aoG = 0.8

FreG or FheG = (aoG)(PeG)(Ro)(KoG)/t = 85,111 psi (eq. 4-16)

c. Inelastic Buckling Stresses

FrcG = n (FreG) (eq. 4-19)   FhcG = n (FheG) (eq. 4-20)

n =	1.0		if d =< 0.55	d = FreG/Fy = 3.4044
n =	0.45/d + 0.18 =	0.312	if 0.55 < d =< 1.6	
n =	1.31/(1 + 1.15d) =	0.267	if 1.6 < d < 6.25	**n = 0.267**
n =	1/d =	0.294	if d >= 6.25	

(eq. 5-3)

FrcG = n (FreG) = 22,684 psi (eq. 4-10)

d. Failure Pressures

poG = (n)(aoG)(peG) = 221.014 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Settlement of 0.250"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 4 OF 6
	DATE 3/9/94	DATE 10MAR94	DATE	DATE	7.38

SECTION 6 PREDICTED SHELL BUCKLING STRESSES FOR COMBINED LOADS

Section 6.3 Axial Compression, Bending and Hoop Compression

(Ra)^2 - c (Ra)(Rh) + (Rh)^2 = 1.0 (eq. 6-3)

Ra = Ficj / Fxcj Rh = Focj / Frcj

a. Unstiffened and Ring Stiffened Cylinders (all buckling modes)

c = (Fxcj + Frcj) / Fy - 1.0 (eq. 6-4)

Local Buckling

c = [FxcL + FrcL] / Fy - 1 = -0.07693

Let FicL = (FocL) (k) (KxL/KoL) = 1.1146 (FocL)

Ra = FicL / FxcL = 6.86E-05 (FocL)

KxL = 1.0

Rh = FocL / FrcL = 0.000147 (FocL)

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.
k = Nx/No = 1.115
e = 0.310

Solve eq. 6-3 for FocL

FocL = 6,092 psi (eq. 6-3)

FicL= (FocL) (k) (KxL/KoL) = 6,790 psi

General Instability

c = [FxcG + FrcG] / Fy - 1 = 0.709645

KxG = 1.0

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.3432 (eq. 11-9)
(If KoG < 0 then ring is in tension and the interaction equation is not applicable. Then FicG = FxcG)

k = Nx / No = 1.115
Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.

Let FicG = (FocG) (k) (KxG/KoG) = 3.248037 (FocG)

Ra = FicG / FxcG : 0.000162 (FocG)

Rh = FocG / FrcG 4.41E-05 (FocG)

Solve eq. 6-3 for FocG

FocG = 6,579 psi (eq. 6-3)

FicG= (FocG) (k) (KxG/KoG) = 21,369 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Settlement of 0.250"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 5 OF 6
	DATE 3/9/94	DATE 10MAR94	DATE	DATE	7, 39

SECTION 9 ALLOWABLE STRESSES

Section 9.1 Allowable Stresses For Shell Buckling Mode

Section 9.1.5 Axial Compression and Hoop Compression and Axial Compression, Bending and Hoop Compression

Fa = Fb = FicL / FS

(eq. 9-7)

Fo = FocL / FS

Factor of Safety (FS) = 2.14

Fa = Fb =	3,173	psi	=	402.98	#/in.	Nx =	401.45	#/in.
Fc =	2,847	psi	=	361.55	#/in.	No =	360.18	#/in.

SECTION 11 STRESS CALCULATIONS

Section 11.3 Hoop Stresses

Section 11.3(b)2 Stress in a Ring Stiffener

Ring Stiffener Stress = (p * Ro / t) * (1.00 - 0.30 * (Nx / No)) * (Le * t) / (Ar + Le * t) (Eq 11-8)

Solving Eq 11-8,

==> Ring Stiffener Stress = 2,146 psi

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	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.40

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 **PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE**

						Ring Stiffener		
Lr =	30.00	in.	b =	0.00	in.	tw =	0.1875	in.
R =	24.439	in.	Fy =	25,000	psi	Ar =	0.3280	sq.in.
t =	0.127	in.	E =	28,300,000	psi	Zr =	0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43		Ir =	0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)				Rr =	25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)				Le=[1.56(Rt)^.5]+tw =	2.936	in.

Nx =	551.18	#/in.	No =	360.18	#/in.
=	4,340	psi (Axial)	=	2,836	psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx =	0.630		if	Mx =< 1.5	(eq. 4-3)
Cx =	[0.904/(Mx)^2] + 0.1013(Mx)^2 =	2.941	if	1.5 < Mx < 1.73	
Cx =	0.605		if	Mx > 1.73	

Mx = 17.03 ==========> **Cx = 0.605**

axL =	0.207		if	R/t >= 610	(eq. 4-4)
axL =	169c/(195 + R/t) < 0.9 =	0.436	if	R/t < 610	

R/t = 192 ==========> **axL = 0.436**

c =	2.64		if	Mx =< 1.5	(eq. 4-5)
c =	3.13/(Mx)^0.42 =	0.952	if	1.5 < Mx =< 15	
c =	1.0		if	Mx > 15	

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 38,812 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:

FxcL = FxeL = 38,812 psi eq. 4-6

FxcL =	233(Fy)/(166 + R/t) =< Fy =	16,251	psi	if	R/t < 300	(eq. 4-7)
FxcL =	0.5(Fy) =	12,500	psi	if	R/t >= 300	

R/t = 192 ==========> FxcL = 16,251 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJN	MADE BY	CHKD BY	SHT 1 OF 6
	DATE 3/9/94	DATE 8MAR99	DATE	DATE	7.41

Section 4.1.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 =========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k = Nx/No = 0
e = 0.449

y = 1.0 if Mx =< 1.26
y = 1.58 - 0.46 Mx = -6.25 if 1.26 < Mx =< 3.42
y = 0.0 if Mx >= 3.42
Mx = 17.03 ====> **y = 0.000**

PeL = [1.27 (E) (t/R)^2]/[A^1.18 + 0.5]= 36.5161 if Mx > 1.5 & A < 2.5
PeL = [0.92 (E) (t/R)^2]/A = 44.3368 if 2.5 < A < 0.208 R/t
PeL = 0.836(Cp)^-1.061 (E)(t/R)^3 = 46.9145 if 0.208 < Cp < 2.85
PeL = 0.275 (E)(t/R)^3 = 1.0922 if Cp > 2.85
PeL = 44.3368

A = Mx - 1.17 + 1.068k = 15.859
Mx = 17.03
k = 0
0.208 R/t = 40.02526
Cp = A/(R/t) = 0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,825 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10)

FhcL = n (FheL) (eq. 4-11)

n = 1.0 if d =< 0.55
n = 0.45/d + 0.18 = 1.83 if 0.55 < d =< 1.6
n = 1.31/(1 + 1.15d) = 1.00 if 1.6 < d < 6.25
n = 1/d = 3.66 if d >= 6.25

d = FreL/Fy = 0.2730 (eq. 5-3)
n = 1.000

FrcL = n (FreL) = 6,825 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 35.469 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJN	MADE BY	CHKD BY	SHT 2 OF 6
	DATE 3/9/94	DATE 10MAR94	DATE	DATE	7.42

Section 4.2 General Instability of Ring Stiffened Cylinders

Section 4.2.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 (eq. 4-13)

A'r = Ar/[Lr) t] = 0.0861

Ar = ring area = 0.328 sq.in.
Lr = ring spacing = 30 in.

b. Imperfection Factors

axG = 0.72		if A'r >= 0.2	
axG = [3.6 - 5.0(axL)] (A'r) + axL =	0.558	if 0.06 < A'r < 0.2	(eq. 4-14)
axG = axL = 0.436209		if A'r =< 0.06	
axG = 0.558	axL from eq. 4-4 with c = 1.0		

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 = 51,775 psi (eq. 4-13)

c. Inelastic Buckling Stresses

FxcG = n (FxeG) (eq. 4-15)

n = 1.0		if d =< 0.55	d = FxeG/Fy = 2.0710	
n = 0.45/d + 0.18 =	0.40	if 0.55 < d =< 1.6		(eq. 5-3)
n = 1.31/(1 + 1.15d) =	0.39	if 1.6 < d < 6.25	**n = 0.387**	
n = 1/d = 0.48		if d >= 6.25		

FxcG = n (FxeG) = 20,057 psi (eq. 4-15)

SUBJECT	OFFICE: NOE		REVISION	REFERENCE NO. 930212
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	DATE 3/9/94	DATE 18MAR94	DATE	DATE	7.43

Section 4.2.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Buckling Stresses With or Without End Pressure

FreG or FheG = (acG)(PeG)(Ro)(KoG)/t (eq. 4-16)

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = **0.531994** (eq. 11-9)

Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k= 0

$$PeG = \frac{(E)(t/R)(Lg)^4}{[N^2 + k(Lg)^2 - 1]\,[N^2 + (Lg)^2]^2} + \frac{(E)(Ier)(N^2 - 1)}{(Lr)(Rc)^2(R)}$$ (eq. 4-17)

lamda G (Lg) = (pi)(R)/Lb = 2.559194 Lb = 30 in.

k = 0

Ier = Ir + (Ar)(Zr)^2 (Le)(t)/[(Ar) + (Le)(t)] + (Le)(t)^3/12 = 0.233 in.^4 (eq. 4-18)

Ir = 0.08374 in.^4
Ar = 0.328 sq.in.
Zr = 0.9385 in.
t = 0.127 in.
Rr = 25.3767 in.

Le = 1.1(Dt)^0.5 = 2.741 in. if Mx > 1.56
Le = Lr = 30.000 in. if Mx=< 1.56
Mx = 17.03 ====> **Le = 2.741 in.**

N = 4 use N that gives PeG min. 2< N

PeG = 1036.55 psi (eq. 4-17)

b. Imperfection Factors

aoG = 0.8

FreG or FheG = (aoG)(PeG)(Ro)(KoG)/t = 85,111 psi (eq. 4-16)

c. Inelastic Buckling Stresses

FrcG = n (FreG) (eq. 4-19) FhcG = n (FheG) (eq. 4-20)

n =	1.0		if d =< 0.55	d = FreG/Fy =	3.4044
n =	0.45/d + 0.18 =	0.312	if 0.55 < d =< 1.6		
n =	1.31/(1 + 1.15d) =	0.267	if 1.6 < d < 6.25	**n =**	**0.267**
n =	1/d = 0.294		if d >= 6.25		

(eq. 5-3)

FrcG = n (FreG) = 22,684 psi (eq. 4-10)

d. Failure Pressures

poG = (n)(aoG)(peG) = 221.014 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJN	MADE BY	CHKD BY	SHT 4 OF 6
	DATE 3/9/94	DATE 10MAR94	DATE	DATE	T.44

SECTION 6 PREDICTED SHELL BUCKLING STRESSES FOR COMBINED LOADS

Section 6.3 Axial Compression, Bending and Hoop Compression

(Ra)^2 - c (Ra)(Rh) + (Rh)^2 = 1.0 (eq. 6-3)

Ra = Ficj / Fxcj Rh = Focj / Frcj

a. Unstiffened and Ring Stiffened Cylinders (all buckling modes)

c = (Fxcj + Frcj) / Fy - 1.0 (eq. 6-4)

Local Buckling

c = [FxcL + FrcL] / Fy - 1 = -0.07693

Let FicL = (FocL) (k) (KxL/KoL) = 1.5303 (FocL)

Ra = FicL / FxcL = 9.42E-05 (FocL)

Rh = FocL / FrcL = 0.000147 (FocL)

KxL = 1.0

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.
k = Nx/No = 1.530
e = 0.252

Solve eq. 6-3 for FocL

FocL = 5,644 psi (eq. 6-3)

FicL = (FocL) (k) (KxL/KoL) = 8,637 psi

General Instability

c = [FxcG + FrcG] / Fy - 1 = 0.709645

KxG = 1.0

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.2789 (eq. 11-9)
(If KoG < 0 then ring is in tension and the interaction equation is not applicable. Then FicG = FxcG)

k = Nx / No = 1.530
Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.

Let FicG = (FocG) (k) (KxG/KoG) = 5.487705 (FocG)

Ra = FicG / FxcG = 0.000274 (FocG)

Rh = FocG / FrcG 4.41E-05 (FocG)

Solve eq. 6-3 for FocG

FocG = 3,828 psi (eq. 6-3)

FicG= (FocG) (k) (KxG/KoG) = 21,007 psi

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	DATE 3/9/94	DATE 10MAR94	DATE	DATE	7.45

SECTION 9 ALLOWABLE STRESSES

Section 9.1 Allowable Stresses For Shell Buckling Mode

Section 9.1.5 Axial Compression and Hoop Compression and Axial Compression, Bending and Hoop Compression

Fa = Fb = FicL / FS

(eq. 9-7)

Fo = FocL / FS

Factor of Safety (FS) = 1.99

Fa = Fb =	4,340	psi	=	551.19	#/in.	Nx =	551.18	#/in.
Fc =	2,836	psi	=	360.19	#/in.	No =	360.18	#/in.

SECTION 11 STRESS CALCULATIONS

Section 11.3 Hoop Stresses

Section 11.3(b)2 Stress in a Ring Stiffener

Ring Stiffener Stress = (p * Ro / t) * (1.00 - 0.30 * (Nx / No)) * (Le * t) / (Ar + Le * t) (Eq 11-8)

Solving Eq 11-8,

==> Ring Stiffener Stress = 1,744 psi

<table>
<tr><td>SUBJECT</td><td colspan="2">OFFICE: NOE</td><td colspan="2">REVISION</td><td>REFERENCE NO.
930212</td></tr>
<tr><td rowspan="2">LIGO Beam Tube -- 49.00" OD x 0.127" Wall
1.75" x 0.1875" Vacuum Stiffener, 30" Spacing
100F Operating + Vacuum, No Seismic
Support Settlement of 0.579"</td><td>MADE BY
WJC</td><td>CHKD
RJW</td><td>MADE BY</td><td>CHKD BY</td><td>SHT 6 OF 6</td></tr>
<tr><td>DATE
3/9/94</td><td>DATE
18MAR94</td><td>DATE</td><td>DATE</td><td>7.4b</td></tr>
</table>

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE

						Ring Stiffener		
Lr =	30.00	in.	b =	0.00	in.	tw =	0.1875	in.
R =	24.439	in.	Fy =	25,000	psi	Ar =	0.3280	sq.in.
t =	0.127	in.	E =	28,300,000	psi	Zr =	0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43		Ir =	0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)				Rr =	25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)				Le=[1.56(Rt)^.5]+tw =	2.936	in.

Nx =	617.35	#/in.	No =	360.18	#/in.
=	4,861	psi (Axial)	=	2,836	psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx =	0.630		if	Mx =< 1.5	(eq. 4-3)
Cx =	[0.904/(Mx)^2] + 0.1013(Mx)^2 =	2.941	if	1.5 < Mx < 1.73	
Cx =	0.605		if	Mx > 1.73	

Mx = 17.03 ==========> **Cx = 0.605**

axL =	0.207		if	R/t >= 610	(eq. 4-4)
axL =	169c/(195 + R/t) < 0.9 =	0.436	if	R/t < 610	

R/t = 192 ==========> **axL = 0.436**

c =	2.64		if	Mx =< 1.5	(eq. 4-5)
c =	3.13/(Mx)^0.42 =	0.952	if	1.5 < Mx =< 15	
c =	1.0		if	Mx > 15	

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 38,812 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:

FxcL = FxeL = 38,812 psi eq. 4-6

FxcL =	233(Fy)/(166 + R/t) =< Fy =	16,251 psi	if	R/t < 300	(eq. 4-7)
FxcL =	0.5(Fy) = 12,500 psi		if	R/t >= 300	

R/t = 192 ==========> FxcL = 16,251 psi

SUBJECT	OFFICE: NOE		REVISION	REFERENCE NO. 930212
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	DATE 3/10/94	DATE 18MAR94	DATE	DATE	7.47

Section 4.1.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL = 1.0		if	Mx >= 3.42	
KoL = 1 - e*y =	1.000	if	Mx < 3.42	(eq. 11-7)
Mx = 17.03	==========>		**KoL =**	**1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]		
A = (Ar)(R/Rr)^2 =	0.304196	sq.in.
Ar =	0.328	sq.in.
Rr =	25.377	in.
Le=[1.56(Rt)^.5]+tw =	2.935797	in.
k = Nx/No =	0	
e =	**0.449**	

y =	1.0	if	Mx =< 1.26
y = 1.58 - 0.46 Mx =	-6.25	if	1.26 < Mx =< 3.42
y =	0.0	if	Mx >= 3.42
Mx = 17.03	====>	**y =**	**0.000**

PeL = [1.27 (E) (t/R)^2]/[A^1.18 + 0.5]=	36.5161	if Mx > 1.5 & A < 2.5
PeL = [0.92 (E) (t/R)^2]/A =	44.3368	if 2.5 < A < 0.208 R/t
PeL = 0.836(Cp)^-1.061 (E)(t/R)^3 =	46.9145	if 0.208 < Cp < 2.85
PeL = 0.275 (E)(t/R)^3 =	1.0922	if Cp > 2.85
PeL = 44.3368		

A = Mx - 1.17 + 1.068k =	15.859
Mx =	17.03
k =	0
0.208 R/t =	40.02526
Cp = A/(R/t) =	0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,825 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10) FhcL = n (FheL) (eq. 4-11)

n = 1.0		if d =< 0.55	d = FreL/Fy = 0.2730
n = 0.45/d + 0.18 =	1.83	if 0.55 < d =< 1.6	
n = 1.31/(1 + 1.15d) =	1.00	if 1.6 < d < 6.25	**n = 1.000**
n = 1/d = 3.66		if d >= 6.25	

(eq. 5-3)

FrcL = n (FreL) = 6,825 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 35.469 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION	REFERENCE NO. 930212
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	DATE 3/10/94	DATE 19MAR94	DATE	DATE	7.48

Section 4.2 General Instability of Ring Stiffened Cylinders

Section 4.2.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 (eq. 4-13)

A'r = Ar/[Lr) t] =	0.0861	Ar = ring area =	0.328	sq.in.
		Lr = ring spacing =	30	in.

b. Imperfection Factors

axG =	0.72		if A'r >= 0.2
axG =	[3.6 - 5.0(axL)] (A'r) + axL =	0.558	if 0.06 < A'r < 0.2
axG =	axL = 0.436209		if A'r =< 0.06
axG =	**0.558**	axL from eq. 4-4 with c = 1.0	

(eq. 4-14)

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 = 51,775 psi (eq. 4-13)

c. Inelastic Buckling Stresses

FxcG = n (FxeG) (eq. 4-15)

n =	1.0		if d =< 0.55	d = FxeG/Fy =	2.0710
n =	0.45/d + 0.18 =	0.40	if 0.55 < d =< 1.6		
n =	1.31/(1 + 1.15d) =	0.39	if 1.6 < d < 6.25	**n =**	**0.387**
n =	1/d = 0.48		if d >= 6.25		

(eq. 5-3)

FxcG = n (FxeG) = 20,057 psi (eq. 4-15)

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	DATE 3/10/94	DATE 10MAR94	DATE	DATE	7.49

Section 4.2.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Buckling Stresses With or Without End Pressure

FreG or FheG = (acG)(PeG)(Ro)(KoG)/t (eq. 4-16)

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = **0.531994** (eq. 11-9)

Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k= 0

$$PeG = \frac{(E)(t/R)(Lg)^4}{[N^2 + k(Lg)^2 - 1]\,[N^2 + (Lg)^2]^2} + \frac{(E)(Ier)(N^2 - 1)}{(Lr)(Rc)^2(R)}$$ (eq. 4-17)

lamda G (Lg) = (pi)(R)/Lb = 2.559194 Lb = 30 in.

k = 0

Ier = Ir + (Ar)(Zr)^2 (Le)(t)/[(Ar) + (Le)(t)] + (Le)(t)^3/12 = 0.233 in.^4 (eq. 4-18)

Ir = 0.08374 in.^4
Ar = 0.328 sq.in.
Zr = 0.9385 in.
t = 0.127 in.
Rr = 25.3767 in.

Le = 1.1(Dt)^0.5 = 2.741 in. if Mx > 1.56
Le = Lr = 30.000 in. if Mx=< 1.56
Mx = 17.03 ====> **Le = 2.741 in.**

N = 4 use N that gives PeG min. 2< N

PeG = 1036.55 psi (eq. 4-17)

b. Imperfection Factors

aoG = 0.8

FreG or FheG = (aoG)(PeG)(Ro)(KoG)/t = 85,111 psi (eq. 4-16)

c. Inelastic Buckling Stresses

FrcG = n (FreG) (eq. 4-19) FhcG = n (FheG) (eq. 4-20)

n =	1.0		if d =< 0.55	d = FreG/Fy = 3.4044
n =	0.45/d + 0.18 =	0.312	if 0.55 < d =< 1.6	
n =	1.31/(1 + 1.15d) =	0.267	if 1.6 < d < 6.25	**n = 0.267**
n =	1/d =	0.294	if d >= 6.25	

(eq. 5-3)

FrcG = n (FreG) = 22,684 psi (eq. 4-10)

d. Failure Pressures

poG = (n)(aoG)(peG) = 221.014 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum + Axial Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 4 OF 6
	DATE 3/10/94	DATE 10 MAR 94	DATE	DATE	7.50

SECTION 6 PREDICTED SHELL BUCKLING STRESSES FOR COMBINED LOADS

Section 6.3 Axial Compression, Bending and Hoop Compression

(Ra)^2 - c (Ra)(Rh) + (Rh)^2 = 1.0 (eq. 6-3)

Ra = Flcj / Fxcj   Rh = Focj / Frcj

a. Unstiffened and Ring Stiffened Cylinders (all buckling modes)

c = (Fxcj + Frcj) / Fy - 1.0 (eq. 6-4)

Local Buckling

c = [FxcL + FrcL] / Fy - 1 = -0.07693

Let FlcL = (FocL) (k) (KxL/KoL) = 1.7140 (FocL)

Ra = FlcL / FxcL = 0.000105 (FocL)

Rh = FocL / FrcL = 0.000147 (FocL)

KxL = 1.0

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.
k = Nx/No = 1.714
e = 0.226

Solve eq. 6-3 for FocL

FocL = 5,441 psi (eq. 6-3)

FlcL= (FocL) (k) (KxL/KoL) = 9,326 psi

General Instability

c = [FxcG + FrcG] / Fy - 1 = 0.709645

KxG = 1.0

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.2504 (eq. 11-9)
(If KoG < 0 then ring is in tension and the interaction equation is not applicable. Then FlcG = FxcG)

k = Nx / No = 1.714
Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.

Let FlcG = (FocG) (k) (KxG/KoG) = 6.843771 (FocG)

Ra = FlcG / FxcG : 0.000341 (FocG)

Rh = FocG / FrcG 4.41E-05 (FocG)

Solve eq. 6-3 for FocG

FocG = 3,047 psi (eq. 6-3)

FlcG= (FocG) (k) (KxG/KoG) = 20,854 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum + Axial Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 5 OF 6
	DATE 3/10/94	DATE 11MAR94	DATE	DATE	7.51

SECTION 9 ALLOWABLE STRESSES

Section 9.1 Allowable Stresses For Shell Buckling Mode

Section 9.1.5 Axial Compression and Hoop Compression and Axial Compression, Bending and Hoop Compression

Fa = Fb = FicL / FS

(eq. 9-7)

Fo = FocL / FS

Factor of Safety (FS) = 1.91

Fa = Fb = 4,883 psi = 620.10 #/in. Nx = 617.35 #/in.

Fc = 2,849 psi = 361.79 #/in. No = 360.18 #/in.

SECTION 11 STRESS CALCULATIONS

Section 11.3 Hoop Stresses

Section 11.3(b)2 Stress in a Ring Stiffener

Ring Stiffener Stress = (p * Ro / t) * (1.00 - 0.30 * (Nx / No)) * (Le * t) / (Ar + Le * t) (Eq 11-8)

Solving Eq 11-8,

==> Ring Stiffener Stress = 1,566 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum + Axial Seismic Support Settlement of 0.579"	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 6 OF 6
	DATE 3/10/94	DATE 18 MAR 94	DATE	DATE	7.52

API BULLETIN 2U, FIRST EDITION, MAY 1, 1987
BULLETIN ON STABILITY DESIGN OF CYLINDRICAL SHELLS

SECTION 4 PREDICTED SHELL BUCKLING STRESSES FOR AXIAL LOAD, BENDING AND EXTERNAL PRESSURE

Lr =	30.00	in.	b =	0.00	in.	tw =	0.1875	in.
R =	24.439	in.	Fy =	25,000	psi	Ar =	0.3280	sq.in.
t =	0.127	in.	E =	28,300,000	psi	Zr =	0.9385	in.
(Rt)^.5 =	1.762	in.	R/t =	192.43		Ir =	0.08374	in.^4
Mx = Lr/(Rt)^.5 =	17.03	(eq. 4.1)				Rr =	25.377	in.
Mc = b/(Rt)^.5 =	0.00	(eq. 4.1)				Le=[1.56(Rt)^.5]+tw =	2.936	in.

Ring Stiffener (heading over tw, Ar, Zr, Ir, Rr, Le)

Nx = 748.41 #/in. No = 360.18 #/in.
= 5,893 psi (Axial) = 2,836 psi (Hoop)

Section 4.1 Local Buckling of Unstiffened or Ring Stiffened Cylinders

Section 4.1.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeL = (axL)(Cx)(E)(t/R) (eq. 4-2)

Cx = 0.630 if Mx =< 1.5
Cx = [0.904/(Mx)^2] + 0.1013(Mx)^2 = 2.941 if 1.5 < Mx < 1.73 (eq. 4-3)
Cx = 0.605 if Mx > 1.73

Mx = 17.03 ==========> **Cx = 0.605**

axL = 0.207 if R/t >= 610 (eq. 4-4)
axL = 169c/(195 + R/t) < 0.9 = 0.436 if R/t < 610

R/t = 192 ==========> **axL = 0.436**

c = 2.64 if Mx =< 1.5
c = 3.13/(Mx)^0.42 = 0.952 if 1.5 < Mx =< 15 (eq. 4-5)
c = 1.0 if Mx > 15

Mx = 17.03 ==========> **c = 1.000**

FxeL = (axL)(Cx)(E)(t/R) = 38,812 psi (eq. 4-2)

b. Inelastic Buckling Stresses

Smaller of:
FxcL = FxeL = 38,812 psi eq. 4-6

FxcL = 233(Fy)/(166 + R/t) =< Fy = 16,251 psi if R/t < 300 (eq. 4-7)
FxcL = 0.5(Fy) = 12,500 psi if R/t >= 300

R/t = 192 ==========> FxcL = 16,251 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 1 OF 6
100F Operating + Vacuum, No Seismic Support Misalignment of 1.000" during Adjustment	DATE 3/16/94	DATE 18 MAR 94	DATE	DATE	7.53

Section 4.1.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Elastic Buckling Stresses

FreL or FheL = (acL)(PeL)(R)(KoL)/t (eq. 4-8)

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k = Nx/No = 0
e = 0.449

y = 1.0 if Mx =< 1.26
y = 1.58 - 0.46 Mx = -6.25 if 1.26 < Mx =< 3.42
y = 0.0 if Mx >= 3.42
Mx = 17.03 ====> **y = 0.000**

PeL = [1.27 (E) (t/R)^2]/[A^1.18 + 0.5]= 36.5161 if Mx > 1.5 & A < 2.5
PeL = [0.92 (E) (t/R)^2]/A = 44.3368 if 2.5 < A < 0.208 R/t
PeL = 0.836(Cp)^-1.061 (E)(t/R)^3 = 46.9145 if 0.208 < Cp < 2.85
PeL = 0.275 (E)(t/R)^3 = 1.0922 if Cp > 2.85
PeL = 44.3368

A = Mx - 1.17 + 1.068k = 15.859
Mx = 17.03
k = 0
0.208 R/t = 40.02526
Cp = A/(R/t) = 0.082413

b. Imperfection Factors

aoL = 0.8

FreL or FheL = (aoL)(PeL)(R)(KoL)/t = 6,825 psi (eq. 4-8)

c. Inelastic Buckling Stresses

FrcL = n (FreL) (eq. 4-10) FhcL = n (FheL) (eq. 4-11)

n = 1.0 if d =< 0.55
n = 0.45/d + 0.18 = 1.83 if 0.55 < d =< 1.6
n = 1.31/(1 + 1.15d) = 1.00 if 1.6 < d < 6.25
n = 1/d = 3.66 if d >= 6.25

d = FreL/Fy = 0.2730 (eq. 5-3)
n = 1.000

FrcL = n (FreL) = 6,825 psi (eq. 4-10)

d. Failure Pressures

poL = (n)(aoL)(peL) = 35.469 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube – 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Misalignment of 1.000" during Adjustment	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 2 OF 6
	DATE 3/16/94	DATE 18 JUNE 94	DATE	DATE	7.54

Section 4.2 General Instability of Ring Stiffened Cylinders

Section 4.2.1 Axial Compression or Bending (No = 0)

a. Elastic Buckling Stresses

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 (eq. 4-13)

A'r = Ar/[Lr) t] = 0.0861

Ar = ring area = 0.328 sq.in.
Lr = ring spacing = 30 in.

b. Imperfection Factors

axG = 0.72		if A'r >= 0.2	(eq. 4-14)
axG = [3.6 - 5.0(axL)] (A'r) + axL =	0.558	if 0.06 < A'r < 0.2	
axG = axL = 0.436209		if A'r =< 0.06	
axG = 0.558		axL from eq. 4-4 with c = 1.0	

FxeG = (axG)(0.605)(E)(t/R)(1 + A'r)^0.5 = 51,775 psi (eq. 4-13)

c. Inelastic Buckling Stresses

FxcG = n (FxeG) (eq. 4-15)

n =	1.0		if d =< 0.55	d = FxeG/Fy = 2.0710	(eq. 5-3)
n =	0.45/d + 0.18 =	0.40	if 0.55 < d =< 1.6		
n =	1.31/(1 + 1.15d) =	0.39	if 1.6 < d < 6.25	**n = 0.387**	
n =	1/d = 0.48		if d >= 6.25		

FxcG = n (FxeG) = 20,057 psi (eq. 4-15)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
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100F Operating + Vacuum, No Seismic Support Misalignment of 1.000" during Adjustment	DATE 3/16/94	DATE 18MAR94	DATE	DATE	7.55

Section 4.2.2 **External Pressure (Nx/No = 0 or 0.5)** **Use Nx/No = 0**

Nx/No = 0 for radial pressure
Nx/No = 0.5 for hydrostatic pressure

a. Buckling Stresses With or Without End Pressure

FreG or FheG = (acG)(PeG)(Ro)(KoG)/t (eq. 4-16)

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.531994 (eq. 11-9)

Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.935797 in.
k= 0

$$PeG = \frac{(E)(t/R)(Lg)^4}{[N^2 + k(Lg)^2 - 1]\,[N^2 + (Lg)^2]^2} + \frac{(E)(Ier)(N^2 - 1)}{(Lr)(Rc)^2(R)} \qquad \text{(eq. 4-17)}$$

lamda G (Lg) = (pi)(R)/Lb = 2.559194 Lb = 30 in.

k = 0

Ier = Ir + (Ar)(Zr)^2 (Le)(t)/[(Ar) + (Le)(t)] + (Le)(t)^3/12 = 0.233 in.^4 (eq. 4-18)

Ir = 0.08374 in.^4
Ar = 0.328 sq.in.
Zr = 0.9385 in.
t = 0.127 in.
Rr = 25.3767 in.

Le = 1.1(Dt)^0.5 = 2.741 in. if Mx > 1.56
Le = Lr = 30.000 in. if Mx=< 1.56
Mx = 17.03 ===> **Le = 2.741 in.**

N = 4 use N that gives PeG min. 2< N

PeG = 1036.55 psi (eq. 4-17)

b. Imperfection Factors

aoG = 0.8

FreG or FheG = (aoG)(PeG)(Ro)(KoG)/t = 85,111 psi (eq. 4-16)

c. Inelastic Buckling Stresses

FrcG = n (FreG) (eq. 4-19) FhcG = n (FheG) (eq. 4-20)

n = 1.0		if d =< 0.55	d = FreG/Fy =	3.4044
n = 0.45/d + 0.18 =	0.312	if 0.55 < d =< 1.6		
n = 1.31/(1 + 1.15d) =	0.267	if 1.6 < d < 6.25	**n =**	**0.267**
n = 1/d = 0.294		if d >= 6.25		

(eq. 5-3)

FrcG = n (FreG) = 22,684 psi (eq. 4-10)

d. Failure Pressures

poG = (n)(aoG)(peG) = 221.014 psi (eq. 4-12)

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Misalignment of 1.000" during Adjustment	MADE BY WJC	CHKD RJM	MADE BY	CHKD BY	SHT 4 OF 6
	DATE 3/16/94	DATE 18MAR94	DATE	DATE	7.56

SECTION 6 PREDICTED SHELL BUCKLING STRESSES FOR COMBINED LOADS

Section 6.3 Axial Compression, Bending and Hoop Compression

(Ra)^2 - c (Ra)(Rh) + (Rh)^2 = 1.0 (eq. 6-3)

Ra = Flcj / Fxcj Rh = Focj / Frcj

a. Unstiffened and Ring Stiffened Cylinders (all buckling modes)

c = (Fxcj + Frcj) / Fy - 1.0 (eq. 6-4)

Local Buckling

c = [FxcL + FrcL] / Fy - 1 = -0.07693

Let FlcL = (FocL) (k) (KxL/KoL) = 2.0779 (FocL)

Ra = FlcL / FxcL = 0.000128 (FocL)

KxL = 1.0

Rh = FocL / FrcL = 0.000147 (FocL)

KoL = 1.0 if Mx >= 3.42
KoL = 1 - e*y = 1.000 if Mx < 3.42 (eq. 11-7)
Mx = 17.03 ==========> **KoL = 1.000**

e = (1 - 0.3k)/[1 + (Le)t/A]
A = (Ar)(R/Rr)^2 = 0.304196 sq.in.
Ar = 0.328 sq.in.
Rr = 25.377 in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.
k = Nx/No = 2.078
e = 0.175

Solve eq. 6-3 for FocL

FocL = 5,047 psi (eq. 6-3)

FlcL= (FocL) (k) (KxL/KoL) = 10,488 psi

General Instability

c = [FxcG + FrcG] / Fy - 1 = 0.709645

KxG = 1.0

KoG = (1 - 0.3k)(Le)(t)/[(Ar + (Le)(t)] = 0.1942 (eq. 11-9)
(If KoG < 0 then ring is in tension and the interaction equation is not applicable. Then FlcG = FxcG)

k = Nx / No = 2.078
Ar = 0.328 sq.in.
Le=[1.56(Rt)^.5]+tw = 2.748297 in.

Let FlcG = (FocG) (k) (KxG/KoG) = 10.70148 (FocG)

Ra = FlcG / FxcG : 0.000534 (FocG)

Rh = FocG / FrcG 4.41E-05 (FocG)

Solve eq. 6-3 for FocG

FocG = 1,925 psi (eq. 6-3)

FlcG= (FocG) (k) (KxG/KoG) = 20,598 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Misalignment of 1.000" during Adjustment	MADE BY WJC	CHKD RJW	MADE BY	CHKD BY	SHT 5 OF 6
	DATE 3/16/94	DATE 19MAR94	DATE	DATE	7.57

SECTION 9 ALLOWABLE STRESSES

Section 9.1 Allowable Stresses For Shell Buckling Mode

Section 9.1.5 Axial Compression and Hoop Compression and Axial Compression, Bending and Hoop Compression

Fa = Fb = FicL / FS

(eq. 9-7)

Fo = FocL / FS

Factor of Safety (FS) = 1.77

Fa = Fb =	**5,925**	**psi**	**=**	**752.50**	**#/in.**	Nx =	748.41	#/in.
Fo =	**2,852**	**psi**	**=**	**362.15**	**#/in.**	No =	360.18	#/in.

SECTION 11 STRESS CALCULATIONS

Section 11.3 Hoop Stresses

Section 11.3(b)2 Stress in a Ring Stiffener

Ring Stiffener Stress = (p * Ro / t) * (1.00 - 0.30 * (Nx / No)) * (Le * t) / (Ar + Le * t) (Eq 11-8)

Solving Eq 11-8,

==> Ring Stiffener Stress = 1,214 psi

SUBJECT	OFFICE: NOE		REVISION		REFERENCE NO. 930212
LIGO Beam Tube -- 49.00" OD x 0.127" Wall 1.75" x 0.1875" Vacuum Stiffener, 30" Spacing 100F Operating + Vacuum, No Seismic Support Misalignment of 1.000" during Adjustment	MADE BY WJC	CHKD RSN	MADE BY	CHKD BY	SHT 6 OF 6
	DATE 3/16/94	DATE 18MAR94	DATE	DATE	7.58

TUBE OVALING FREQUENCY

THE FREQUENCY OF ANY IN-PLANE MODE OF VIBRATION OF A CIRCULAR RING.

$$f_i = \frac{1}{2\pi}\sqrt{\frac{Eg}{\gamma}\;\frac{I}{Ar^4}\;\frac{n^2(1-n^2)^2}{1+n^2}}$$

REF: "VIBRATION PROBLEMS IN ENGINEERING", TIMOSHENKO, 2^{ND} EDITION
Pg. 410 , EQ. 202

E = MODULUS OF ELASTICITY = 28,300,000 PSI @ 70°F
(STAINLESS STEEL) = 27,000,000 PSI @ 300°F

γ = UNIT WEIGHT OF MATERIAL = 500 PCF = 0.2894 $^{\#}/_{IN^3}$

g = ACCELERATION DUE TO GRAVITY = 386 $^{IN}/_{SEC^2}$

I = RING MOMENT OF INERTIA (IN^4)

A = AREA OF RING (IN^2)

r = RADIUS OF RING (IN)

n = NUMBER OF WAVES AROUND CIRCUMFERENCE

f = FREQUENCY

SUBJECT Tube Ovaling Frequency Ligo Beam Tube	CBI OFFICE NoE C		REVISION		REFERENCE NO. 93021V
	MADE BY MRS	CHKD BY WJC	MADE BY	CHKD BY	SHT 1 OF 18
	DATE 2/17/94	DATE 4-5-94	DATE	DATE	8.1

FOR UNSTIFFENED CYLINDER

THE FUNDAMENTAL MODE OF VIBRATION $n = 2$

$I = t^3/12$ $\quad A = t$ $\quad r = 24.4385$

$$f = \frac{1}{2\pi}\sqrt{\frac{(28{,}300{,}000)(386)}{0.2894} \; \frac{t^3/12}{t\,r^4} \; \frac{n^2(1-n^2)^2}{1+n^2}}$$

$$f = 8{,}926.21 \; t/r^2 \sqrt{\frac{n^2(1-n^2)^2}{1+n^2}}$$

$t = 0.127''$ $\quad r = 24.4385''$ $\quad n = 2$

$f = 23{,}952 \; t/r^2$

$f = 5.1$ CYCLES/SEC

PERIOD $(T) = 0.196$ SEC.

SUBJECT TUBE OVALING FREQUENCY LIGO BEAM TUBE	CBI NOEC OFFICE		REVISION		REFERENCE NO. 93021
	MADE BY MRS	CHKD BY WJC	MADE BY	CHKD BY	SHT 2 OF 18
	DATE 2/17/94	DATE 4.5.94	DATE	DATE	8.2

Printed in USA

GO 64 REV SEP 84

TUBE OVALING FREQUENCY

The frequency of any in-plane mode of vibration of a circular ring can be found using the following formula.

fi = 1/[2(pi)] x {[Eg/d][I/Ar^4][n^2(1-n^2)^2]/[1+n^2]}

Ref: "Vibration Problems in Engineering", Timoshenko, 2nd Edition

E = modulus of elasticity = 28300 ksi

d = unit weight of material = 0.2894 lbs/cu.in.

g = acceleration due to gravity = 386 in/sec^2

I = ring moment of inertia = 0.0002 in^4

A = area of ring = 0.127 sq.in.

r = ring radius = 24.439 in.

n = number of waves around circumference fi = frequency (Hz)

n	fi (Hz)	T (sec.)
2	5.0932	0.1963
3	14.406	0.0694
4	27.622	0.0362
5	44.67	0.0224
6	65.53	0.0153
7	90.194	0.0111
8	118.66	0.0084
9	150.92	0.0066
10	186.98	0.0053

<table>
<tr><td rowspan="3">SUBJECT
TUBE OVALING FREQUENCY
LIGO BEAM TUBE</td><td colspan="2">OFFICE: NOE</td><td colspan="2">REVISION:</td><td>REFERENCE NO.
930212</td></tr>
<tr><td>MADE
MRS</td><td>CHKD
WJC</td><td>MADE</td><td>CHKD</td><td>SHT 3 OF 18</td></tr>
<tr><td>DATE
2/17/94</td><td>DATE
4-5-94</td><td>DATE</td><td>DATE</td><td>8.3</td></tr>
</table>

"Formulas for Stress & Strain", Roark, 4th ed.
Table VIII Case 15, Page 175

Theta = 0.001 deg. cos = 1 sin = 2E-05
2E-05 rad.

R = 24.439 in.

W = 11.287 lbs w = 13231 #/in

M1 = -0.0012 in-lbs T1 = -5E-05 lbs

x = 0 deg. cos = 1 sin = 0
0 rad.

(x=0 to x=theta) M = -0.0012 in-lbs
T = -5E-05 lbs
V = 5.6435 lbs

"Formulas for Stress & Strain", Roark, 4th ed.
Table VIII Case 18, Page 176

R = 24.439 in.

W = 11.287 lbs w = 0.0735 #/in

M (max) = M1 = 65.851 in-lbs

x = 0 deg. cos = 1 sin = 0
0 rad.

M = 65.851 in-lbs
T = -0.8982 lbs
V = -5.6435 lbs

Case 15 + Case 18
theta = 0.001 deg. = 0 rad.

x = 0 deg. = 0 rad.

M = 65.85 in-lbs
T = -0.8982 lbs
V = 0 lbs

t = 0.127 in. A = 0.127 sq.in. Z = 0.0027 cu.in.

S = M/Z + T/A = 24496 + -7.0728 = 24489 psi

SUBJECT STRESS IN PIPE UNDER DL & 1g FORCE IN VERTICAL DIRECTION N=2 OVALING MODE	OFFICE: NOE		REVISION:	REFERENCE NO. 930212
	MADE MRS	CHKD WJC	MADE	CHKD	SHT 4 OF 18
	DATE 2/17/94	DATE 4-5-94	DATE	DATE	8.4

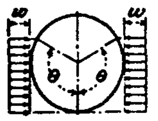
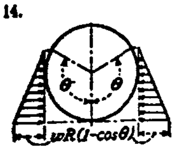
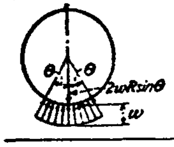
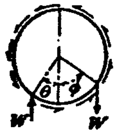
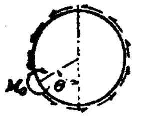
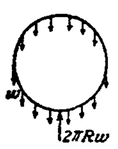
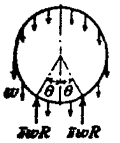
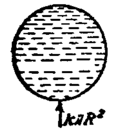
13. 	$M_1 = wR^2[0.3183(\frac{1}{2}s - \theta c + \frac{1}{2}sc^2 + \frac{1}{2}\theta c^2 - \frac{1}{2}sc - \frac{1}{6}s^3) - \frac{1}{2} + c - \frac{1}{2}c^2]$ $T_1 = wR[0.3183(\frac{1}{2}s + \frac{1}{2}sc^2 - \theta c) + c - 1]$ $(x = 0 \text{ to } x = \theta)$ $M = M_1 - T_1R(1-u) - \frac{1}{2}wR^2(1-u)^2$ $T = T_1u + wR(1-u)u$ $V = -T_1z - wR(1-u)z$ $(x = \theta \text{ to } x = \pi)$ $M = M_1 - T_1R(1-u) - \frac{1}{2}wR^2(1-c)(1+c-2u)$ $T = T_1u + wR(1-c)u$ $V = -T_1z - wR(1-c)z$
14. 	$M_1 = wR^2[0.3183(\frac{3}{4}\theta + \frac{3}{4}s - \frac{3}{4}\theta c - \frac{1}{4}sc + \frac{1}{4}sc^2 - \frac{1}{2}\theta c^2 - \frac{1}{12}sc^3 - \frac{1}{4}\theta c^3) - \frac{1}{6}(1-c)^3]$ $T_1 = wR^2[0.3183(\frac{1}{4}\theta + \frac{1}{4}\theta c^2 - \frac{1}{4}sc - \frac{1}{12}sc^3) - \frac{1}{6}(1-c)^3]$ $(x = 0 \text{ to } x = \theta)$ $M = M_1 - T_1R(1-u) + wR^2[\frac{1}{6}(1-u)^3 - \frac{1}{2}(1-c)(1-u)^2]$ $T = T_1u + wR^2[\frac{1}{2}(1-2c+u)(1-u)u]$ $V = -T_1z - wR^2[\frac{1}{2}(1-2c+u)(1-u)z]$ $(x = \theta \text{ to } x = \pi)$ $M = M_1 - T_1R(1-u) - wR^2[\frac{1}{2}(1-c)^2(\frac{1}{3} + \frac{2}{3}c - u)]$ $T = T_1u + wR^2[\frac{1}{2}u(1-c)^2]$ $V = -T_1z - wR^2[\frac{1}{2}z(1-c)^2]$
15. 	$M_1 = wR^2[c - 0.3183(\theta c - \theta) - 1]$ $T_1 = wR[0.3183(s - \theta c) + c - 1]$ $(x = 0 \text{ to } x = \theta)$ $M = M_1 - T_1R(1-u) - wR^2(1 - u - sz)$ $T = T_1u + wR(sz + u - 1)$ $V = -T_1z + wR(su - z)$ $(x = \theta \text{ to } x = \pi)$ $M = M_1 - T_1R(1-u) - wR^2(cu - u)$ $T = T_1u + wR(u - cu)$ $V = -T_1z + wR(cz - z)$ $D_x = \frac{2wR^4}{EI}\left[\frac{1}{4}\theta c + 0.3183\theta - 0.5683s\right]$ when $\theta < \frac{\pi}{2}$ $D_y = \frac{2wR^4}{EI}\left[\frac{1}{4}\theta s + 0.3183\theta + \frac{1}{2}c - 0.3183s - \frac{1}{2}\right]$
16. 	$(x = 0 \text{ to } x = \theta)$ $M = WR\{0.15915(s\theta + c - n\phi - e - u(s^2 - n^2) - z(sc + \theta + ne + \phi) - z(s + n)] - \frac{1}{2}(s - n) + z\}$ $(x = \theta \text{ to } x = 2\pi - \phi)$ $M = WR\{0.15915(s\theta - c - n\phi - e - u(s^2 - n^2) - z(sc + \theta + ne + \phi) - z(s + n)] - \frac{1}{2}(s - n)\}$ $(x = 2\pi - \phi \text{ to } 2\pi)$ $M = WR\{0.15915(s\theta + c - n\phi - e - u(s^2 - n^2) - z(sc + \theta + ne + \phi) - z(s + n)] + \frac{1}{2}(s - 3n) - z\}$ $(x = 0 \text{ to } x = \theta \text{ and } x = 2\pi - \phi \text{ to } x = 2\pi)$ $T = W[0.15915(us^2 - un^2 - zsc - z\theta - zne - z\phi) + z]$ $V = W[0.15915(-s - n - zs^2 + zn^2 - usc - u\theta - une - u\phi) + u]$ $(x = \theta \text{ to } x = 2\pi - \phi)$ $T = W[0.15915(us^2 - un^2 - zsc - z\theta - zne - z\phi)]$ $V = W[0.15915(-s - n - zs^2 + zn^2 - usc - u\theta - une - u\phi)]$
17. Ring under localized couple M_0 and uniform tangential shear of $(M_0 \div 2\pi R^2)$ lb. per linear in. 	$(x = 0 \text{ to } x = \theta)$ $M = M_0[0.3183(us - zc + \frac{1}{2}\theta - \frac{1}{2}x) - \frac{1}{2}]$ $(x = \theta \text{ to } x = 2\pi)$ $M = M_0[0.3183(us - zc + \frac{1}{2}\theta - \frac{1}{2}x) + \frac{1}{2}]$ $T = -\frac{M_0}{R}[0.318\ (zc - us)]$ $T = -\frac{M_0}{R}[0.3183(zc - us)]$ $V = -\frac{M_0}{R}\left[0.3183\left(zs + uc + \frac{1}{2}\right)\right]$ $V = -\frac{M_0}{R}\left[0.3183\left(zs + uc + \frac{1}{2}\right)\right]$

TABLE VIII.—FORMULAS FOR CIRCULAR RINGS AND ARCHES.—(*Continued*)

Loading, support and case number	Formulas for bending moment M, circumferential tension T, radial shear V at angular distance x from bottom of ring and for D_x, change in horizontal diameter, and D_y, change in vertical diameter
18. Ring supported at base and loaded by own weight of w lb. per linear in. 	$M = wR^2(1 + \frac{1}{2}u - \pi z + xz)$ Max $+M = M_1 = \frac{3}{2}wR^2$ Max $-M = -0.642wR^2$ at $x = 1.3$ rad (74.6°) $T = wR(xz - \frac{1}{2}u - \pi z)$ $V = wR(xu + \frac{1}{2}z - \pi u)$ $D_x = \frac{wR^4}{EI}(0.4292)$ $D_y = -\frac{wR^4}{EI}(0.4674)$ $\Delta R = -\frac{wR^4}{EI}(0.18765)$
19. Ring symmetrically supported and loaded by own weight of w lb. per linear in. 	$M_1 = wR^2(\frac{1}{2} + c + \theta s - \pi s + s^2)$ $T_1 = wR(s^2 - \frac{1}{2})$ $(x = 0 \text{ to } x = \theta)$ $M = M_1 - T_1R(1-u) + wR^2(xz + u - 1)$ $T = T_1u + wRxz$ $V = -T_1z + wRxu$ $(x = \theta \text{ to } x = \pi)$ $M = M_1 - T_1R(1-u) - wR^2(xz + u - 1 - \pi z + \pi s)$ $T = T_1u + wR(xz - \pi z)$ $V = -T_1z + wR(xu - \pi u)$ $D_x = \frac{2wR^4}{EI}\left[c + \theta s - \frac{1}{4}\pi(1 + s^2)\right]$ $D_y = \frac{wR^4}{EI}\left[-2.4674 + \frac{1}{2}\pi(sc + \theta - 2s) + 2(\theta s + c)\right]$ $\Delta R = \frac{wR^4}{EI}\left[0.38315 - 0.5708(c + \theta s) + \frac{1}{2}s^2\right]$
20. 1-in. segment of pipe filled with liquid of specific weight k lb. per cu. in. and supported at base 	$M_1 = \frac{3}{4}kR^3$ $T_1 = \frac{3}{4}kR^2$ Max $+M = M_1$ Max $-M = -0.321kR^3$ at $x = 1.3$ rad (74.6°) $M = kR^3(\frac{3}{4} + \frac{1}{4}u - \frac{1}{2}\pi z + \frac{1}{2}xz)$ $T = kR^2(1 + \frac{1}{4}u - \frac{1}{2}\pi z + \frac{1}{2}xz)$ $V = kR^2(\frac{1}{2}xu + \frac{1}{4}z - \frac{1}{2}\pi u)$ $D_x = \frac{kR^5}{EI}(0.2146)$ $D_y = -\frac{kR^5}{EI}(0.2337)$ $\Delta R = -\frac{kR^5}{EI}(0.093825)$

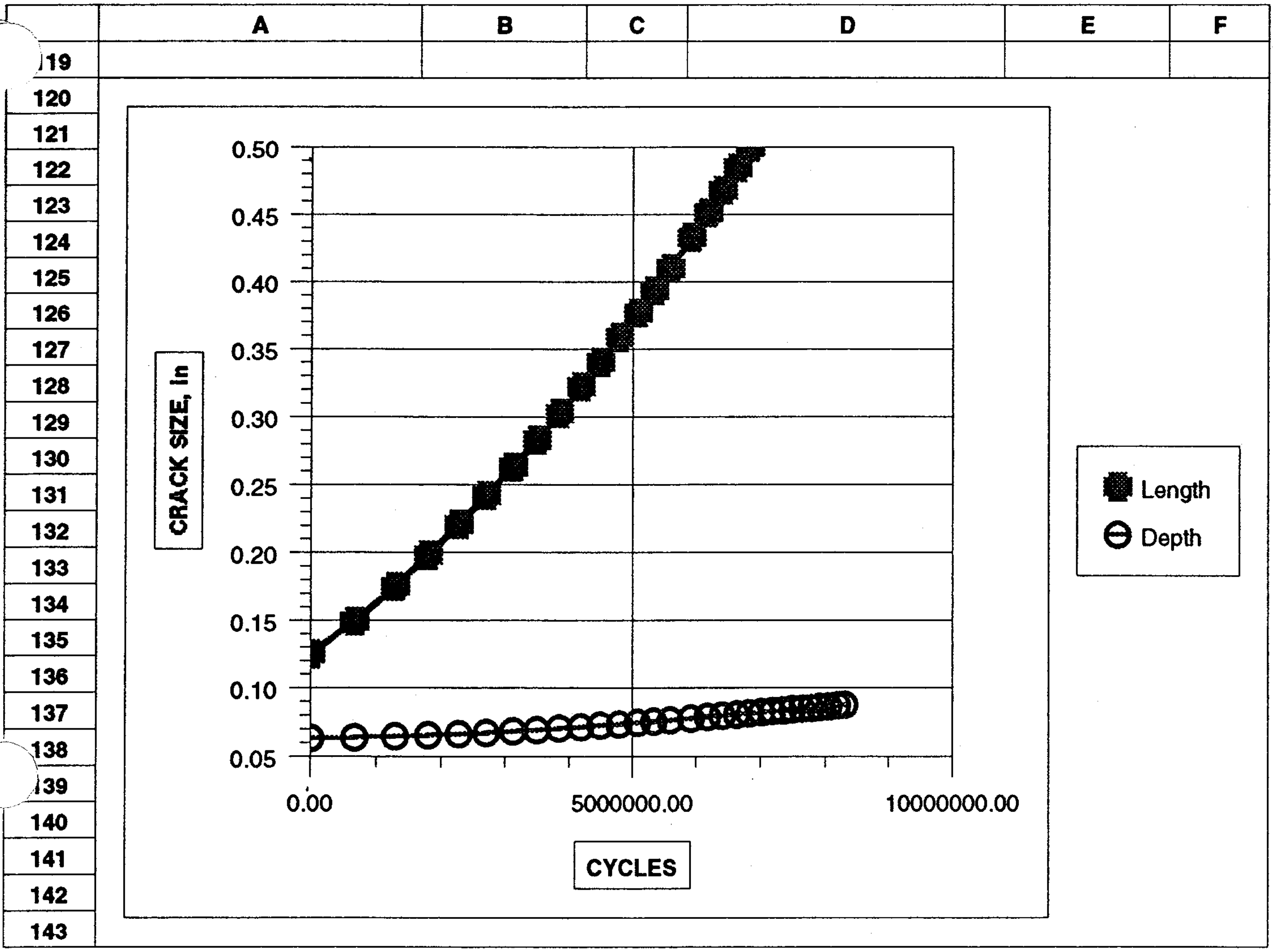
8.5

	A	B	C	D	E	F
1	[illegible]					
2						
3						
4						
5						
6	Previous		Calculate		Next	
7						
8						
9	da/dN = C*deltaK^m					
10	C	3.00E-10				
11	m	3.25				
12	**DIMENSIONS**					
13	Flaw type	Surface				
14	Initial flaw depth (a)	0.06	in	Dist. to free edge (W)	100.00	in
15	Initial flaw length (2c)	0.13	in			
16	Wall thickness	0.13	in			
17						
18	Temperature	0.00	Deg. F			
19						
20	**STRESSES**					
21	Prim. memb. stress (Pm)	0.00	ksi	Sec. memb. stress (Sm)	25.00	ksi**
22	Prim. bend stress (Pb)	12.25	ksi	Sec. bend stress (Sb)	0.00	ksi**
23	Cyclic memb. stress	0.00	ksi			
24	Cyclic bend stress	12.25	ksi			
25	**MATERIAL PROP.**					
26	Parent metal yield str.	25.00	ksi*	Fracture toughness (Kc)	120.00	ksiVin
27	Parent metal tensile str.	70.00	ksi*			
28	Weld metal yield str.	25.00	ksi*			
29	Weld metal tensile str.	70.00	ksi*			
30	*Specified minimum values			**These values may be reduced by		
31				mechanical stress relief		
32						
33						
34						
35						
36						
37						
38						
39						
40						
41						

8.b

	A	B	C	D	E	F
42						
43						
44						
45						
46						
47	Cycles	Length (2c)		Crack Depth, inches	Type	
48	0.000E+00	0.125	in	0.064	Surface	
49	6.633E+05	0.149	in	0.064	Surface	
50	1.289E+06	0.175	in	0.065	Surface	
51	1.798E+06	0.198	in	0.065	Surface	
52	2.279E+06	0.221	in	0.066	Surface	
53	2.708E+06	0.242	in	0.067	Surface	
54	3.119E+06	0.263	in	0.068	Surface	
55	3.487E+06	0.283	in	0.069	Surface	
56	3.843E+06	0.302	in	0.070	Surface	
57	4.187E+06	0.322	in	0.071	Surface	
58	4.495E+06	0.340	in	0.072	Surface	
59	4.793E+06	0.359	in	0.073	Surface	
60	5.082E+06	0.377	in	0.075	Surface	
61	5.340E+06	0.394	in	0.075	Surface	
62	5.590E+06	0.410	in	0.076	Surface	
63	5.920E+06	0.433	in	0.078	Surface	
64	6.176E+06	0.451	in	0.079	Surface	
65	6.404E+06	0.468	in	0.080	Surface	
66	6.626E+06	0.485	in	0.081	Surface	
67	6.823E+06	0.500	in	0.081	Surface	
68	7.016E+06	0.515	in	0.082	Surface	
69	7.185E+06	0.529	in	0.083	Surface	
70	7.352E+06	0.542	in	0.084	Surface	
71	7.497E+06	0.554	in	0.084	Surface	
72	7.639E+06	0.566	in	0.085	Surface	
73	7.779E+06	0.579	in	0.085	Surface	
74	7.917E+06	0.591	in	0.086	Surface	
75	8.053E+06	0.603	in	0.086	Surface	
76	8.186E+06	0.615	in	0.087	Surface	
77	8.301E+06	0.626	in	0.088	Surface	

	A	B	C	D	E	F
78	8414161.20	0.64	in	0.09	Surface	
79	8525895.36	0.65	in	0.09	Surface	
80	8636112.87	0.66	in	0.09	Surface	
81	8744851.02	0.67	in	0.09	Surface	
82	8852145.66	0.68	in	0.09	Surface	
83	8958031.29	0.69	in	0.09	Surface	
84	9062541.04	0.70	in	0.09	Surface	
85	9151049.94	0.71	in	0.09	Surface	
86	9238590.77	0.72	in	0.09	Surface	
87	9325182.22	0.73	in	0.09	Surface	
88	9410842.35	0.74	in	0.09	Surface	
89	9495588.61	0.75	in	0.09	Surface	
90	9579437.87	0.75	in	0.09	Surface	
91	9662406.41	0.76	in	0.09	Surface	
92	9744509.98	0.77	in	0.09	Surface	
93	9825763.79	0.78	in	0.09	Surface	
94	9906182.53	0.79	in	0.09	Surface	
95	9985780.40	0.80	in	0.09	Surface	
96	10064571.13	0.81	in	0.10	Surface	
97	10129623.08	0.82	in	0.10	Surface	
98	10194131.17	0.82	in	0.10	Surface	
99	10258102.62	0.83	in	0.10	Surface	
100	10321544.46	0.84	in	0.10	Surface	
101	10384463.52	0.85	in	0.10	Surface	
102	10407478.28	0.85	in	0.10	Surface	
103						
104						
105						
106						
107	**Estimated life = 10,407,478.28 cycles**					
108						
109	**Limiting crack length = 0.85 in**					
110						
111	**Limiting crack depth = 0.097 in**					
112						
113						
114						
115						
116						
117						
18						


A
B
C
D
E
F
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
CRACK SIZE, In
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
5000000.00
10000000.00
CYCLES
Length
Depth

TOTAL STRESS = 24,989 PSI ≈ F_y

∴ VERTICAL PIPE STUL MUST BE USED AT EACH TUBE SUPPORT

FRACTURE MECHANICS METHODS WERE USED TO EVALUATE BEAM TUBE FOR OVALING ASSUMING PEAK STRESSES VARY FROM 12,250 PSI TO 24,500 PSI.

DL TO DL + 1g LOAD ON TUBE

ASSUMED FLAW SIZE $L = \frac{1}{2}t$ $D = \frac{1}{4}t$

ESTIMATED LIFE = 10,000,000 CYCLES

TUBE SHIPPING DISTANCE = 3000 MILES

AVE. SHIPPING SPEED ≈ 40 MPH

TRAVEL TIME $= \frac{3000 \text{ MILES}}{40 \text{ MPH}}$ = 75 HRS = 270,000 SEC.

N	FREQ.	CYCLES
2	5.09	1,374,300
3	14.41	3,890,700
4	27.62	7,457,400
5	44.67	12,060,900

THE FUNDAMENTAL MODE OF VIBRATION FOR UNSTIFFENED CYLINDER IS N=2. FOR N=2 CYCLES = 1,374,000 < 10,000,000
∴ OK

SUBJECT	CBI OFFICE NOE C		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY WJC	MADE BY	CHKD BY	SHT 10 OF 18
	DATE 2/17/94	DATE 4-6-94	DATE	DATE	8.10

BEAM BENDING MODE

REF: TIMOSHENKO

$$f_n = \frac{\pi n^2}{2L^2}\sqrt{\frac{EIg}{A\gamma}}$$

$g = 386$ #/SEC^2

$E = 28{,}300{,}000$ PSI

$\gamma = 0.2894$ #/IN^3

$A = 2\pi r t = 2\pi(24.4385)(.127) = 19.5$ IN^2

$I = \pi r^3 t = \pi(24.4385)^3(.127) = 5823.4$ IN^4

$L = 65' = 780''$

LET $n = 1$

$$f = \frac{\pi(1)^2}{2(780)^2}\sqrt{\frac{(28{,}300{,}000)(5823.4)(386)}{(19.5)(0.2894)}}$$

$f = 8.67$ CYCLES/SEC

$T = 0.115$ SEC.

SUBJECT	CBI OFFICE NOE C		REVISION		REFERENCE NO. 931212
	MADE BY MRS	CHKD BY WJC	MADE BY	CHKD BY	SHT 11 OF 18
	DATE 2/17/94	DATE 4-5-94	DATE	DATE	8.11

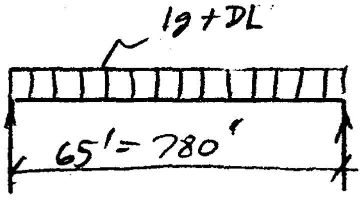
REF ASME SECTION VIII, DIV. 2 APP. 5, FIG. 5-110.2.2
& TABLE 5-10.2

ENDURANCE LIMIT = 13,600 PSI

$w = [2\pi r t \gamma]\, 2$

$w = [2\pi(24.4385)(.127)(0.2894)]\, 2$

$w = 11.29$ #/IN



$M = \frac{wl^2}{8} = \frac{(11.294)(780)^2}{8} = 859,000$ IN-LBS

$\sigma = M/S$

$S = \pi R^2 t = \pi(24.4385)^2(.127) = 238.3$

$\sigma = \frac{859,000}{238.3} = 3,600$ PSI $< 13,600$ $\therefore$ FATIGUE NO PROBLEM

SUBJECT	CBI OFFICE NOE C	REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY WJC	MADE BY	CHKD BY	SHT 12 OF 18
	DATE 2/17/94	DATE 4-6-94	DATE	DATE	8.12

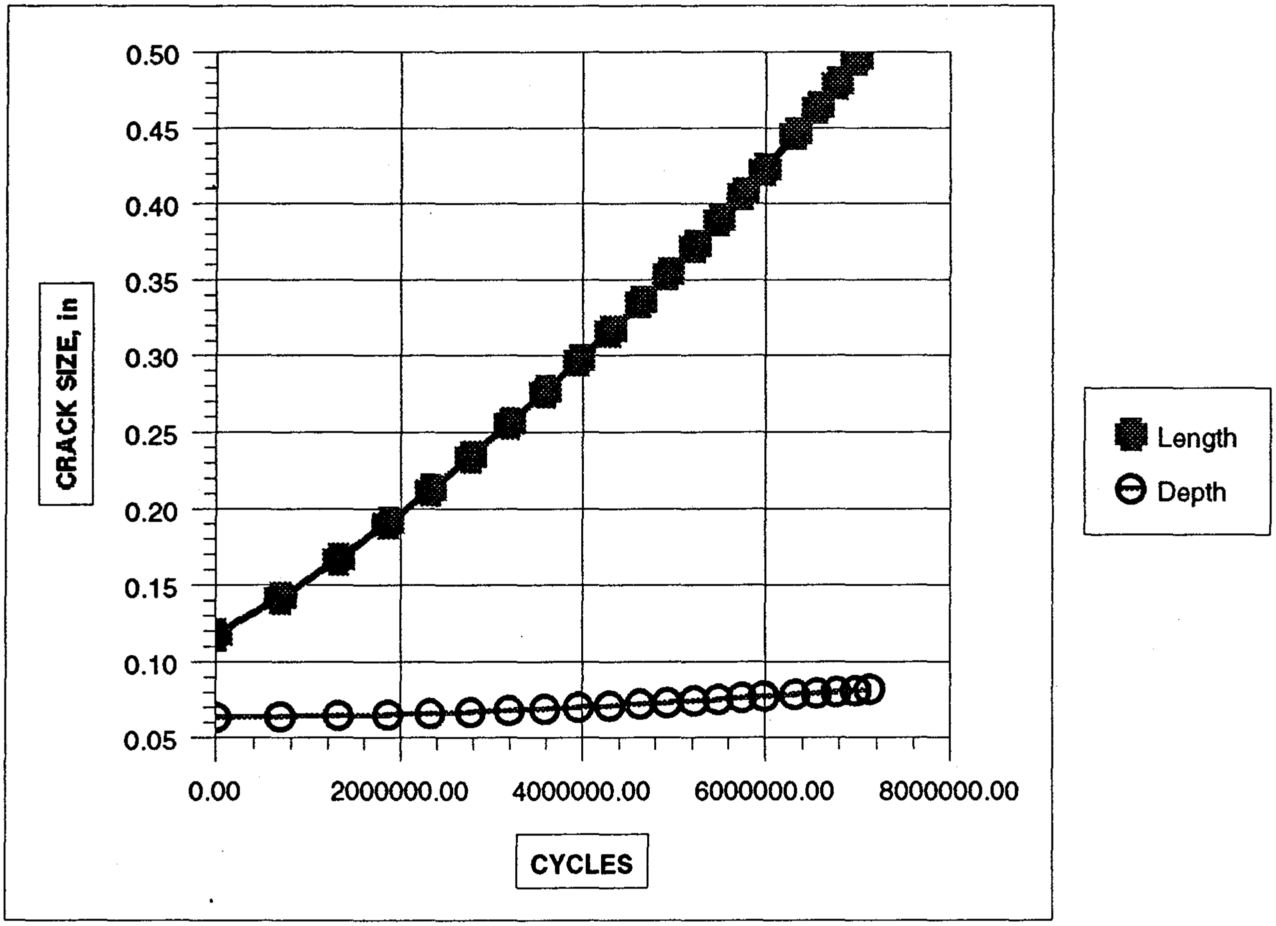
	A	B	C	D	E	F
1	CYCLE LIFE FOR BEAM BENDING MODE DURING SHIPPING OF TUBES					
2	0.125" LONG X 0.064" DEPTH CRACK					
3	CYCLE LIFE					
4						
5						
6	Previous			Calculate	Next	
7						
8						
9	da/dN = C*deltaK^m					
10	C	3.00E-10				
11	m	3.25				
12	**DIMENSIONS**					
13	Flaw type	Surface				
14	Initial flaw depth (a)	0.06	in	Dist. to free edge (W)	100.00	in
15	Initial flaw length (2c)	0.13	in			
16	Wall thickness	0.13	in			
17						
18	Temperature	0.00	Deg. F			
19						
20	**STRESSES**					
21	Prim. memb. stress (Pm)	1.80	ksi	Sec. memb. stress (Sm)	25.00	ksi**
22	Prim. bend stress (Pb)	0.00	ksi	Sec. bend stress (Sb)	0.00	ksi**
23	Cyclic memb. stress	1.80	ksi			
24	Cyclic bend stress	0.00	ksi			
25	**MATERIAL PROP.**					
26	Parent metal yield str.	25.00	ksi*	Fracture toughness (Kc)	120.00	ksiVin
27	Parent metal tensile str.	70.00	ksi*			
28	Weld metal yield str.	25.00	ksi*			
29	Weld metal tensile str.	70.00	ksi*			
30	*Specified minimum values			**These values may be reduced by		
31				mechanical stress relief		
32						
33						
34						
35						
36						
37						
38						
39						
40						
41						

	A	B	C	D	E	F
42		TIME-DEPENDENT CRACK GROWTH				
43						
44						
45						
46						
47	Cycles	Length (2c)		Crack Depth, inches	Type	
48	0.000E+00	0.125	in	0.064	Surface	
49	2.826E+08	0.182	in	0.080	Surface	
50	4.283E+08	0.240	in	0.097	Surface	
51	5.077E+08	0.297	in	0.119	Surface	
52	6.520E+08	0.584	in	0.127	Through-wall	
53	7.108E+08	0.871	in	0.127	Through-wall	
54	7.497E+08	1.215	in	0.127	Through-wall	
55	7.739E+08	1.559	in	0.127	Through-wall	
56	7.931E+08	1.960	in	0.127	Through-wall	
57	8.084E+08	2.419	in	0.127	Through-wall	
58	8.208E+08	2.935	in	0.127	Through-wall	
59	8.301E+08	3.452	in	0.127	Through-wall	
60	8.381E+08	4.025	in	0.127	Through-wall	
61	8.450E+08	4.656	in	0.127	Through-wall	
62	8.510E+08	5.344	in	0.127	Through-wall	
63	8.558E+08	6.033	in	0.127	Through-wall	
64	8.602E+08	6.778	in	0.127	Through-wall	
65	8.640E+08	7.581	in	0.127	Through-wall	
66	8.673E+08	8.384	in	0.127	Through-wall	
67	8.702E+08	9.245	in	0.127	Through-wall	
68	8.729E+08	10.162	in	0.127	Through-wall	
69	8.735E+08	10.375	in	0.127	Through-wall	
70						
71						
72						
73						
74						
75						
76						
77						

	A	B	C	D	E	F
1	[illegible]					
2						
3						
4						
5						
6	Previous			Calculate	Next	
7						
8						
9	da/dN = C*deltaK^m					
10	C	3.00E-10				
11	m	3.25				
12	**DIMENSIONS**					
13	Flaw type	Surface				
14	Initial flaw depth (a)	0.06	in	Dist. to free edge (W)	100.00	in
15	Initial flaw length (2c)	0.12	in			
16	Wall thickness	0.13	in			
17						
18	Temperature	0.00	Deg. F			
19						
20	**STRESSES**					
21	Prim. memb. stress (Pm)	0.00	ksi	Sec. memb. stress (Sm)	25.00	ksi**
22	Prim. bend stress (Pb)	12.25	ksi	Sec. bend stress (Sb)	0.00	ksi**
23	Cyclic memb. stress	0.00	ksi			
24	Cyclic bend stress	12.25	ksi			
25	**MATERIAL PROP.**					
26	Parent metal yield str.	25.00	ksi*	Fracture toughness (Kc)	120.00	ksiVin
27	Parent metal tensile str.	70.00	ksi*			
28	Weld metal yield str.	25.00	ksi*			
29	Weld metal tensile str.	25.00	ksi*			
30	*Specified minimum values			**These values may be reduced by		
31				mechanical stress relief		
32						
33	$\sigma_2/\sigma_1 = 0.144$					
34	$\beta = 30^{\circ}$					
35	PARALLEL TO WELD					
36						
37						
38						
39						
40						
41						

TIME-DEPENDENT CRACK GROWTH

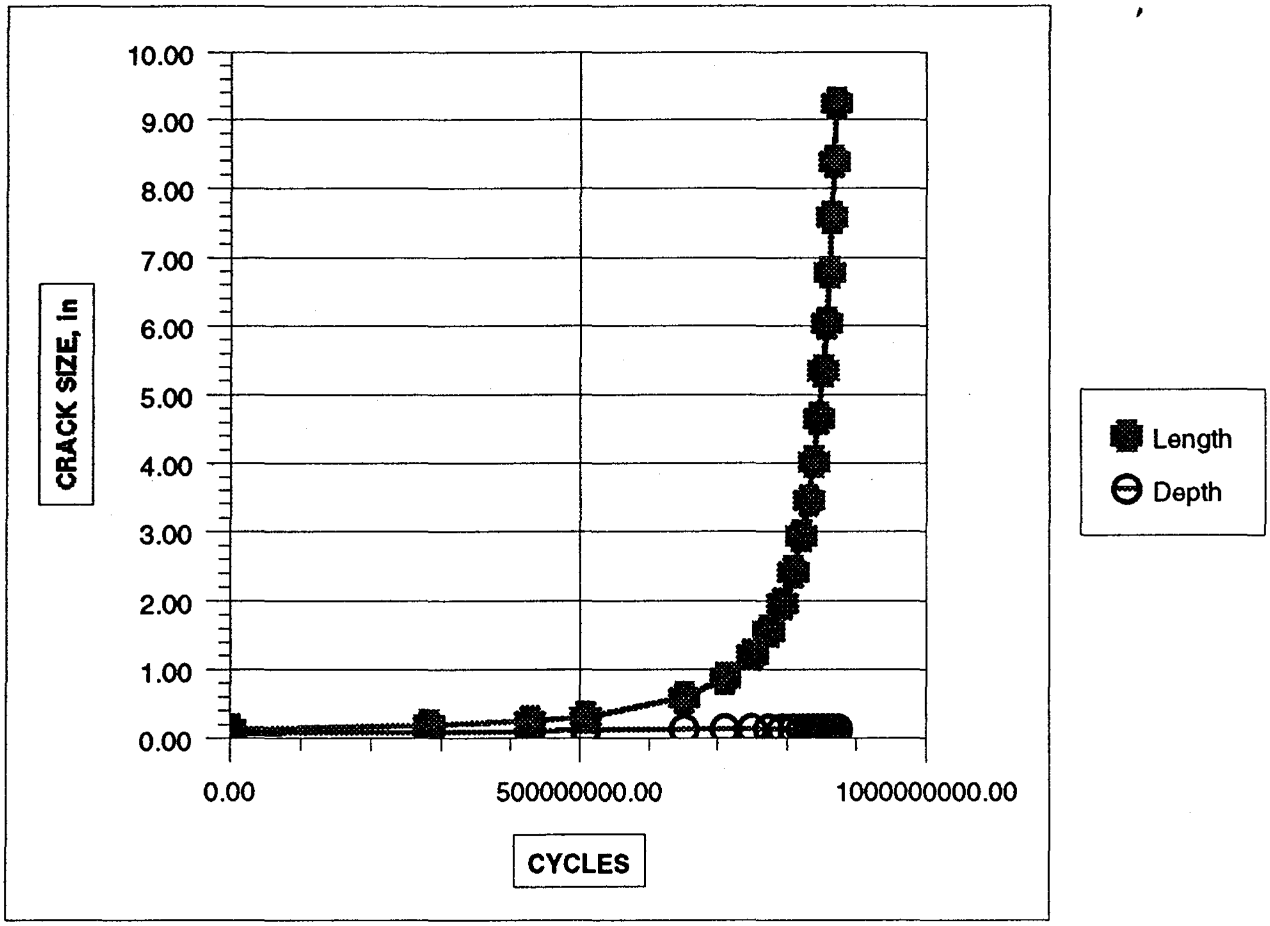
	A	B	C	D	E	F
42						
43						
44						
45						
46						
47	Cycles	Length (2c)		Crack Depth, inches	Type	
48	0.000E+00	0.118	in	0.064	Surface	
49	6.832E+05	0.142	in	0.064	Surface	
50	1.312E+06	0.167	in	0.064	Surface	
51	1.860E+06	0.191	in	0.065	Surface	
52	2.326E+06	0.212	in	0.066	Surface	
53	2.770E+06	0.234	in	0.067	Surface	
54	3.195E+06	0.256	in	0.068	Surface	
55	3.583E+06	0.276	in	0.069	Surface	
56	3.957E+06	0.297	in	0.070	Surface	
57	4.299E+06	0.316	in	0.071	Surface	
58	4.629E+06	0.336	in	0.072	Surface	
59	4.930E+06	0.354	in	0.073	Surface	
60	5.222E+06	0.372	in	0.074	Surface	
61	5.488E+06	0.389	in	0.075	Surface	
62	5.747E+06	0.406	in	0.076	Surface	
63	5.981E+06	0.422	in	0.077	Surface	
64	6.322E+06	0.446	in	0.078	Surface	
65	6.557E+06	0.463	in	0.079	Surface	
66	6.772E+06	0.479	in	0.080	Surface	
67	6.981E+06	0.495	in	0.081	Surface	
68	7.124E+06	0.506	in	0.082	Surface	
69						
70						
71						
72						
73						
74						
75						
76						
77						



Estimated life = 7124168.76 cycles

Limiting crack length = 0.506 in

Limiting crack depth = 0.082 in



Estimated life = 873496918.15 cycles

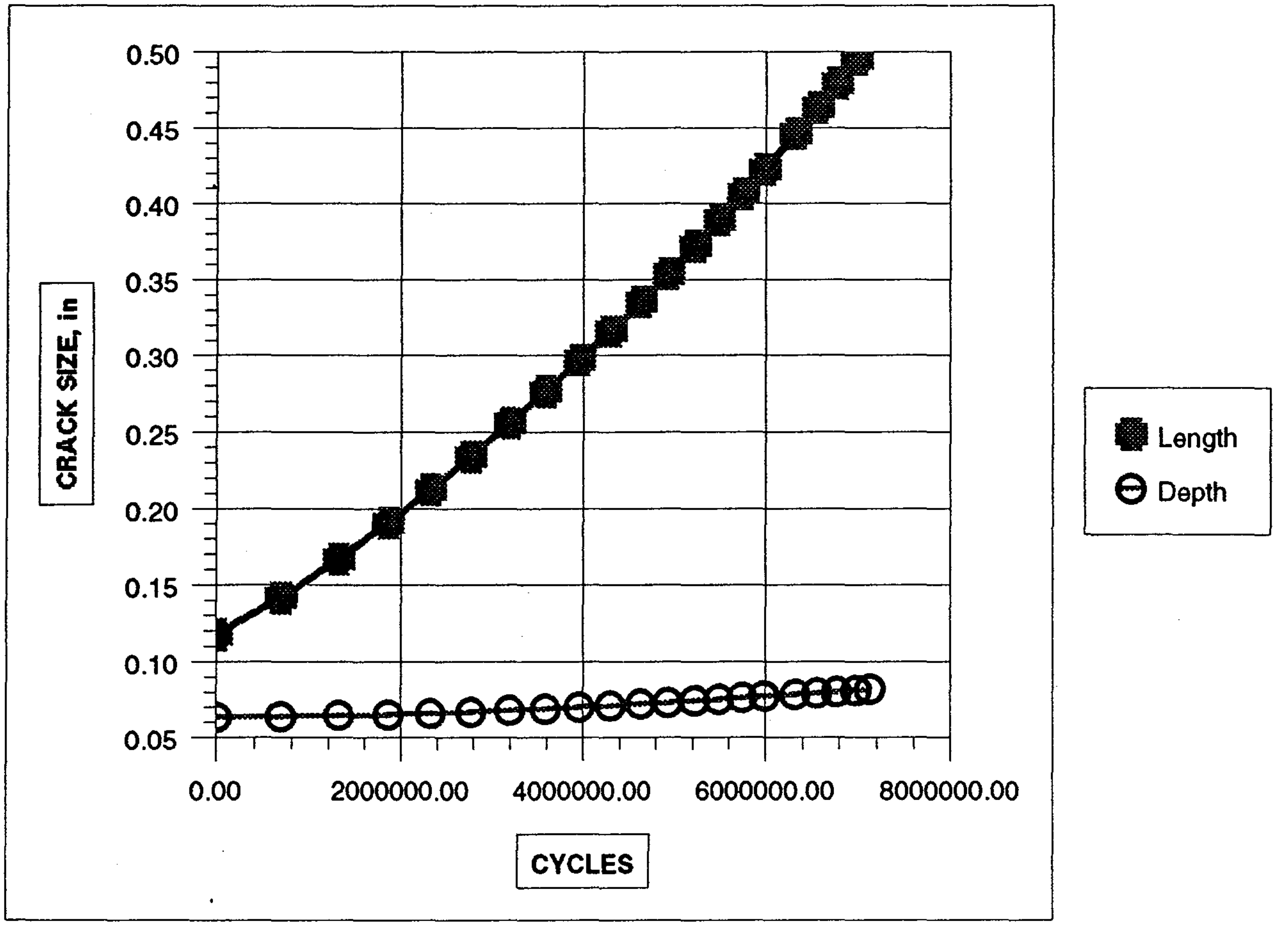
Limiting crack length = 10.374 in

Limiting crack depth = 0.127 in (Through-wall)

	A	B	C	D	E	F
1	[illegible]					
2						
3						
4						
5						
6	Previous		Calculate		Next	
7						
8						
9	da/dN = C*deltaK^m					
10	C	3.00E-10				
11	m	3.25				
12	**DIMENSIONS**					
13	Flaw type	Surface				
14	Initial flaw depth (a)	0.06	in	Dist. to free edge (W)	100.00	in
15	Initial flaw length (2c)	0.12	in			
16	Wall thickness	0.13	in			
17						
18	Temperature	0.00	Deg. F			
19						
20	**STRESSES**					
21	Prim. memb. stress (Pm)	0.00	ksi	Sec. memb. stress (Sm)	25.00	ksi**
22	Prim. bend stress (Pb)	12.25	ksi	Sec. bend stress (Sb)	0.00	ksi**
23	Cyclic memb. stress	0.00	ksi			
24	Cyclic bend stress	12.25	ksi			
25	**MATERIAL PROP.**					
26	Parent metal yield str.	25.00	ksi*	Fracture toughness (Kc)	120.00	ksiVin
27	Parent metal tensile str.	70.00	ksi*			
28	Weld metal yield str.	25.00	ksi*			
29	Weld metal tensile str.	25.00	ksi*			
30	*Specified minimum values			**These values may be reduced by		
31				mechanical stress relief		
32						
33	$\sigma_2/\sigma_1 = 0.144$					
34	$\beta = 30^0$					
35	PARALLEL TO WELD					
36						
37						
38						
39						
40						
41						

TIME-DEPENDENT CRACK GROWTH

	A	B	C	D	E	F
42						
43						
44						
45						
46						
47	Cycles	Length (2c)		Crack Depth, inches	Type	
48	0.000E+00	0.118	in	0.064	Surface	
49	6.832E+05	0.142	in	0.064	Surface	
50	1.312E+06	0.167	in	0.064	Surface	
51	1.860E+06	0.191	in	0.065	Surface	
52	2.326E+06	0.212	in	0.066	Surface	
53	2.770E+06	0.234	in	0.067	Surface	
54	3.195E+06	0.256	in	0.068	Surface	
55	3.583E+06	0.276	in	0.069	Surface	
56	3.957E+06	0.297	in	0.070	Surface	
57	4.299E+06	0.316	in	0.071	Surface	
58	4.629E+06	0.336	in	0.072	Surface	
59	4.930E+06	0.354	in	0.073	Surface	
60	5.222E+06	0.372	in	0.074	Surface	
61	5.488E+06	0.389	in	0.075	Surface	
62	5.747E+06	0.406	in	0.076	Surface	
63	5.981E+06	0.422	in	0.077	Surface	
64	6.322E+06	0.446	in	0.078	Surface	
65	6.557E+06	0.463	in	0.079	Surface	
66	6.772E+06	0.479	in	0.080	Surface	
67	6.981E+06	0.495	in	0.081	Surface	
68	7.124E+06	0.506	in	0.082	Surface	
69						
70						
71						
72						
73						
74						
75						
76						
77						



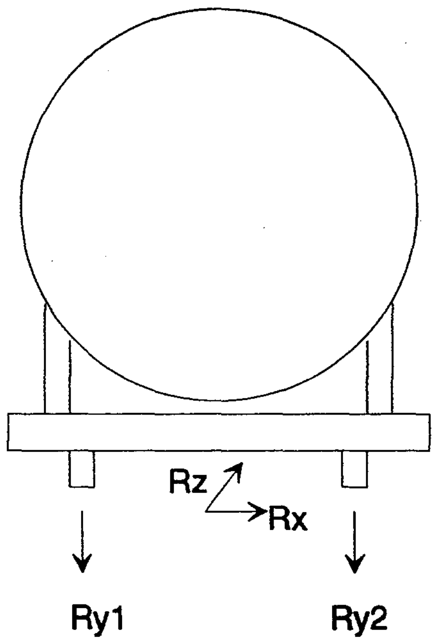
Estimated life = 7124168.76 cycles

Limiting crack length = 0.506 in

Limiting crack depth = 0.082 in

LIGO BEAM TUBE FOUNDATION LOAD SUMMARY

FIXED SUPPORT FOUNDATION LOADS



FIXED SUPPORT FOUNDATION LOADS	Lateral	Vertical			Axial
Load Case Support Weight = 500 lbs	Rx	Ry1	Ry2	Ry total	Rz
1. Operating	85	3870	3648	7518	771
2. Bake Out @ 302 F	656	860	-860	0	5959
3. 0.579" Differential Settlement @ Fixed Support	0	+/- 715	+/- 715	+/- 1430	0
4. 1" Differential Settlement @ Fixed Support	0	+/- 1235	+/- 1235	+/- 2470	0
5. 0.5" Horizontal Misalignment @ Fixed Support	1235	1621	-1621	0	0
6. 0.579" Differential Settlement @ Guided Support	0	+/- 356	+/- 356	+/- 712	0
7. 1" Differential Settlement @ Guided Support	0	+/- 615	+/- 615	+/- 1230	0
8. 0.5" Misalignment @ Guided Support	615	807	-807	0	0
9. Lateral Seismic (x direction)	1287	1689	-1689	0	0
10. Axial Seismic (z direction)	0	0	0	0	2169
11. Wind Load	1275	1673	-1673	0	0

Maximum Reactions - Normal Operating Conditions

Max Rx = 1320 lbs, 1+3+5
Max Ry1= 6206 lbs, 1+3+5
Min Ry2= 1312 lbs, 1-3+5
Max Ry= 9988 lbs, 1+4
Max Rz = 6730 lbs, 1+2+3

Maximum Reactions - Seismic or Wind Conditions

Max Rx = 2607 lbs, 1+3+5+9
Max Ry1= 7895 lbs, 1+3+5+9
Min Ry2= -377 lbs, 1-3+5+9
Max Ry= 9988 lbs, 1+4+9
Max Rz = 8899 lbs, 1+2+6+10

SUBJECT LIGO Beam Tube Foundation Load Summary	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 1 OF 4
	DATE 3/22/94	DATE 4-4-94	DATE	DATE	9.1

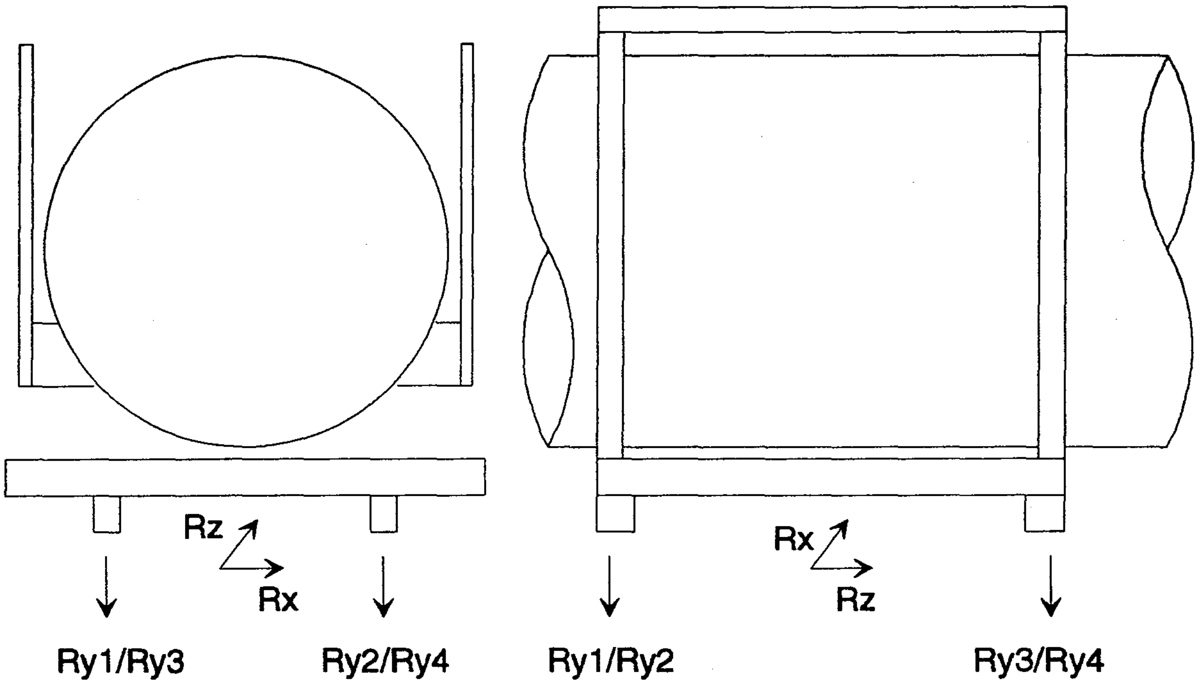
LIGO BEAM TUBE FOUNDATION LOAD SUMMARY

RESULTS OF LOAD COMBINATIONS

FIXED SUPPORT FOUNDATION LOADS	Lateral	Vertical			Axial
Load Combination Support Weight = 500 lbs	Rx	Ry1	Ry2	Ry total	Rz
W/O Increased allowable					
1+2+3	740	5446	3502	8948	6730
1+4	85	5105	4883	9988	771
1+3+5	1320	6206	2742	8948	771
1+7	85	4485	4263	8748	771
1+6+8	700	5034	3197	8230	771
1+2-3	740	4016	2072	6088	6730
1-4	85	2635	2413	5048	771
1-3+5	1320	4776	1312	6088	771
1-7	85	3255	3033	6288	771
1-6+8	700	4321	2484	6806	771
MAXIMUM	1320	6206	4883	9988	6730
MINIMUM	85	2635	1312	5048	771
With Increased allowable					
1+2+3+9	2027	7135	1813	8948	6730
1+2+3+10	740	5446	3502	8948	8899
1+2+6+9	2027	6776	1454	8230	6730
1+2+6+10	740	5087	3143	8230	8899
1+4+9	1372	6794	3194	9988	771
1+4+10	85	5105	4883	9988	2940
1+7+9	1372	6174	2574	8748	771
1+7+10	85	4485	4263	8748	2940
1+3+5+9	2607	7895	1053	8948	771
1+3+5+10	1320	6206	2742	8948	2940
1+6+8+9	1987	6723	1507	8230	771
1+6+8+10	700	5034	3197	8230	2940
1+2-3+9	2027	5705	383	6088	6730
1+2-3+10	740	4016	2072	6088	8899
1+2-6+9	2027	6064	742	6806	6730
1+2-6+10	740	4375	2431	6806	8899
1-4+9	1372	4324	724	5048	771
1-4+10	85	2635	2413	5048	2940
1-7+9	1372	4944	1344	6288	771
1-7+10	85	3255	3033	6288	2940
1-3+5+9	2607	6465	-377	6088	771
1-3+5+10	1320	4776	1312	6088	2940
1-6+8+9	1987	6011	795	6806	771
1-6+8+10	700	4321	2484	6806	2940
MAXIMUM	2607	7895	4883	9988	8899
MINIMUM	85	2635	-377	5048	771

SUBJECT LIGO Beam Tube Foundation Load Summary	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 2 OF 4
	DATE 3/22/94	DATE 4-4-94	DATE	DATE	9.2

GUIDED SUPPORT FOUNDATION LOADS



GUIDED SUPPORT FOUNDATION LOADS	Lateral	Vertical				
Load Case Support Weight = 1600 lbs	Rx	Ry1	Ry2	Ry3	Ry4	Ry total
1. Operating	85	1664	1553	1664	1553	6434
2a. Bake Out @ 302 F	656	598	-262	598	-262	672
2b. Bake Out @ 302 F	656	262	-598	262	-598	-672
3. 0.579" Differential Settlement @ Fixed Support	0	+/- 715	+/- 715	-/+ 365	-/+ 365	+/- 701
4. 1" Differential Settlement @ Fixed Support	0	+/- 1235	+/- 1235	-/+ 630	-/+ 630	+/- 1210
5. 0.5" Horizontal Misalignment @ Fixed Support	605	397	-397	397	-397	0
6. 0.579" Differential Settlement @ Guided Support	0	+/- 162	+/- 162	+/- 155	+/- 155	+/- 635
7. 1" Differential Settlement @ Guided Support	0	+/- 280	+/- 280	+/- 269	+/- 269	+/- 1097
8. 0.5" Misalignment @ Guided Support	549	360	-360	360	-360	0
9. Lateral Seismic (x direction)	882	579	-579	579	-579	0
10. Axial Seismic (z direction)	0	0	0	0	0	0
11. Wind Load	874	574	-574	574	-574	0

Maximum Reactions - Normal Operating Conditions

Max Rx = 740 lbs, 1+2a+3
Max Ry1= 2977 lbs, 1+2a+3
Min Ry2= 240 lbs, 1+2b-3
Max Ry3= 2627 lbs, 1+2a+3
Min Ry4= 590 lbs, 1+2b-3
Max Ry= 7807 lbs, 1+2a+3

Maximum Reactions - Seismic or Wind Conditions

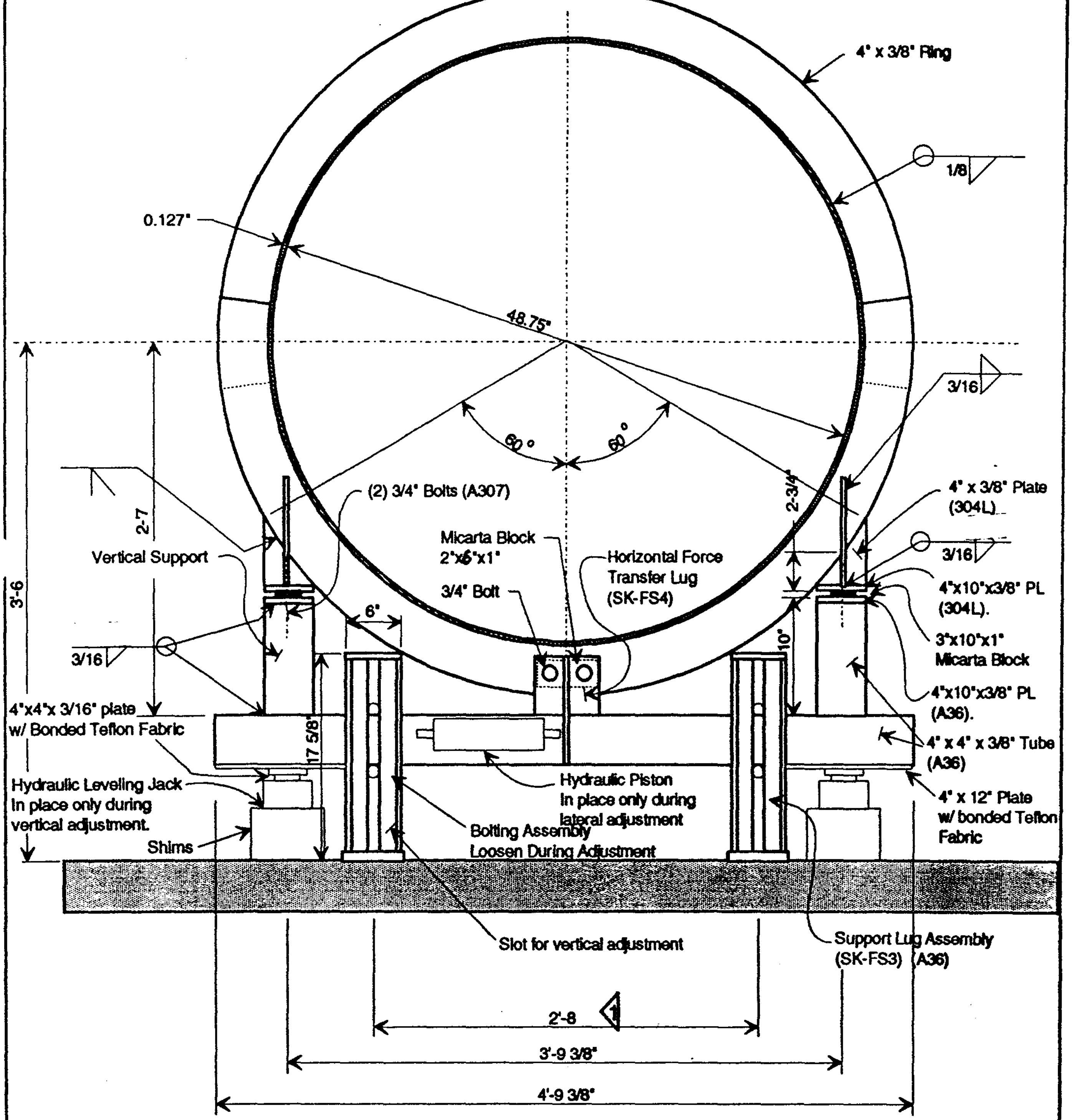
Max Rx = 1622 lbs, 1+2a+3+9
Max Ry1= 3556 lbs, 1+2a+3+9
Min Ry2= -339 lbs, 1+2b-3+9
Max Ry1= 3206 lbs, 1+2a+3+9
Min Ry2= 11 lbs, 1+2b-3+9
Max Ry= 7807 lbs, 1+2a+3+9

SUBJECT LIGO Beam Tube Foundation Load Summary	OFFICE: NOE-C		REVISION:	REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 3 OF 4
	DATE 3/22/94	DATE 4-4-94	DATE	DATE	9.3

RESULTS OF LOAD COMBINATIONS

GUIDED SUPPORT FOUNDATION LOADS	Lateral	Vertical				
Load Case Support Weight = 1600 lbs	Rx	Ry1	Ry2	Ry3	Ry4	Ry total
W/O Increased allowable						
1+2a+3	740	2977	2006	2627	1655	7807
1+4	85	2899	2788	2294	2183	7644
1+3+5	690	2776	1871	2426	1521	7135
1+7	85	1944	1833	1933	1821	7531
1+6+8	633	2186	1355	2180	1348	7069
1+2b-3	740	1211	240	1562	590	5061
1-4	85	429	318	1034	923	5224
1-3+5	690	1346	441	1696	791	5733
1-7	85	1384	1273	1396	1284	5337
1-6+8	633	1862	1031	1869	1037	5799
MAXIMUM	740	2977	2788	2627	2183	7807
MINIMUM	85	429	240	1034	590	5061
With Increased allowable						
1+2a+3+9	1622	3556	1427	3206	1077	7807
1+2a+3+10	740	2977	2006	2627	1655	7807
1+2a+6+9	1622	3003	874	2997	867	7741
1+2a+6+10	740	2424	1453	2418	1446	7741
1+4+9	967	3478	2209	2873	1604	7644
1+4+10	85	2899	2788	2294	2183	7644
1+7+9	967	2523	1254	2511	1243	7531
1+7+10	85	1944	1833	1933	1821	7531
1+3+5+9	1572	3355	1292	3005	942	7135
1+3+5+10	690	2776	1871	2426	1521	7135
1+6+8+9	1515	2765	776	2758	770	7069
1+6+8+10	633	2186	1355	2180	1348	7069
1+2b-3+9	1622	1790	-339	2140	11	5061
1+2b-3+10	740	1211	240	1562	590	5061
1+2b-6+9	1622	2343	214	2350	220	5127
1+2b-6+10	740	1764	793	1771	799	5127
1-4+9	967	1008	-261	1613	344	5224
1-4+10	85	429	318	1034	923	5224
1-7+9	967	1963	694	1974	706	5337
1-7+10	85	1384	1273	1396	1284	5337
1-3+5+9	1572	1925	-138	2275	212	5733
1-3+5+10	690	1346	441	1696	791	5733
1-6+8+9	1515	2441	452	2447	459	5799
1-6+8+10	633	1862	1031	1869	1037	5799
MAXIMUM	1622	3556	2788	3206	2183	7807
MINIMUM	85	429	-339	1034	11	5061

SUBJECT LIGO Beam Tube Foundation Load Summary	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 4 OF 4
	DATE 3/22/94	DATE 4-4-94	DATE	DATE	9.4



SUBJECT

LIGO
BEAM TUBE FIXED SUPPORT

CBI OFFICE

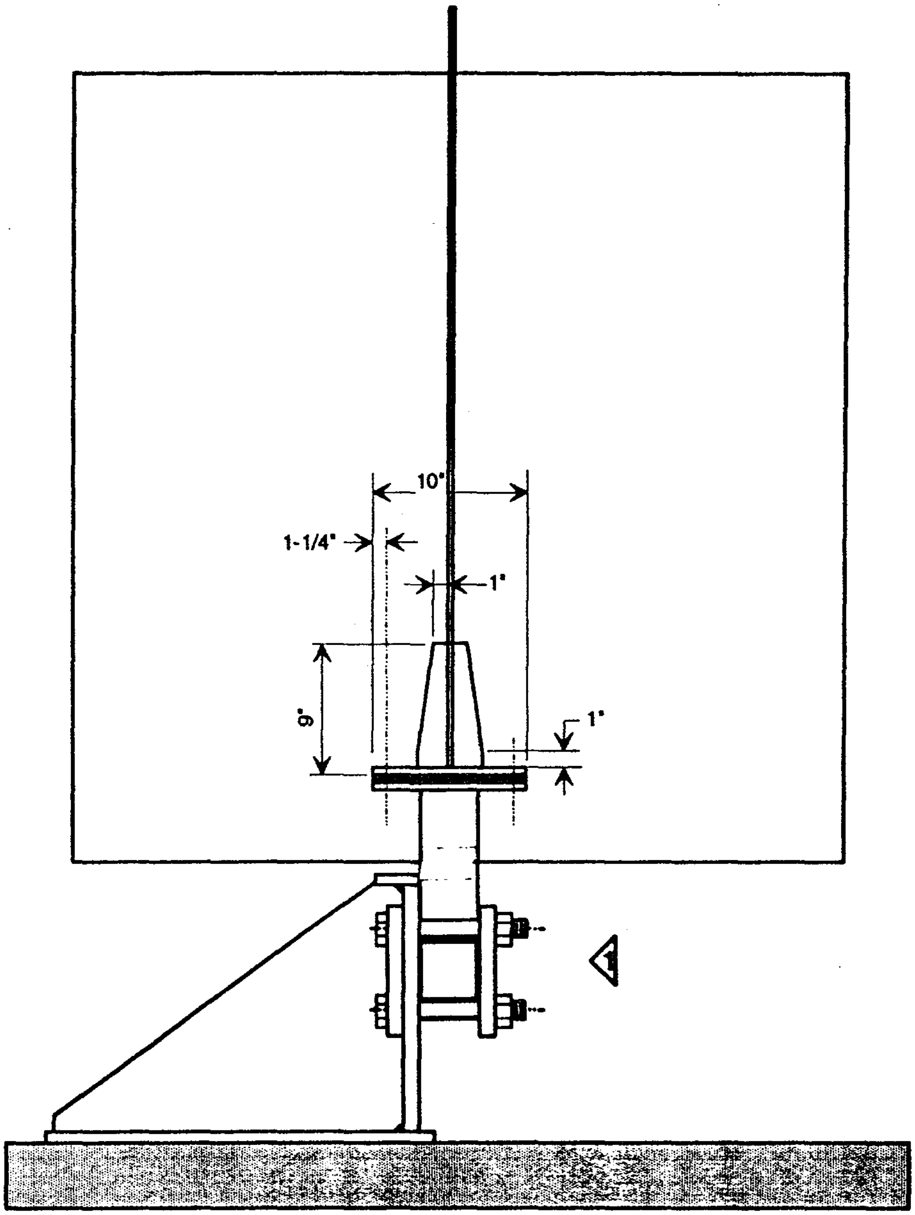
REVISION: 1

REFERENCE NO. 930212

MADE	CHK'D	MADE	CHK'D
MRS	DDG	MRS	DDG
DATE	DATE	DATE	DATE
2/22/94	4/6/94	3/7/94	4/6/94

SHT 1 OF 48

SK - FS1



SIDE VIEW

SUBJECT

LIGO
BEAM TUBE FIXED SUPPORT

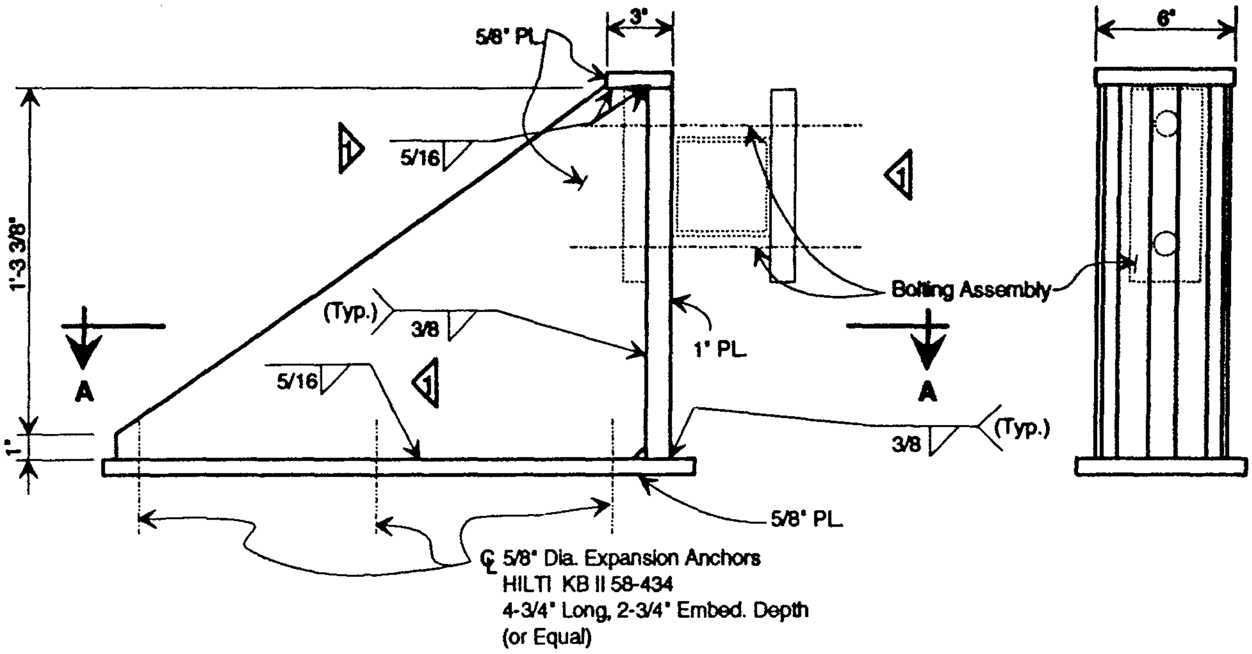
CBI OFFICE

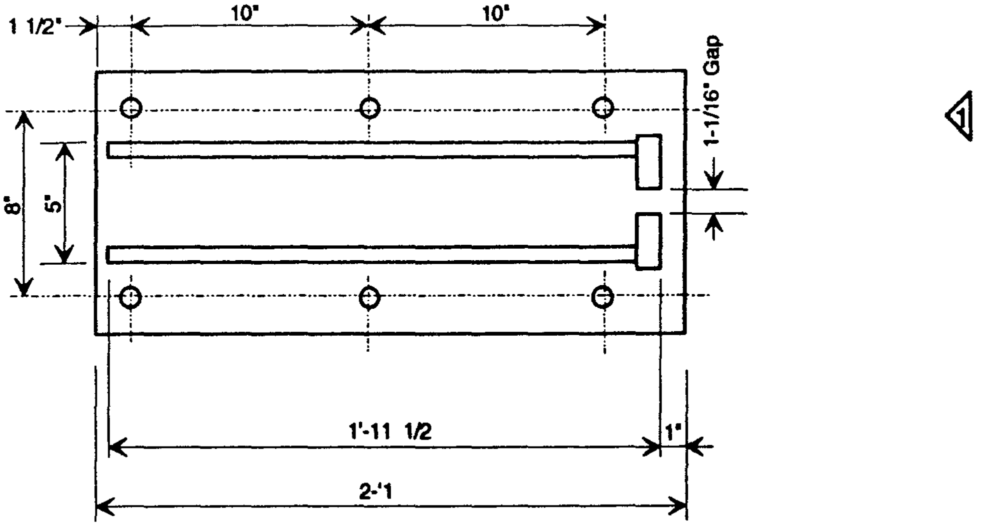
REVISION: 1

REFERENCE NO. 930212

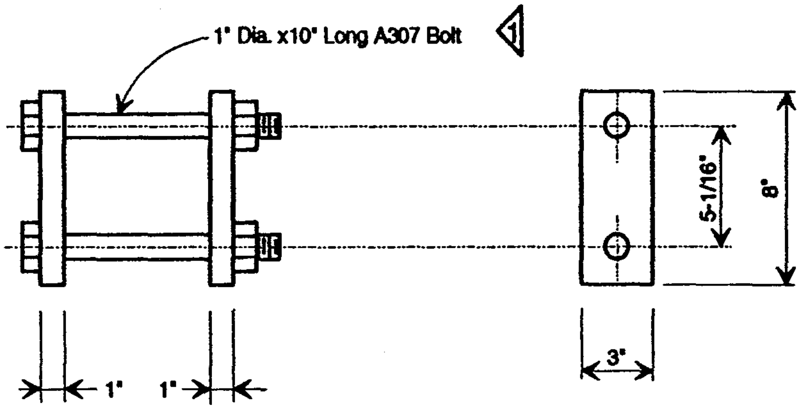
MADE	CHK'D	MADE	CHK'D	SHT 2 OF 48
MRS	DDG	MRS	DDG	
DATE	DATE	DATE	DATE	SK - FS2
2/19/94	4/6/94	3/7/94	4/6/94	

11.2



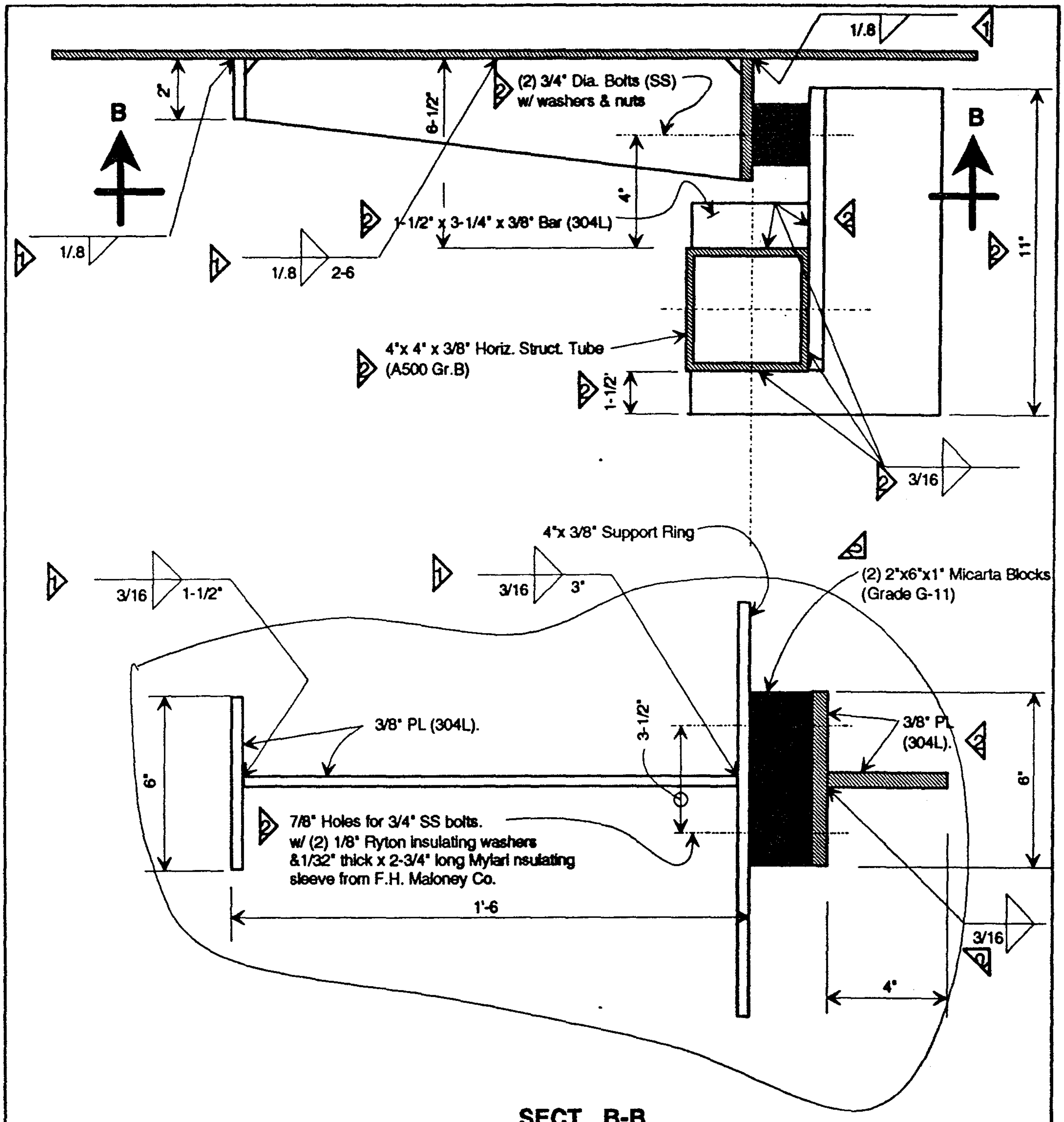


SECT. A-A



BOLTING ASSEMBLY

SUBJECT	CBI **OFFICE**		**REVISION: 1**		**REFERENCE NO.** 931212
SUPPORT LUG ASSEMBLY BEAM TUBE FIXED SUPPORT LIGO	**MADE** MRS	**CHK'D** DDG	**MADE** MRS	**CHK'D** DDG	**SHT** 3 **OF** 48
	DATE 2/23/94	**DATE** 4/6/94	**DATE** 3/7/94	**DATE** 4/6/94	**SK - FS3**



SECT. B-B

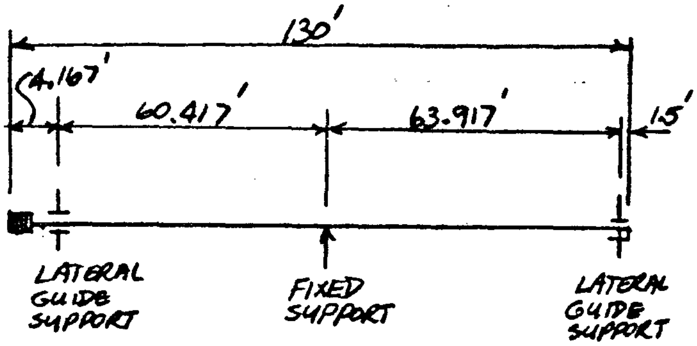
SUBJECT	CBI OFFICE		REVISION: 2		REFERENCE NO. 930212
HORIZONTAL RESTRAINT BEAM TUBE FIXED SUPPORT LIGO	MADE MRS	CHK'D DDG	MADE MRS	CHK'D DDG	SHT 4 OF 48
	DATE 2/24/94	DATE 4/6/94	DATE 3/7/94	DATE 4/6/94	SK - FS4

LOADS.XLS

10.5

Load Case	Fixed Support Loads	Magnitude		Direction	Comments				
1	DL (Metal Wt + Insul'n)	7,000	lbs	down	(per RISA-2D analysis for continuous beam system)				
2	Axial Seismic Load	2,260	lbs	axial	(~ 18% * 90 plf * 130 ft), assumes guided support does not take axial loads				
3	Lateral Seismic Load	1,130	lbs	lateral	(~ 18% * 90 plf * 65 ft), assumes guided support takes lateral loads				
4	Axial BakeOut Load	5,300	lbs	axial	(~ 3.2 inches of growth * 8300 lb/in bellows axial spring rate * 20% variation in bellows)				
5	Axial Contraction Load	830	lbs	axial	(Due to daily Delta T above assumed ambient)				
6	Axial Extension Load	2,158	lbs	axial	(Due to daily Delta T below assumed ambient)				
7	Vertical Stability Load	600	lbs	down	(Assumed)				
8	Lateral Stability Load	600	lbs	lateral	(Assumed)				
Comb'n	**Load Combination**				**Vert Load**	**Axial Load**	**Lateral Load**	**Stress Increase**	
1	DL + Vertical Stability				7,600	0	0	1.000	
2	DL + Axial EQ + Axial Ext'n + Vert Stability + Lat Stability				7,600	4,418	600	1.333	
3	DL + Lat EQ + Axial Ext'n + Vert Stability + Lat Stability				7,600	2,158	1,730	1.333	
4	DL + Axial BakeOut + Vert Stability + Lat Stability				7,600	5,300	600	1.000	<== GOVERNS

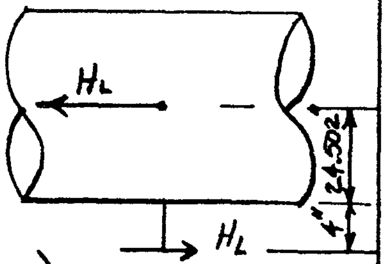
LONGITUDINAL TUBE LOADS



AXIAL TUBE LOAD FROM EXP. JTS. = 5300# (BAKE OUT)

AXIAL TUBE SEISMIC LOAD = 2260#

THE LONGITUDINAL TUBE FORCES WILL BE RESISTED AT THE FIXED SUPPORT AT 28.502" BELOW THE TUBE CENTERLINE. THE RESULTING MOMENT ON THE TUBE CROSS SECTION IS:



$$M = 28.502"(H_L) = 151{,}061 \text{ IN-LBS (BAKE OUT)}$$

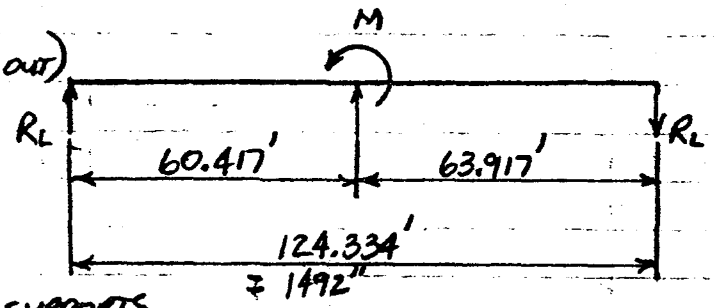
$$= 64{,}415 \text{ IN-LBS (SEISMIC)}$$

THE MOMENT WILL BE RESISTED BY THE LATERAL GUIDE SUPPORTS AS A COUPLE

$$R_L = \frac{M}{L}$$

$$R_L = \frac{151{,}061 \text{ IN-LBS}}{1492"} = \pm 102\# \text{ (BAKE OUT)}$$

$$R_L = \frac{64{,}415 \text{ IN-LBS}}{1492"} = \pm 44\# \text{ (SEISMIC)}$$



THESE LOADS ARE ADDED TO OTHER VERTICAL LOADS AT GUIDE SUPPORTS.

SUBJECT LIGO BEAM TUBE FIXED SUPPORT DESIGN	OFFICE CBI NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 6 OF 48
	DATE 2/18/94	DATE 4/5/94	DATE	DATE	10.6

ADDITIONAL STRESS IN TUBE WALL

$M = 767''(102^{\#}) = 78{,}234$ IN-LBS

TUBE SECTION MODULUS $= \pi r^2 t$

$r = \frac{48.75 + .127}{2} = 24.4385''$

$t = 0.127''$

$S = \pi r^2 t = \pi(24.4385'')^2(0.127'')$

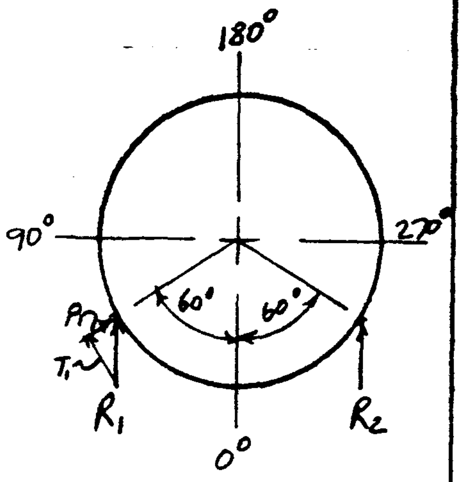
$S = 238.2\ \text{IN}^3$

$\sigma = M/S = \frac{78{,}234\ \text{IN-LBS}}{238.2\ \text{IN}^3} = 329$ PSI

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 7 OF 48
	DATE 2/22/94	DATE 4/5/94	DATE	DATE	10.7

SHELL RING DESIGN

LOAD COMBINATION 1



VERTICAL LOAD = 7600#

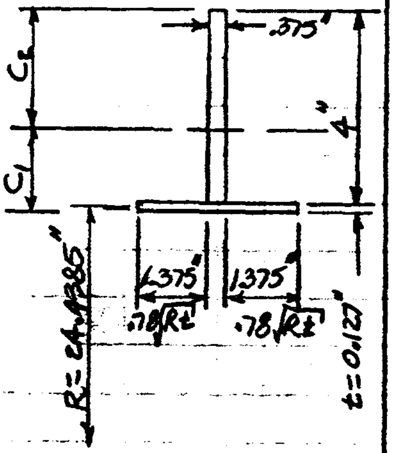
ASSUME 2 VERTICAL SUPPORTS @ 60° FROM INVERT.

$R_1 = R_2 = \frac{7600}{2} = 3800^{\#}$

RADIAL COMPONENT $(P) = R \cos 60° = 3800^{\#}(.5) = 1900^{\#}$

TANGENTIAL COMPONENT $(T) = R \sin 60° = 3800^{\#}(.866) = 3{,}291^{\#}$

THESE LOADS WILL BE RESISTED BY A SINGLE RING COMPOSED OF A STIFFENER PLATE AND A PORTION OF TUBE WALL PARTICIPATION.



USE 4" X 3/8" STIFFENER

RING PROPERTIES CALCULATED ON NEXT SHEET.

$A = 1.897 \text{ IN}^2$

$C_1 = 1.695"$ $C_2 = 2.432"$

$I = 3.34 \text{ IN}^4$

$S_1 = I/C_1 = 1.97 \text{ IN}^3$ $S_2 = I/C_2 = 1.37 \text{ IN}^4$

SUBJECT

CBI OFFICE NOE

REVISION

REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY
MRS	DDG		
DATE	DATE	DATE	DATE
2/18/94	4/5/94		

SHT 8 OF 48

10.8

MOMENT OF INERTIA CALCULATION

```
                  |---------> X
                  |   d1                d2
                  |<------->|<----------------------->|
                  |         |                         |
     -----        -----------          Y              |
    |            |  AREA    |          |
    |            |   1      |-------------------------   -----
b1  |            |          |         AREA           |  |b2
    |            |          |          2             |  |
    |            |          |-------------------------   -----
    |            |          |          |
     -----        -----------          Y
```

	1	2	3	4	5	6	7
d	0.127	4					
b	3.125	0.375					
X	0.0635	2.1270	4.1270	4.1270	4.1270	4.1270	4.1270
THETA	0	0	0	0	0	0	0

	AREA	X	AX	AX^2	Io
1	0.397	0.064	0.03	0.00	0.00
2	1.500	2.127	3.19	6.79	2.00
3	0.000	4.127	0.00	0.00	0.00
4	0.000	4.127	0.00	0.00	0.00
5	0.000	4.127	0.00	0.00	0.00
6	0.000	4.127	0.00	0.00	0.00
7	0.000	4.127	0.00	0.00	0.00
	1.897		3.22		8.79

TOTAL DEPTH = 4.1270 in.

CENTROID $(\bar{X})$ = SUM(AX)/SUM(AREA) = 1.695 in.

I(total)= $[\mathrm{SUM}(AX^2)+\mathrm{SUM}(Io)]-(\mathrm{AREA})(\bar{X})^2$ = 3.34 $\mathrm{in.}^4$

C1 = $\bar{X}$ = 1.695 in. C2 = DEPTH - $\bar{X}$ = 2.432 in.

Sy1 = I/C1 = 1.97 $\mathrm{in.}^3$ Sy2 = I/C2 = 1.37 $\mathrm{in.}^3$

Radius of gyration (r) = $(I/A)^{1/2}$ = 1.326 in.

Torsional constant (J) = in^4

```
-------------------------------------------------------------------------------
 UBJECT                       !MADE BY: MRS ! R !MADE  BY:     !REFERENCE NO.!
  TION PROPERTIES             !-------------! E !--------------!   930212    !
4" X 3/8" STIFFENER           !CHKD BY: DDG ! V !CHKD BY:      !-------------!
!FIXED SUPPORT SHELL RING     !-------------!   !--------------!             !
!LIGO BEAM TUBE               !DATE: 2/18/94!   !DATE:         !SHT 9 OF 48  !
-------------------------------------------------------------------------------
```

10.9

CBI COMPUTER PROGRAM E0405A

"ANALYSIS OF CIRCULAR RINGS WITH CONCENTRATED LOADS IN PLANE OF RING"

IS USED TO EVALUATE THE RING FOR THE APPLIED LOADS.

E0405A INPUT

2 RADIAL LOADS $1900^{\#}$ @ 60° & 300°

2 TANGENTIAL LOADS $-3291^{\#}$ @ 60°
$+3291^{\#}$ @ 300°

$R = 24.375'' + 1.695'' = 26.07''$

$E = 28{,}000{,}000$ PSI @ AMBIENT

$I = 3.34\ IN^4$ $A = 1.897\ IN^2$

$C_1 = 1.695''$ $C_2 = 2.432''$

FROM E0405A OUTPUT (NEXT 2 SHEETS)

MAXIMUM INSIDE STRESS = 3,829 PSI @ 60° & 300°

MAXIMUM OUTSIDE STRESS = -6,404 PSI @ 60° & 300°

$V_{max} = (806\ PSI)(1.897\ IN^2) = 1{,}529^{\#}$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 10 OF 48
	DATE 2/18/94	DATE 4/5/94	DATE	DATE	10.10

```
ROGRAM E0405A (STD 9110-1-2)  [ IBM RS/6000 ]
TRESS AND STRAIN COEFFICIENTS FOR CIRCULAR RINGS
EVISION 11 - JANUARY 7, 1992


     TANDARDS 9110-1-1 AND 9110-1-2

IXED SUPPORT DEAD LOAD - 2 PT. AT 60 DEG.


     N(R)     N(T)     N(M)     DATA SHEET NO.     PLOT CODE
       2        2        0            1                0


    RADIUS     MOD-ELAS    MOM-INER        AREA          C(1)          C(2)
     26.07 28000000.00        3.34         1.90          1.70          2.43

QUILIBRIUM LOADS          FV          FH          M/R
            INPUT   7600.000        .000         .000
         COMPUTED   7600.179        .000         .000

NPUT LOADS AND THEIR LOCATIONS

ADIAL LOADS AND ANGLES

      LOADS           1900.00     1900.00
      ANGLES            60.00      300.00

TANGENTIAL LOADS AND ANGLES                                                10.11

      OADS           -3291.00     3291.00
      ANGLES            60.00      300.00

O MOMENT/R LOADS

NIT STRESS VALUES FOR CIRCULAR RINGS

RINTOUT AT EQUAL ANGLE INCREMENTS

     X       V/A         T/A       M(FORCE-LG)     THETA          DR            DC          X
    .00  0.0000E+00 -4.7821E+02 -2.0116E+03  0.0000E+00 -2.1789E-03  0.0000E+00      .
   5.00  4.1538E+01 -4.7154E+02 -1.9218E+03 -4.8207E-05 -2.2258E-03  1.9151E-04     5.
  10.00  8.1914E+01 -4.5162E+02 -1.6548E+03 -9.2063E-05 -2.3612E-03  3.9106E-04    10.
  15.00  1.1998E+02 -4.1871E+02 -1.2181E+03 -1.2734E-04 -2.5695E-03  6.0575E-04    15.
  20.00  1.5463E+02 -3.7324E+02 -6.2406E+02 -1.5005E-04 -2.8248E-03  8.4090E-04    20.
  25.00  1.8478E+02 -3.1582E+02  1.1013E+02 -1.5656E-04 -3.0925E-03  1.0991E-03    25.
  30.00  2.0942E+02 -2.4721E+02  9.6292E+02 -1.4373E-04 -3.3300E-03  1.3798E-03    30.
  35.00  2.2762E+02 -1.6831E+02  1.9085E+03 -1.0896E-04 -3.4885E-03  1.6780E-03    35.
  40.00  2.3853E+02 -8.0188E+01  2.9172E+03 -5.0360E-05 -3.5145E-03  1.9848E-03    40.
  45.00  2.4139E+02  1.5976E+01  3.9558E+03  3.3212E-05 -3.3524E-03  2.2860E-03    45.
  50.00  2.3555E+02  1.1888E+02  4.9882E+03  1.4205E-04 -2.9460E-03  2.5628E-03    50.
  55.00  2.2048E+02  2.2711E+02  5.9756E+03  2.7554E-04 -2.2414E-03  2.7915E-03    55.
  60.00 -8.0579E+02 -1.3957E+03  6.8774E+03  4.3209E-04 -1.1897E-03  2.9439E-03    60.
  65.00 -6.8535E+02 -1.3620E+03  3.6608E+03  5.5922E-04  2.1246E-04  2.9886E-03    65.
  70.00 -5.6849E+02 -1.3139E+03  9.5666E+02  6.1436E-04  1.8179E-03  2.9009E-03    70.
  7    0 -4.5641E+02 -1.2525E+03 -1.2530E+03  6.0977E-04  3.4647E-03  2.6702E-03    75.
       0 -3.5024E+02 -1.1790E+03 -2.9914E+03  5.5722E-04  5.0180E-03  2.2989E-03    80.
     .00 -2.5094E+02 -1.0949E+03 -4.2860E+03  4.6783E-04  6.3697E-03  1.8003E-03    85.
  90.00 -1.5941E+02 -1.0016E+03 -5.1685E+03  3.5203E-04  7.4377E-03  1.1955E-03    90.
  95.00 -7.6353E+01 -9.0068E+02 -5.6741E+03  2.1942E-04  8.1651E-03  5.1206E-04    95.
 100.00 -2.3817E+00 -7.9374E+02 -5.8406E+03  7.8717E-05  8.5180E-03 -2.1867E-04   100.
 105.00  6.2055E+01 -6.8245E+02 -5.7084E+03 -6.2322E-05  8.4845E-03 -9.6335E-04   105.
 110.00  1.1445E+02 -5.6848E+02 -5.3192E+03 -1.9693E-04  8.0718E-03 -1.6884E-03   110.
```

```
 20.00  1.9582E+02 -3.3916E+02 -3.9418E+03 -4.2479E-04
 25.00  2.2050E+02 -2.2709E+02 -3.0399E+03 -5.1013E-04  4.8738E-03 -3.4400E-03 125
 30.00  2.3557E+02 -1.1886E+02 -2.0524E+03 -5.7220E-04  3.3212E-03 -3.7988E-03 130
 35.00  2.4140E+02 -1.5957E+01 -1.0199E+03 -6.0962E-04  1.6301E-03 -4.0156E-03 135
 40.00  2.3855E+02  8.0209E+01  1.8778E+01 -6.2177E-04 -1.2987E-04 -4.0813E-03 140
 4[illegible]  2.2764E+02  1.6833E+02  1.0275E+03 -6.0895E-04 -1.8879E-03 -3.9930E-03 145
 5[illegible]  2.0944E+02  2.4723E+02  1.9731E+03 -5.7229E-04 -3.5751E-03 -3.7538E-03 150
 [illegible]0  1.8479E+02  3.1585E+02  2.8260E+03 -5.1370E-04 -5.1263E-03 -3.3730E-03 155
 6[illegible].00  1.5464E+02  3.7327E+02  3.5602E+03 -4.3576E-04 -6.4828E-03 -2.8648E-03 160
 65.00  1.1999E+02  4.1874E+02  4.1543E+03 -3.4163E-04 -7.5936E-03 -2.2487E-03 165
 70.00  8.1918E+01  4.5165E+02  4.5910E+03 -2.3492E-04 -8.4176E-03 -1.5478E-03 170
 75.00  4.1540E+01  4.7157E+02  4.8580E+03 -1.1964E-04 -8.9245E-03 -7.8875E-04 175
 80.00  0.0000E+00  4.7824E+02  4.9479E+03  0.0000E+00 -9.0955E-03  0.0000E+00 180
 80.00  0.0000E+00  4.7824E+02  4.9479E+03  0.0000E+00 -9.0955E-03  0.0000E+00 180

RINTOUT AT LOAD AND/OR MOMENT POINTS

 60.00 -8.0579E+02 -1.3957E+03  6.8774E+03  4.3209E-04 -1.1897E-03  2.9439E-03  60
 59.99  1.9586E+02  3.3895E+02  6.8757E+03  4.3176E-04 -1.1922E-03  2.9437E-03  60
300.00 -1.9580E+02  3.3917E+02  6.8774E+03 -4.3209E-04 -1.1897E-03 -2.9439E-03 300
 99.99  8.0554E+02 -1.3956E+03  6.8704E+03 -4.3243E-04 -1.1873E-03 -2.9441E-03 300

RINTOUT OF MAXIMUM AND MINIMUM VALUES OF SHEAR, THRUST, AND MOMENT
ALUES TAKEN FROM BOTH OF THE TABLES ABOVE

AXIMUM V/A=              8.0554E+02   AT  299.99  DEGREES
INIMUM V/A=             -8.0579E+02   AT   60.00  DEGREES
AXIMUM T/A=              4.7824E+02   AT  180.00  DEGREES
INIMUM T/A=             -1.3957E+03   AT   60.00  DEGREES
AXIMUM M(FORCE-LG)=      6.8774E+03   AT   60.00  DEGREES
INIMUM M(FORCE-LG)=     -5.8406E+03   AT  100.00  DEGREES

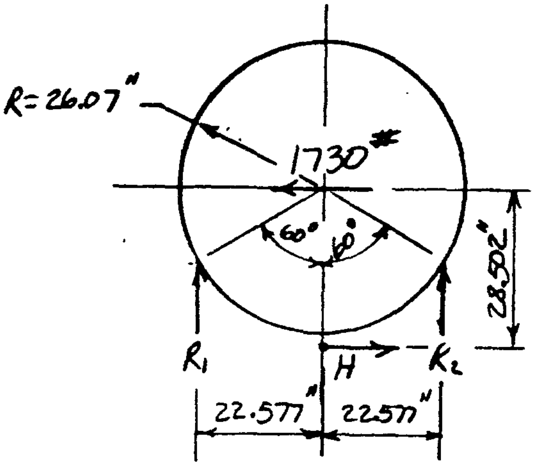

RINTOUT OF MAXIMUM AND MINIMUM (AXIAL + BENDING) STRESSES FOR MOMENT
RMS OF C1 AND C2 - VALUES TAKEN FROM BOTH OF THE TABLES ABOVE

AXIMUM STRESS (C1)=     3.8293E+03   AT  300.00  DEGREES
INIMUM STRESS (C1)=    -3.7802E+03   AT   95.00  DEGREES
AXIMUM STRESS (C2)=     3.4741E+03   AT  105.00  DEGREES
INIMUM STRESS (C2)=    -6.4034E+03   AT   60.00  DEGREES
TOP [SYSIN]
```

DDG 4/5/94

10.1✓

LOAD COMBINATION 3



VERTICAL LOAD = 7600#

LATERAL SEISMIC LOAD = 1,730#

$H = 1730^{\#}$

VERTICAL LOADS DUE TO SEISMIC

$\Sigma M_{@H} = 0$

$(1730^{\#})(28.502") - 22.577"(R_1) - 22.577"(R_2) = 0$

$R_2 = -R_1$

$R = 1092^{\#}$

VERTICAL LOAD DUE TO DL

$R_1 = R_2 = \frac{7600^{\#}}{2} = 3800^{\#}$

$R_1 = 3800^{\#} + 1092^{\#} = 4892^{\#}$

$R_2 = 3800^{\#} - 1092^{\#} = 2708^{\#}$

MOMENT @ INVERT $= (4.127" - 1.695")(1730^{\#}) = 4{,}208$ IN-LBS

USING SAME RING AS LOAD #1

SUBJECT

CBI OFFICE NoE

REVISION

REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY	
MRS	DDG			SHT 13 OF 48
DATE 2/18/94	DATE 4/5/94	DATE	DATE	10.13

INPUT TO CBI COMPUTER PROGRAM E0405A

2 RADIAL LOADS @ 60° & 300°

$P_{60} = (4892^{\#}) \cos 60° = 2446^{\#}$ @ 60°

$P_{300} = (2708^{\#}) \cos 60° = 1354^{\#}$ @ 300°

3 TANGENTIAL LOADS @ 0°, 60° & 300°

$T_0 = 1730^{\#}$

$T_{60} = (-4892^{\#})(\sin 60°) = -4237^{\#}$ @ 60°

$T_{300} = (2708^{\#})(\sin 60°) = 2345^{\#}$ @ 300°

1 MOMENT LOAD @ 0°

$M/R = \frac{4208 \text{ IN-LBS}}{26.07''} = 161.4^{\#}$ @ 0°

$R = 26.07''$ $E = 28,000,000$ PSI $I = 3.34 \text{ IN}^4$

$A = 1.897 \text{ IN}^2$ $C_1 = 1.695''$ $C_2 = 2.432''$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 14 OF 48
	DATE 2/18/94	DATE 4/5/94	DATE	DATE	10.14

FROM E0405A OUTPUT (NEXT 2 SHEETS)

MAXIMUM INSIDE STRESS = 7,445 PSI @60°

MINIMUM INSIDE STRESS = -5,810 PSI @ 105°

MAXIMUM OUTSIDE STRESS = 6,025 PSI @ 110°

MINIMUM INSIDE STRESS = -11,175 PSI @ 60°

$V_{MAX} = (1155 \text{ PSI})(1.897 \text{ IN}^2) = 2,191^{\#}$ @ 60°

<u>STIFFENER TO SHELL WELD</u>

$$f = \frac{VQ}{I_n}$$

$V = 2191^{\#}$ $\quad\quad$ $I' = 3.34 \text{ IN}^4$

$Q = A'\bar{y}$ $\quad\quad$ $A' = [(2)(1.375'') + .375''](.127'') = 0.397 \text{ IN}^2$

$\bar{y} = C_1 - t/2 = 1.695'' - .127''/2 = 1.632''$

$$f = \frac{2191(1.632'')(0.397 \text{ IN}^2)}{3.34 \text{ IN}^4} = 425^{\#}/\text{IN}$$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 15 OF 48
	DATE 2/18/94	DATE 4/5/94	DATE	DATE	10.15

```
PROGRAM E0405A (STD 9110-1-2)  [ IBM RS/6000 ]
STRESS AND STRAIN COEFFICIENTS FOR CIRCULAR RINGS
REVISION 11 - JANUARY 7, 1992


S    STANDARDS 9110-1-1 AND 9110-1-2

FIXED SUPPORT DEAD LOAD + LATERAL SEISMIC - 2 PT. AT 60 DEG.


    N(R)     N(T)     N(M)     DATA SHEET NO.     PLOT CODE
     2        3        1             1                0


   RADIUS     MOD-ELAS     MOM-INER          AREA          C(1)          C(2)
    26.07 28000000.00          3.34          1.90          1.70          2.43

EQUILIBRIUM LOADS          FV          FH          M/R
             INPUT  7600.000    1730.000          .000
          COMPUTED  7600.179    1729.700          .600

INPUT LOADS AND THEIR LOCATIONS

RADIAL LOADS AND ANGLES

      LOADS          2446.00     1354.00
      ANGLES           60.00      300.00

TANGENTIAL LOADS AND ANGLES

      LOADS          1730.00    -4237.00     2345.00
      ANGLES             .00       60.00      300.00

MOMENT LOADS/R AND ANGLES

      LOADS          -161.40
      ANGLES             .00

UNIT STRESS VALUES FOR CIRCULAR RINGS

PRINTOUT AT EQUAL ANGLE INCREMENTS

    X      V/A          T/A       M(FORCE-LG)     THETA          DR          DC
    .00  4.0410E+02 -2.2226E+01 -4.1155E+03 -7.4310E-04 -2.1789E-03 -6.9789E-03
   5.00  4.0547E+02 -7.3311E+00 -2.3680E+03 -8.2198E-04 -4.5650E-03 -6.6858E-03   5
  10.00  4.0510E+02  1.7475E+01 -6.1818E+02 -8.5829E-04 -7.0473E-03 -6.1794E-03  10
  15.00  4.0213E+02  5.2083E+01  1.1248E+03 -8.5211E-04 -9.5102E-03 -5.4563E-03  15
  20.00  3.9573E+02  9.6235E+01  2.8479E+03 -8.0373E-04 -1.1839E-02 -4.5234E-03  20
  25.00  3.8507E+02  1.4952E+02  4.5344E+03 -7.1384E-04 -1.3920E-02 -3.3973E-03  25
  30.00  3.6938E+02  2.1140E+02  6.1643E+03 -5.8357E-04 -1.5644E-02 -2.1044E-03  30
  35.00  3.4794E+02  2.8117E+02  7.7144E+03 -4.1457E-04 -1.6909E-02 -6.8027E-04  35
  40.00  3.2010E+02  3.5801E+02  9.1584E+03 -2.0910E-04 -1.7619E-02  8.3066E-04  40
  45.00  2.8528E+02  4.4098E+02  1.0467E+04  2.9919E-05 -1.7689E-02  2.3762E-03  45
  50.00  2.4299E+02  5.2901E+02  1.1610E+04  2.9882E-04 -1.7046E-02  3.8972E-03  50
  55.00  1.9284E+02  6.2094E+02  1.2553E+04  5.9317E-04 -1.5632E-02  5.3289E-03  55
      0 -1.1549E+03 -1.5180E+03  1.3263E+04  9.0769E-04 -1.3406E-02  6.6019E-03  60
      0 -1.0219E+03 -1.5260E+03  8.5653E+03  1.1720E-03 -1.0395E-02  7.6455E-03  65
   0.00 -8.8904E+02 -1.5163E+03  4.4420E+03  1.3291E-03 -6.8290E-03  8.4002E-03  70
  75.00 -7.5777E+02 -1.4896E+03  8.8923E+02  1.3928E-03 -2.9622E-03  8.8287E-03  75
  80.00 -6.2952E+02 -1.4470E+03 -2.1030E+03  1.3769E-03  9.7884E-04  8.9150E-03  80
  85.00 -5.0565E+02 -1.3895E+03 -4.5508E+03  1.2949E-03  4.7986E-03  8.6614E-03  85
  90.00 -3.8741E+02 -1.3184E+03 -6.4757E+03  1.1597E-03  8.3327E-03  8.0859E-03  90
  95.00 -2.7584E+02 -1.2350E+03 -7.9044E+03  9.8384E-04  1.1447E-02  7.2193E-03  95
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10.16

```
105.00 -7.7062E+01 -1.0376E+03 -9.4029E+03  5.5584E-04  1.6037E-02  4.7882E-03 105.
110.00  8.6972E+00 -9.2676E+02 -9.5470E+03  3.2460E-04  1.7394E-02  3.3228E-03 110.
115.00  8.4520E+01 -8.1014E+02 -9.3422E+03  9.4178E-05  1.8092E-02  1.7696E-03 115.
120.00  1.4998E+02 -6.8945E+02 -8.8324E+03 -1.2746E-04  1.8137E-02  1.8414E-04 120.
125.00  2.0479E+02 -5.6646E+02 -8.0630E+03 -3.3344E-04  1.7557E-02 -1.3777E-03 125.
130.00  2.4882E+02 -4.4290E+02 -7.0803E+03 -5.1802E-04  1.6398E-02 -2.8633E-03 130.
135.00  2.8212E+02 -3.2052E+02 -5.9307E+03 -6.7657E-04  1.4723E-02 -4.2247E-03 135.
140.00  3.0485E+02 -2.0100E+02 -4.6604E+03 -8.0559E-04  1.2609E-02 -5.4202E-03 140.
145.00  3.1733E+02 -8.5962E+01 -3.3142E+03 -9.0270E-04  1.0142E-02 -6.4151E-03 145.
150.00  3.2003E+02  2.3053E+01 -1.9354E+03 -9.6657E-04  7.4143E-03 -7.1827E-03 150.
155.00  3.1353E+02  1.2460E+02 -5.6508E+02 -9.9693E-04  4.5230E-03 -7.7044E-03 155.
160.00  2.9854E+02  2.1733E+02  7.5859E+02 -9.9445E-04  1.5659E-03 -7.9702E-03 160.
165.00  2.7589E+02  3.0006E+02  2.0007E+03 -9.6068E-04 -1.3616E-03 -7.9786E-03 165.
170.00  2.4649E+02  3.7170E+02  3.1302E+03 -8.9802E-04 -4.1686E-03 -7.7361E-03 170.
175.00  2.1136E+02  4.3134E+02  4.1201E+03 -8.0952E-04 -6.7714E-03 -7.2570E-03 175.
180.00  1.7158E+02  4.7824E+02  4.9479E+03 -6.9888E-04 -9.0955E-03 -6.5624E-03 180.
180.00  1.7158E+02  4.7824E+02  4.9479E+03 -6.9888E-04 -9.0955E-03 -6.5624E-03 180.

PRINTOUT AT LOAD AND/OR MOMENT POINTS

   .00  4.0410E+02 -2.2226E+01 -4.1155E+03 -7.4310E-04 -2.1789E-03 -6.9789E-03
  -.01  4.0394E+02 -9.3421E+02  8.8749E+01 -7.4311E-04 -2.1743E-03 -6.9793E-03
 60.00 -1.1549E+03 -1.5180E+03  1.3263E+04  9.0769E-04 -1.3406E-02  6.6019E-03  60.
 59.99  1.3466E+02  7.1532E+02  1.3262E+04  9.0705E-04 -1.3412E-02  6.5996E-03  60.
300.00 -2.5705E+02 -3.7167E+01  4.9202E+02  4.3509E-05  1.1027E-02  7.1422E-04 300.
299.99  4.5648E+02 -1.2732E+03  4.8808E+02  4.3485E-05  1.1027E-02  7.1615E-04 300.

PRINTOUT OF MAXIMUM AND MINIMUM VALUES OF SHEAR, THRUST, AND MOMENT
VALUES TAKEN FROM BOTH OF THE TABLES ABOVE

MAXIMUM V/A=             4.5648E+02   AT  299.99  DEGREES
MINIMUM V/A=            -1.1549E+03   AT   60.00  DEGREES
MAXIMUM T/A=             7.1532E+02   AT   59.99  DEGREES
MINIMUM T/A=            -1.5260E+03   AT   65.00  DEGREES
MAXIMUM M(FORCE-LG)=     1.3263E+04   AT   60.00  DEGREES
MINIMUM M(FORCE-LG)=    -9.5470E+03   AT  110.00  DEGREES


PRINTOUT OF MAXIMUM AND MINIMUM (AXIAL + BENDING) STRESSES FOR MOMENT
ARMS OF C1 AND C2 - VALUES TAKEN FROM BOTH OF THE TABLES ABOVE

MAXIMUM STRESS (C1)=   7.4454E+03   AT   59.99  DEGREES
MINIMUM STRESS (C1)=  -5.8094E+03   AT  105.00  DEGREES
MAXIMUM STRESS (C2)=   6.0248E+03   AT  110.00  DEGREES
MINIMUM STRESS (C2)=  -1.1175E+04   AT   60.00  DEGREES
TOP [SYSIN]
```

DDG 4/5/94

10.17

11

LOAD COMBINATION #4

VERTICAL LOAD = $7600^{\#}$

LATERAL STABILITY = $600^{\#}$

$H = 600^{\#}$

VERTICAL LOADS DUE TO LATERAL FORCES

$\Sigma M_{@H} = 0$

$(600^{\#})(28.502'') - 2(22.577'')(R) = 0$

$R = \pm 379^{\#}$

TOTAL VERTICAL LOADS

$R_1 = \frac{7600^{\#}}{2} + 379^{\#} = 4179^{\#}$. $R_2 = \frac{7600^{\#}}{2} - 379^{\#} = 3421^{\#}$

MOMENT @ INVERT (M) = $(4.127'' - 1.695'')(600^{\#})$ = 1459 IN-LBS

INPUT INTO PROGRAM E0405A

$P_{60} = (4179^{\#}) \cos 60^{\circ} = 2090^{\#}$ $P_{300} = (3421^{\#}) \cos 60 = 1711^{\#}$

$T_0 = 600^{\#}$, $T_{60} = (-4179^{\#})(\sin 60) = -3619^{\#}$, $T_{300} = (3421^{\#}) \sin 60 = 2963^{\#}$

$M_0/R = \frac{-1459 \text{ IN-LBS}}{26.07''} = -56.0^{\#}$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 18 OF 48
	DATE 2/18/94	DATE 4/5/94	DATE	DATE	10.18

Printed in USA

GO 84 REV SEP 84

FROM E0405A OUTPUT (NEXT 2 SHEETS)

MAXIMUM INSIDE STRESS = 5,085 PSI @ 60°

MINIMUM INSIDE STRESS = −4,411 PSI @ 100°

MAXIMUM OUTSIDE STRESS = 4,284 PSI @ 105°

MINIMUM OUTSIDE STRESS = −8,061 PSI @ 60°

$V_{max} = (927 PSI)(1.897 IN^2) = 1,759^{\#}$

SUBJECT	OFFICE	REVISION		REFERENCE NO.
	CBI NOE			930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 19 OF 48
	DATE 2/18/94	DATE 4/5/94	DATE	DATE	10.19

```
ROGRAM E0405A (STD 9110-1-2)  [ IBM RS/6000 ]
TRESS AND STRAIN COEFFICIENTS FOR CIRCULAR RINGS
EVISION 11 - JANUARY 7, 1992



E     TANDARDS 9110-1-1 AND 9110-1-2

IXED SUPPORT LOAD COMBINATION #4 - 2 PT. AT 60 DEG.


   N(R)     N(T)     N(M)     DATA SHEET NO.     PLOT CODE
     2        3        1             1                0


  RADIUS    MOD-ELAS     MOM-INER         AREA         C(1)          C(2)
   26.07 28000000.00        3.34          1.90         1.70          2.43

QUILIBRIUM LOADS          FV          FH          M/R
           INPUT   7600.000    600.000        .000
        COMPUTED   7600.679    600.224        .000

NPUT LOADS AND THEIR LOCATIONS

ADIAL LOADS AND ANGLES

    LOADS         2090.00    1711.00
    ANGLES          60.00     300.00

ANGENTIAL LOADS AND ANGLES

    _OADS          600.00   -3619.00     2963.00
    ANGLES            .00      60.00      300.00

IOMENT LOADS/R AND ANGLES

    LOADS          -56.00
    ANGLES            .00                                                 11.20

NIT STRESS VALUES FOR CIRCULAR RINGS

RINTOUT AT EQUAL ANGLE INCREMENTS

    X      V/A         T/A      M(FORCE-LG)    THETA          DR           DC           )
   .00  1.4016E+02 -3.2028E+02 -2.7439E+03 -2.5774E-04 -2.1745E-03 -2.4209E-03        .
  5.00  1.6779E+02 -3.1076E+02 -2.0791E+03 -3.1665E-04 -3.0329E-03 -2.1945E-03       5.
 10.00  1.9405E+02 -2.8915E+02 -1.2976E+03 -3.5795E-04 -3.9827E-03 -1.8889E-03      10.
 15.00  2.1791E+02 -2.5565E+02 -4.0763E+02 -3.7890E-04 -4.9734E-03 -1.4982E-03      15.
 20.00  2.3833E+02 -2.1064E+02  5.7828E+02 -3.7701E-04 -5.9483E-03 -1.0213E-03      20.
 25.00  2.5435E+02 -1.5464E+02  1.6432E+03 -3.5013E-04 -6.8457E-03 -4.6226E-04      25.
 30.00  2.6502E+02 -8.8358E+01  2.7660E+03 -2.9659E-04 -7.5998E-03  1.6933E-04      30.
 35.00  2.6950E+02 -1.2616E+01  3.9218E+03 -2.1528E-04 -8.1429E-03  8.5802E-04      35.
 40.00  2.6698E+02  7.1606E+01  5.0821E+03 -1.0574E-04 -8.4071E-03  1.5824E-03      40.
 45.00  2.5678E+02  1.6321E+02  6.2152E+03  3.1761E-05 -8.3263E-03  2.3153E-03      45.
 50.00  2.3831E+02  2.6097E+02  7.2866E+03  1.9615E-04 -7.8388E-03  3.0238E-03      50.
 55.00  2.1109E+02  3.6356E+02  8.2596E+03  3.8548E-04 -6.8890E-03  3.6700E-03      55.
      ) -9.2698E+02 -1.4382E+03  9.0956E+03  5.9690E-04 -5.4305E-03  4.2113E-03      60.
      ) -8.0220E+02 -1.4190E+03  5.3648E+03  7.7169E-04 -3.4707E-03  4.6029E-03      65
   .00 -6.7977E+02 -1.3842E+03  2.1680E+03  8.6224E-04 -1.1853E-03  4.8077E-03      70.
 75.00 -5.6103E+02 -1.3348E+03 -5.0794E+02  8.8140E-04  1.2315E-03  4.8059E-03      75.
 80.00 -4.4719E+02 -1.2721E+03 -2.6816E+03  8.4161E-04  3.6131E-03  4.5938E-03      80
 85.00 -3.3937E+02 -1.1972E+03 -4.3766E+03  7.5481E-04  5.8211E-03  4.1804E-03      85
 90.00 -2.3856E+02 -1.1116E+03 -5.6210E+03  6.3233E-04  7.7449E-03  3.5861E-03      90
                                            4.8472E-04  9.3007E-03  2.8394E-03      95
```

```
05.00  1.3750E+01 -8.0571E+02 -6.9897E+03  1.5227E-04  1.1102E-02  1.0322E-03 105.(
10.00  7.9162E+01 -6.9283E+02 -6.7857E+03 -1.5856E-05  1.1304E-02  5.1176E-05 110.(
15.00  1.3459E+02 -5.7727E+02 -6.3208E+03 -1.7576E-04  1.1045E-02 -9.2726E-04 115.(
20.00  1.7989E+02 -4.6073E+02 -5.6385E+03 -3.2162E-04  1.0354E-02 -1.8640E-03 120.(
25.00  2.1503E+02 -3.4487E+02 -4.7827E+03 -4.4869E-04  9.2732E-03 -2.7231E-03 125.(
3   )  2.4014E+02 -2.3132E+02 -3.7970E+03 -5.5326E-04  7.8577E-03 -3.4727E-03 130.(
3   0  2.5551E+02 -1.2165E+02 -2.7240E+03 -6.3272E-04  6.1727E-03 -4.0866E-03 135.(
4   )  2.6153E+02 -1.7382E+01 -1.6050E+03 -6.8542E-04  4.2904E-03 -4.5443E-03 140.(
45.00  2.5874E+02  8.0083E+01 -4.7920E+02 -7.1075E-04  2.2866E-03 -4.8319E-03 145.(
50.00  2.4779E+02  1.6943E+02  6.1664E+02 -7.0898E-04  2.3881E-04 -4.9421E-03 150.(
55.00  2.2944E+02  2.4948E+02  1.6490E+03 -6.8126E-04 -1.7770E-03 -4.8745E-03 155.(
60.00  2.0455E+02  3.1915E+02  2.5877E+03 -6.2951E-04 -3.6885E-03 -4.6350E-03 160.(
65.00  1.7407E+02  3.7755E+02  3.4065E+03 -5.5634E-04 -5.4294E-03 -4.2357E-03 165.(
70.00  1.3901E+02  4.2390E+02  4.0836E+03 -4.6492E-04 -6.9412E-03 -3.6941E-03 170.(
75.00  1.0045E+02  4.5760E+02  4.6013E+03 -3.5895E-04 -8.1750E-03 -3.0324E-03 175.(
80.00  5.9524E+01  4.7822E+02  4.9472E+03 -2.4245E-04 -9.0929E-03 -2.2765E-03 180.(
80.00  5.9524E+01  4.7822E+02  4.9472E+03 -2.4245E-04 -9.0929E-03 -2.2765E-03 180.(

RINTOUT AT LOAD AND/OR MOMENT POINTS

  .00  1.4016E+02 -3.2028E+02 -2.7439E+03 -2.5774E-04 -2.1745E-03 -2.4209E-03    .(
 -.01  1.4005E+02 -6.3658E+02 -1.2852E+03 -2.5768E-04 -2.1729E-03 -2.4213E-03    .(
60.00 -9.2698E+02 -1.4382E+03  9.0956E+03  5.9690E-04 -5.4305E-03  4.2113E-03  60.(
59.99  1.7484E+02  4.6937E+02  9.0940E+03  5.9645E-04 -5.4340E-03  4.2104E-03  60.(
00.00 -2.1717E+02  2.0862E+02  4.6648E+03 -2.6697E-04  3.0455E-03 -1.6735E-03 300.(
99.99  6.8454E+02 -1.3532E+03  4.6589E+03 -2.6720E-04  3.0470E-03 -1.6730E-03 300.(

RINTOUT OF MAXIMUM AND MINIMUM VALUES OF SHEAR, THRUST, AND MOMENT
ALUES TAKEN FROM BOTH OF THE TABLES ABOVE

AXIMUM V/A=               6.8454E+02   AT   299.99  DEGREES
I   UM V/A=              -9.2698E+02   AT    60.00  DEGREES
   JM T/A=                4.7822E+02   AT   180.00  DEGREES
I.  IUM T/A=             -1.4382E+03   AT    60.00  DEGREES
AXIMUM M(FORCE-LG)=       9.0956E+03   AT    60.00  DEGREES
INIMUM M(FORCE-LG)=      -6.9897E+03   AT   105.00  DEGREES


RINTOUT OF MAXIMUM AND MINIMUM (AXIAL + BENDING) STRESSES FOR MOMENT
RMS OF C1 AND C2 - VALUES TAKEN FROM BOTH OF THE TABLES ABOVE

AXIMUM STRESS (C1)=   5.0845E+03   AT    59.99  DEGREES
INIMUM STRESS (C1)=  -4.4110E+03   AT   100.00  DEGREES
AXIMUM STRESS (C2)=   4.2838E+03   AT   105.00  DEGREES
INIMUM STRESS (C2)=  -8.0610E+03   AT    60.00  DEGREES
OP [SYSIN]
```

DDG 4/5/94

10.21

DESIGN RING SUPPORT LUGS

MAX - VERTICAL LOAD = 4892# (VERT. DL + VERT STAB. + LAT. EQ)

DESIGN LUG AS A CANTILEVER COLUMN.

$L = 11''$

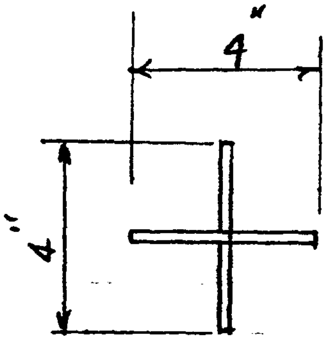
TRY $4'' \times 3/8''$ PLATE

$A = 4(.375) = 1.5 \text{ IN}^2$ $\qquad I_{MIN} = \dfrac{(.375)^3(4)}{12} = 0.0176 \text{ IN}^4$

$r = \sqrt{I/A} = 0.108''$ $\qquad$ LET $K = 2.1$

$KL/r = \dfrac{(2.1)(11'')}{.108''} = 214$ TOO LARGE

USE $3/8''$ STIFFENERS



$A = [4 + (4 - .375)](.375'') = 2.86 \text{ IN}^2$

$I = \dfrac{(4)^3(.375)}{12} + \dfrac{(.375)^3(3.625)}{12} = 2.016 \text{ IN}^4$

$r = \sqrt{I/A} = 0.840''$

$KL/r = \dfrac{(2.1)(11'')}{.840} = 27.5$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 22 OF 48
	DATE 2/22/94	DATE 4/5/94	DATE	DATE	10.22

(AISC E2)

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

$$\left.\begin{array}{ll} E = 27{,}000{,}000 \text{ PSI} & @\ 300°F \\ F_y = 19{,}200 \text{ PSI} & @\ 300°F \end{array}\right\} \text{ASME SEC. VIII, DIV. 2}$$

$C_c = 166.6$ $\qquad KL/r = 27.5$

$$F_a = \frac{\left[1 - \frac{(KL/r)^2}{2C_c^2}\right]F_y}{5/3 + \frac{3(KL/r)}{8C_c} - \frac{(KL/r)^3}{8C_c^3}}$$

$F_a = 10{,}960$ PSI

$$f_a = \frac{4{,}892^{\#}}{2.86 \text{ in}^2} = 1{,}710 \text{ PSI} < F_a \therefore \text{OK}$$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 23 OF 48
	DATE 2/22/94	DATE 4/5/94	DATE	DATE	10.23

DESIGN COLUMN SUPPORT

MAX. VERTICAL LOAD = 4,892# (VERT. DL + VERT. STABILITY + LAT. EQ)

$L = 10''$ $\qquad K = 2.1$

TRY 2 x 2 x 3/16 TUBE

$A = 1.27\ IN^2 \qquad I = 0.668'' \qquad r = 0.726^4$

$$KL/r = \frac{2.1(10)}{.726} = 29$$

(AISC E2)

$$C_c = 166.6 \qquad \frac{KL/r}{C_c} = 0.174$$

$$F_a = \frac{\left[1 - \frac{(0.174)^2}{2}\right] 19{,}200\ PSI}{5/3 + 3/8(.174) - \frac{(.174)^3}{8}} = 10{,}922\ PSI$$

$$f_a = \frac{4892^{\#}}{1.27\ IN^2} = 3852\ PSI < F_a \quad \therefore \text{OK}$$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 93021L
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 24 OF 48
	DATE 2/22/94	DATE 4/5/94	DATE	DATE	10.24

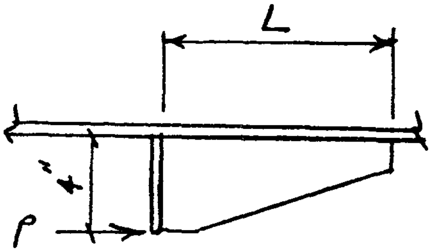
Printed in USA

GO 64 REV SEP 84

LATERAL RESTRAINT

CHECK SHELL FOR LONGITUDINAL BAKE OUT FORCE

P = 5,300#



TO PREVENT BENDING OF RING AND OVER STRESSING THE TUBE WALL A LONGITUDINAL GUSSET IS WELDED TO THE TUBE & SUPPORT RING.

DESIGN GUSSET AS A BRACKET ON A CYLINDRICAL SHELL

REF: CBI STD. 9108-7 "BRACKET SUPPORTS ON CYLINDERS"

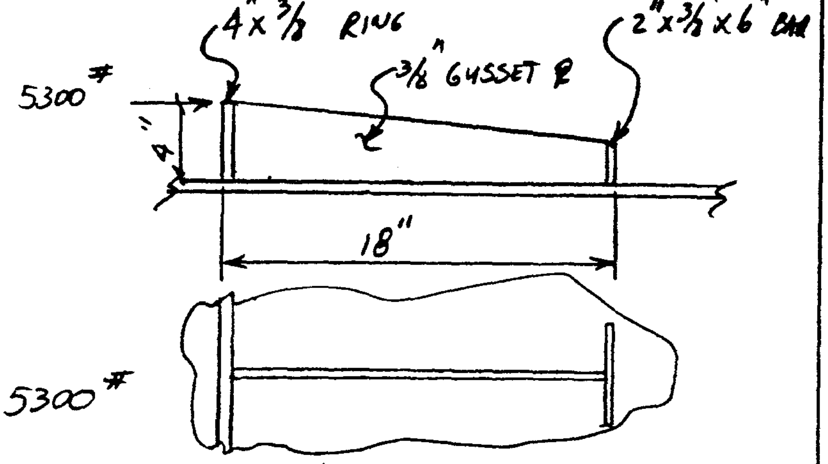
CHECK TUBE WALL FOR LONGITUDINAL BENDING

MAXIMUM CALCULATED LONGITUDINAL STRESS IN WALL

$$\sigma = \underbrace{1533\ \text{PSI}}_{\text{PER WALL CALCS}} + \underbrace{329\ \text{PSI}}_{\text{ADDITIONAL BENDING DUE TO LONG. BAKE OUT FORCE}} = 1862\ \text{PSI}$$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 26 OF 48
	DATE 2/22/94	DATE 4/5/94	DATE	DATE	10.25

USE AN 18" LONG LUG WITH A 6" WIDE PLATE AT THE END



LONGITUDINAL FORCE (P) = 5300#

MOMENT ON TUBE WALL $(M_1) = 4''(5300^{\#}) = 21,200$ IN-LBS

ALLOWABLE LONGITUDINAL COMPRESSIVE STRESS $(\sigma_A) = 5800$ PSI
(PER BEAM TUBE CALCS)

DESIGN LUG AS A BRACKET ON A CYLINDRICAL SHELL

REF. CBI STD. 9108-7 "BRACKET SUPPORTS ON CYLINDERS"

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 26 OF 48
	DATE 2/22/94	DATE 4/5/94	DATE	DATE	10.26

STANDARD 9108-7

BRACKET SUPPORTS ON CYLINDERS

$t =$ 0.127 in. Shell thickness

. $=$ 24.4385 in. Shell radius

$L =$ 18 in. Length of lug

$tl =$ 6 in. Lug thickness

$tw =$ 0.125 in. Weld size

$W =$ 6.25 in. $tl + 2(tw)$

$P =$ 5300 lbs. Vertical load

Mact = 21200 in-lbs Longitudinal moment on shell from lug

Qact = 0 lbs. Radial load on shell from lug

$SL =$ 0 psi Longitudinal shell stress due to internal pressure.

$SH =$ 0 psi Circumferential shell stress due to internal pressure.

$Slc =$ 1862 psi Longitudinal shell compression stress.

ALLOWABLE STRESS (Sa) = 14400 psi = 1.25(.6Fy)

$= 1.285/(Rt)^{.5} = 0.729397$

$M1 = 1390(t^2)\ [6 + 6BL + (B^2)(L^2)]\ W =$ 20754 in-lbs

$M2 = 2520(t^2)\ [6 + 6BL + (B^2)(L^2)]\ W =$ 37627 in-lbs

$Q1 = 8333(t^2)\ WB\ (2 + BL) =$ 5339 lbs.

$Q2 = 15150(t^2)\ WB\ (2 + BL) =$ 9707 lbs.

$Ma/M1 + Qa/Q1 + SL/Sa = 1.0 =< 1.0$

$Ma/M2 + Qa/Q2 + SH/Sa = 0.56 =< 1.0$

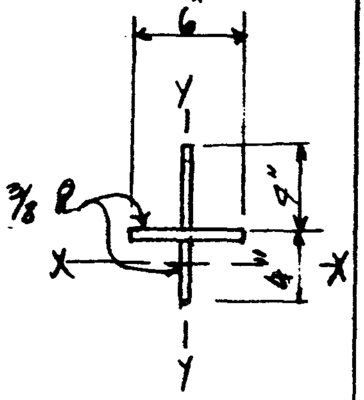
ALLOWABLE SHELL COMPRESSION (Sca) = 1,800,000 (t/R) = 9354 psi

$$Sc = \frac{P}{[1.154(L) + W](t)} + Slc = 3406 \text{ psi}$$

SUBJECT	MADE BY: MRS	R	MADE BY:	REFERENCE NO.
	CHKD BY: DDG	E	CHKD BY:	930212
	DATE: 2/22/94	V	DATE:	SHT 27 OF 48

10,27

HORIZONTAL RESTRAINT DESIGN



$F = 5300^{\#}$ LONGITUDINAL BAKE OUT

$F = 1730^{\#}$ LATERAL SEISMIC

MOMENT @ BASE OF RESTRAINT

$M_{LONG.} = 4''(5300^{\#}) = 21{,}200^{\#-IN}$

$M_{LAT} = 4''(1730^{\#}) = 6{,}920^{\#-IN}$

$A = (6 + 8 - .375)(.375) = 5.11 \ IN^2$

$I_x = 16.02 \ IN^4$ $\quad S_{x\,MIN} = 4.01 \ IN^3$

$I_y = 6.8 \ IN^4$ $\quad S_{y\,MIN} = 2.26 \ IN^3$

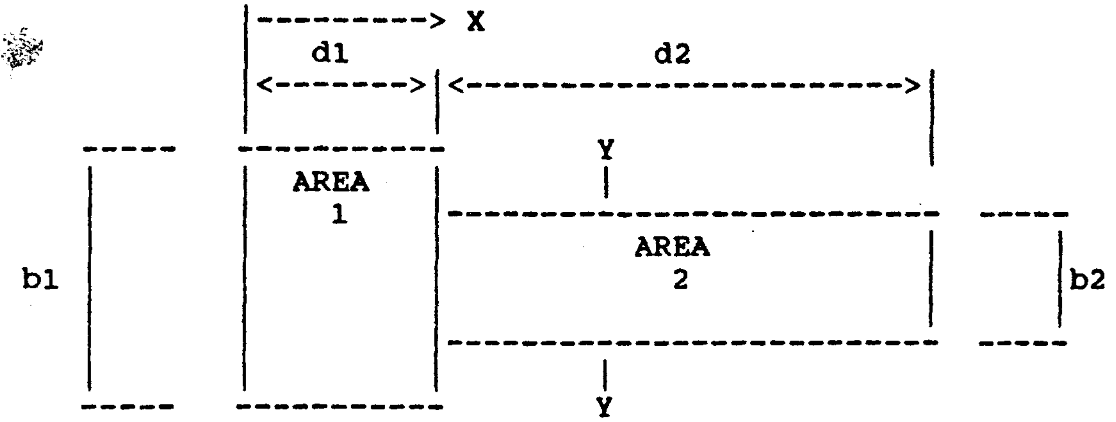
$\sigma_{b_x} = M/S = \frac{21{,}200^{\#}}{4.01 IN^3} = 5{,}286 \ PSI < \sigma_{ALLOW} \therefore OK$

$\sigma_{ALLOW} = .6(F_y) = .6(19{,}200) = 11{,}520 \ PSI$

$\sigma_{by} = M_{LAT}/S = \frac{6{,}920}{2.26} = 3{,}062 \ PSI < \sigma_{ALLOW} \therefore OK$

SUBJECT	CBI OFFICE NoE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 28 OF 48
	DATE 2/22/94	DATE 4/6/94	DATE	DATE	10.28

MOMENT OF INERTIA CALCULATION



	1	2	3	4	5	6	7
d	3.8125	0.375	3.8125				
b	0.375	6	0.375				
X	1.9063	4.0000	6.0938	8.0000	8.0000	8.0000	8.0000
THETA	0	0	0	0	0	0	0

	AREA	X	AX	AX^2	Io
1	1.430	1.906	2.73	5.20	1.73
2	2.250	4.000	9.00	36.00	0.03
3	1.430	6.094	8.71	53.09	1.73
4	0.000	8.000	0.00	0.00	0.00
5	0.000	8.000	0.00	0.00	0.00
6	0.000	8.000	0.00	0.00	0.00
7	0.000	8.000	0.00	0.00	0.00
	5.109		20.44		97.77

TOTAL DEPTH = 8.0000 in.

CENTROID $(\bar{X})$ = SUM(AX)/SUM(AREA) = 4.000 in.

I(total)= $[\mathrm{SUM}(AX^2)+\mathrm{SUM}(Io)]-(\mathrm{AREA})(\bar{X})^2$ = 16.02 $\mathrm{in.}^4$

C1 = $\bar{X}$ = 4.000 in.   C2 = DEPTH - $\bar{X}$ = 4.000 in.

Sy1 = I/C1 = 4.01 $\mathrm{in.}^3$ Sy2 = I/C2 = 4.01 $\mathrm{in.}^3$

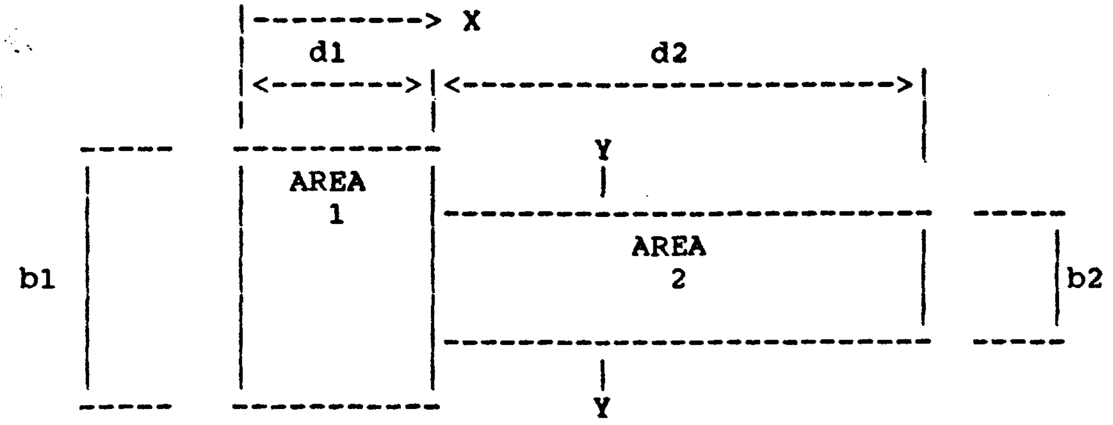
Radius of gyration (r) = $(I/A)^{1/2}$ = 1.771 in.

Torsional constant (J) = in^4

UBJECT TION PROPERTIES ABOUT X-X HORIZONTAL RESTRAINT	MADE BY: MRS	R	MADE BY:	REFERENCE NO.
	CHKD BY: DDG	E V	CHKD BY:	930212
LIGO BEAM TUBE	DATE: 2/22/94		DATE:	SHT 29 OF 48

10.29

MOMENT OF INERTIA CALCULATION



	1	2	3	4	5	6	7
d	2.8125	0.375	2.8125				
b	0.375	8	0.375				
X	1.4063	3.0000	4.5938	6.0000	6.0000	6.0000	6.0000
THETA	0	0	0	0	0	0	0

	AREA	X	AX	AX^2	Io
1	1.055	1.406	1.48	2.09	0.70
2	3.000	3.000	9.00	27.00	0.04
3	1.055	4.594	4.84	22.26	0.70
4	0.000	6.000	0.00	0.00	0.00
5	0.000	6.000	0.00	0.00	0.00
6	0.000	6.000	0.00	0.00	0.00
7	0.000	6.000	0.00	0.00	0.00
	5.109		15.33		52.77

TOTAL DEPTH = 6.0000 in.

CENTROID $(\bar{X})$ = SUM(AX)/SUM(AREA) = 3.000 in.

I(total)= $[\mathrm{SUM}(AX^2)+\mathrm{SUM}(Io)]-(\mathrm{AREA})(\bar{X})^2$ = 6.78 $\mathrm{in.}^4$

C1 = $\bar{X}$ = 3.000 in. C2 = DEPTH - $\bar{X}$ = 3.000 in.

Sy1 = I/C1 = 2.26 $\mathrm{in.}^3$ Sy2 = I/C2 = 2.26 $\mathrm{in.}^3$

Radius of gyration (r) = $(I/A)^{1/2}$ = 1.152 in.

Torsional constant (J) = in^4

UBJECT
TION PROPERTIES ABOUT Y-Y
HORIZONTAL RESTRAINT
!
!LIGO BEAM TUBE

!MADE BY: MRS !
!CHKD BY: DDG !
!DATE: 2/22/94!

R E V

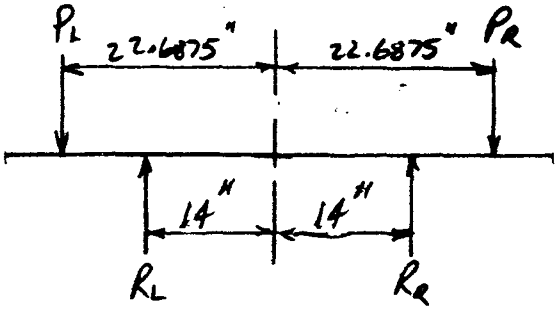
!MADE BY:
!CHKD BY:
!DATE:

!REFERENCE NO.!
! 93021✓ !
!SHT 30 OF 49 !

10.30

DESIGN HORIZONTAL SUPPORT BEAM

LOAD COMBINATION #1



DL + VERT. STABILITY

$P_L = P_R = 7600^{\#}/2 = 3800^{\#}$

$R_L = R_R = 7600^{\#}/2 = 3800^{\#}$

$M_x = (3800^{\#})(22.6875 - 14) = 33{,}013$ IN-LBS

$\sigma_{ALLOW} = .6F_y = .6(36{,}000$ PSI$) = 21{,}600$ PSI

$S_{REQ'D} = \dfrac{M}{\sigma_A} = \dfrac{33{,}013}{21{,}600} = 1.53$ IN^3

TRY STRUCTURAL TUBE 4x4x 3/16

SUBJECT	OFFICE	REVISION	REFERENCE NO.
	CBI NOE		930212

MADE BY	CHKD BY	MADE BY	CHKD BY	
MRS	DDG			SHT. 31 OF 48
DATE 2/23/94	DATE 4/6/94	DATE	DATE	10.31

Printed In USA

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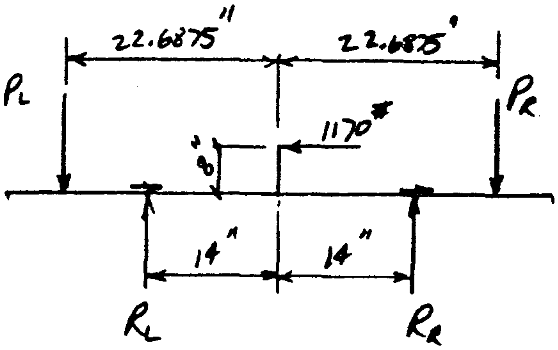
LOAD COMBINATION #3



$P_L = 4892^{\#}$

$P_R = 2708^{\#}$

$\Sigma M_{R_R} = 0$

$8''(1730^{\#}) + (36.6875'')(4892^{\#}) - 8.6875''(2708^{\#}) - 28''(R_L) = 0$

$R_L = 6064^{\#}$

$R_R = 4892^{\#} + 2708^{\#} - 6040^{\#} = 1536^{\#}$

$M_{max} = (4892^{\#})(22.6875'' - 14'') = 42{,}500$ IN-LBS

AXIAL LOAD $= 1730^{\#}$

$S_{REQ'D} = \dfrac{42{,}500 \text{ IN-LBS}}{21{,}600\,(1.33)} = 1.48 \text{ IN}^3$

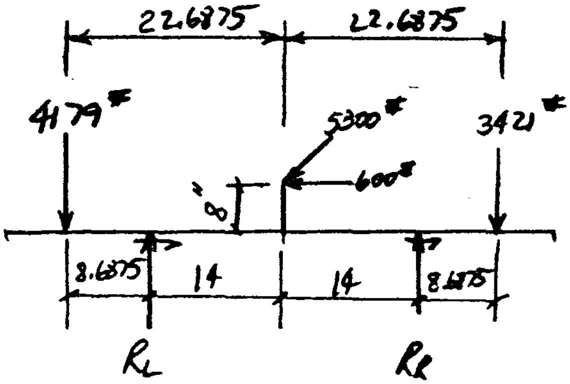
TRY $4 \times 4 \times 3/16''$ TUBE $\quad A = 2.77 \text{ IN}^2 \quad S = 3.30 \text{ IN}^3$

$\nabla = P/A + M/S = \dfrac{1730^{\#}}{2.77 \text{ IN}^2} + \dfrac{42{,}500 \text{ IN-LBS}}{3.30 \text{ IN}^3} = 625 + 12{,}879 = 13{,}504$ PSI

$< 1.33(21{,}600) = 28{,}800$ PSI

SUBJECT	CBI OFFICE NOE	REVISION		REFERENCE NO. 930212
	MADE BY mRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 32 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	11.32

LOAD COMBINATION #4



MOMENTS ABOUT X-X AXIS

$\Sigma M_{R_R} = 0$

$(4179^{\#})(36.6875'') - 28'' R_L + 8''(600^{\#}) - (8.6875'')(3421^{\#}) = 0$

$R_L = 4{,}586^{\#}$

$R_R = 4179 + 3421 - 4586 = 3014^{\#}$

$M_{MAX} = 4179^{\#}(8.6875'') = 36{,}305$ IN-LBS

TRY 4 X 4 X 3/8 TUBE $A = 5.08\ IN^2$ $S = 5.35\ IN^3$

$f_{bx} = \frac{36{,}305}{5.35\ IN^3} = 6{,}786$ PSI

MOMENT ABOUT Y-Y AXIS

$M_y = \frac{PL}{4} = \frac{(5300^{\#})(28'')}{4} = 37{,}100$ IN-LBS

$f_{by} = \frac{37{,}100\ IN\text{-}LBS}{5.35\ IN^3} = 6{,}935$ PSI

SUBJECT	CBI OFFICE NOE		REVISION	REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 33 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	10.33

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AXIAL LOAD

$P = 600^{\#}$

$$f_a = \frac{P}{A} = \frac{600^{\#}}{5.08 in^2} = 118 \text{ PSI}$$

COMBINED STRESS

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

$$\frac{118}{21,600} + \frac{6786}{21,600} + \frac{6935}{21,600} = 0.641 < 1.0 \quad \therefore \text{ OK}$$

$4 \times 4 \times \frac{3}{8}$ STRUCT. TUBE OK

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 93-212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 34 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	10.34

CHECK SHEAR STRESSES DUE TO TORQUE

TORQUE (T) = $\frac{8''(5300^{\#})}{2}$ = 21,200 IN-LBS

$$\tau_{TOT} = \tau_T + \tau_V$$

MAX HORIZONTAL SHEAR = $5300^{\#}/2 = 2650^{\#}$

MAX VERTICAL SHEAR = $4179^{\#}$

TRY 4" X 4" X 3/8" TUBE

AREA = 5.08 IN^2 $\quad$ $A_V = 2(4'')(.375'') = 3\ IN^2$

TORSIONAL RESISTANCE (R) = $\frac{2b^2d^2}{b/t + d/t}$

b = d = 4 - .375 = 3.625"

R = 17.863 IN^4

[A] AREA ENCLOSED BY MEAN DIMENSIONS

[A] = bd = 13.14 IN^2

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930242
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 35 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	11.35

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$$\tau_V = \frac{V}{A_V} = \frac{4179^{\#}}{3 \text{ IN}^2} = 1{,}393 \text{ PSI}$$

$$\tau_T = \frac{T}{2[A]\,t} = \frac{21{,}200 \text{ IN-LBS}}{2(13.14 \text{ IN}^2)(.375)} = 2{,}151 \text{ PSI}$$

$$\tau_{TOT.} = 2{,}151 \text{ PSI} + 1393 \text{ PSI} = 3{,}544 \text{ PSI}$$

MAX. ALLOWABLE SHEAR STRESS = $.4F_y = .4(36{,}000) = 14{,}400$ PSI

4x4x3/8 TUBE OK

ROTATION

$$\theta = \frac{TL}{E_s R} \qquad E_s = 12{,}000{,}000 \text{ PSI}$$

$$\theta = \frac{(21{,}200)(32'')}{(12{,}000{,}000)(17.863 \text{ IN}^4)} = 0.00316 \text{ RAD} = 0.1813^\circ$$

DISPLACEMENT @ TOP OF LATERAL RESTRAINT.

$8''(.00316) = 0.0253''$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 93042
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 36 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	11.36

DESIGN SUPPORT BRACKETS

LOAD COMBINATION # 4 (DL + AXIAL BACK OUT + VERT STAB. + LAT. STAB)

MAX. VERT. LOAD = 4586# T = 21,200 IN-LBS

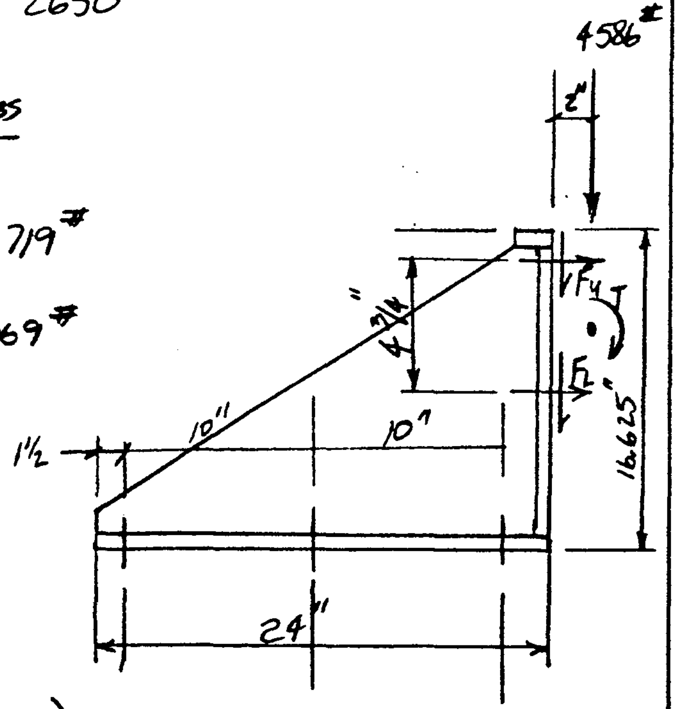
MAX TRANS. LOAD = 600#

MAX. LONG. LOAD = $\frac{5300^{\#}}{2}$ = 2650#

$$F_u = \frac{2650^{\#}}{2} + \frac{2''(4586^{\#})}{4.75''} + \frac{21{,}200\text{ IN-LBS}}{4.75''}$$

$$F_u = 1325^{\#} + 1931^{\#} + 4463^{\#} = 7{,}719^{\#}$$

$$F_L = 1325 - 1931 - 4463^{\#} = -5069^{\#}$$



SIZE BOLT

$F_u = 7{,}719^{\#}$

FOR 3/4" ϕ A307 BOLTS

ALLOWABLE TENSILE = 8,800#

(TABLE I-A, AISC, P 4-3)

BOLT SHEAR = $4586^{\#}/2$ = 2300#

SINGLE SHEAR ALLOWABLE FOR 3/4" ϕ = 4,400# (TABLE I-D, AISC, P 4-5)

SUBJECT	CBI OFFICE NOE	REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 37 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	10.37

COMBINED TENSION & SHEAR

(AISC J3-5)

A307 BOLTS

BOLT SHEAR = 2300# BOLT TENSION = 7719#

ASSUME SINGLE SHEAR

TRY 1" ϕ BOLTS @ THREADS IN SHEAR PLANE.

$A_K = .551 \text{ IN}^2$ $A_t = 0.606 \text{ IN}^2$ $A_D = .785 \text{ IN}^2$

$f_v = \frac{2300^{\#}}{.563 \text{ IN}^2} = 4,174 \text{ PSI}$

$F_t = 26,000 - 1.8 f_v = 18,486 \text{ PSI}$

$f_t = \frac{7719}{.6061} = 12,738 \text{ PSI} < F_t \quad \therefore \text{OK}$

(AISC J3-6)

$f_t = 12,738 \text{ PSI}$ $T_b = 0.7 F_u A_T = .7(60)(.606) = 25,452^{\#}$

$A_b = .785 \text{ IN}^2$

$F_v = (10,000 \text{ PSI})\left(1 - \frac{f_t A_b}{T_b}\right) = 6,069 \text{ PSI}$

$f_v = 4,085 \text{ PSI} < F_v \quad \therefore \text{OK}$

USE 1" ϕ A307 BOLTS

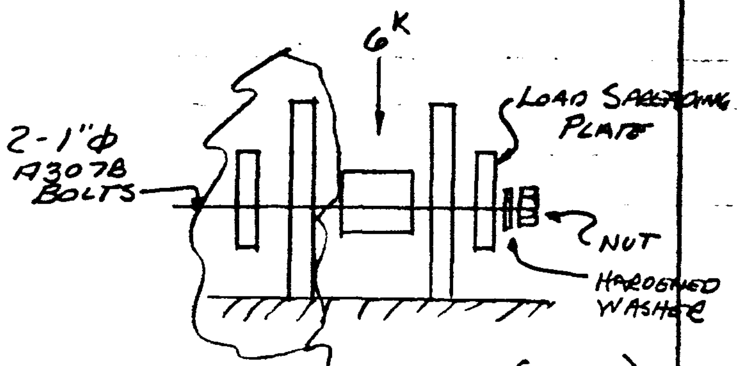
SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 93024
	MADE BY MRS	CHKD BY DDG	MADE BY -	CHKD BY	SHT 38 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	10.38

DESIGN FRICTION CONNECTION

LOADS ~

6^K VERT

1.2^K LATERAL



REVISED (REMOVED)

▷1 (ONLY 2 SLIP SURFACES)

$$\text{LOAD ON JOINT} = [6^2 + 1.2^2]^{.5}$$

$$\approx 6.2^k$$

$R_s = \mu_s F_p N M$ WHERE

R_s = SLIP RESISTANCE LOAD (lb)

μ_s = FRICTION COEFF

F_p = LOAD PER BOLT

N = NUMBER OF BOLTS

M = NUMBER OF SLIP SURFACES

NOW

$6200 = (.5)(F_p)(2)(2)$ ◁1

$F_p = 3100$ # ◁1

USE A307B BOLTS @ 20^{KSI} DESIGN STRESS ~ 1"φ x 8UNC

PRELOAD AT 20^{KSI} = 12.12 KIP

TORQUE TO ACHIEVE $20^{KSI} \approx 200$ FT-lb

SUMMARY

USE A307B BOLTS TORQUED TO 200 FT-lb. USE GOOD LUBRICANT SUCH AS LOCTITE NICKEL ANTI-SEIZE 771 ON THREADS AND BEARING SURFACE OF NUT. SLIP PLANES TO BE CLEAN AND DRY

NOTE: THIS CALCULATION EXCEEDS F_p x 7.8 TIMES. TORQUE, COEFF FRICTION &/OR NUMBER OF SLIP PLANES CAN BE REDUCED WHILE STILL MEETING THE LOAD REQUIREMENT

SUBJECT	OFFICE		REVISION 1		REFERENCE NO.
LIGO	CBI RDA				920212
FRICTION LOADING ON	MADE BY FAF	CHKD BY DDG	MADE BY MRS	CHKD BY DDG	SHT 39 OF 48
FIXED SUPPORT	DATE 2/23/94	DATE 4/6/94	DATE 3/7/94	DATE 4/6/94	10.39

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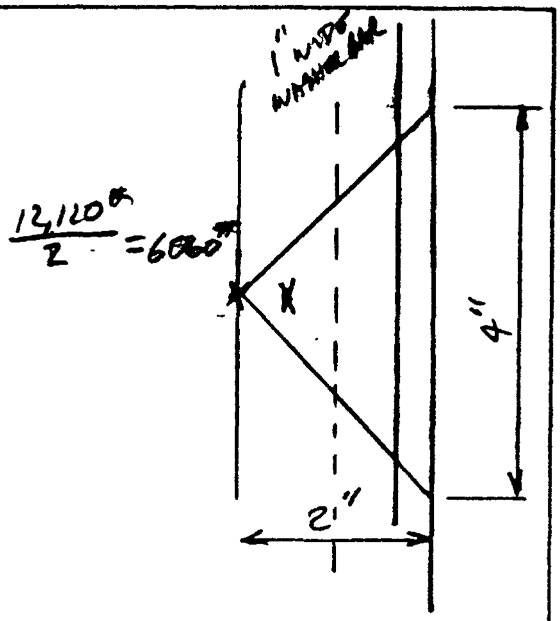
DESIGN VERTICAL GUIDE PLATES



$$M = 2''(6060) = 12,120 \text{ IN-LBS}$$

$$\sigma_{ALLOW} = .75(F_y) = .75(36,000) = 27,000 \text{ PSI}$$

$$S_{REQ'D} = M/\sigma_A = \frac{12,120}{27,000} = 0.449 \text{ IN}^3$$

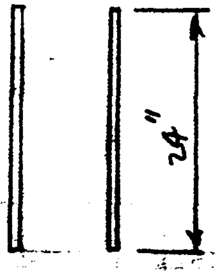
$$S = \frac{t^2 b}{6} \Rightarrow 0.449 = \frac{t^2(4)}{6}$$

$$t = 0.821''$$

USE 1" PLATE

DESIGN GUSSET PLATES

@ BASE $M = 21,200 \text{ IN-LBS} + 2650^{\#}(16.625 - 4.75/2)$
$M = 59,000. \text{ IN-LBS}$



$$S_{REQ'D} = \frac{M}{.6F_y} = \frac{59,000}{.6(36,000)} = 2.73 \text{ IN}^3$$

$$2.73 = \frac{t^2(24)}{6}(2)$$

$t = .584''$ USE 5/8" PL

SUBJECT	CBI OFFICE NOE	REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 40 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	10.40

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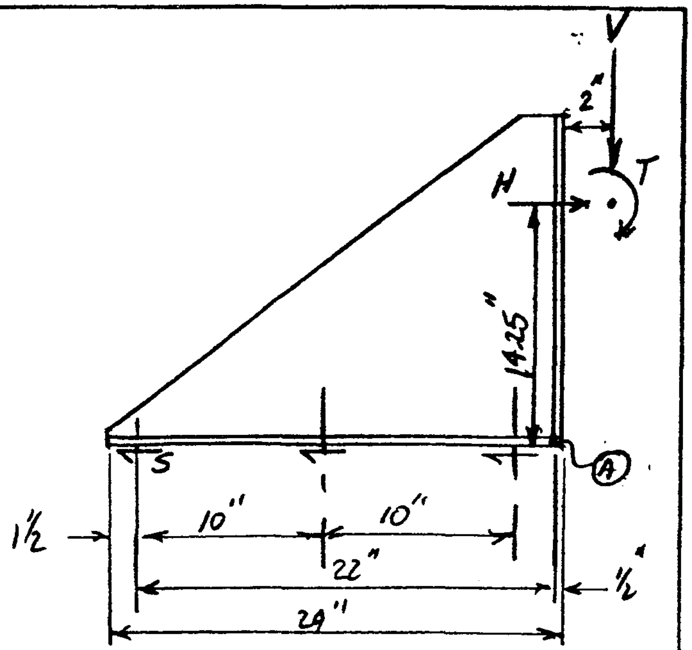
ANCHORAGE DESIGN

LOAD COMB. #4



V = 4586#

$H = \frac{5300\#}{2} = 2650\#$

T = 21,200 IN-LBS

ΣM@ A = 0

25"(4586#) + 21,200 IN-LBS + 14.25"(2650#) − 2P(22") = 0

P = 1600#/BOLT

MAXIMUM SHEAR (S) = 2650#/6 BOLTS = 442#/BOLT

TRY 5/8" Φ HILTI EXPANSION ANCHORS KB-II

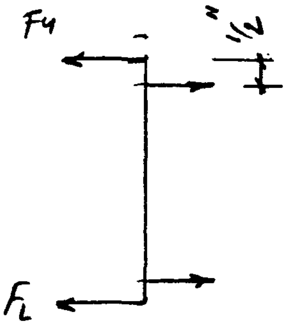
ASSUME 4" THICK 3000# CONCRETE

PALLOW = 1750# > P ∴ OK
(ASSUMES UBC SPECIAL INSPECTION)

SALLOW = 2875# > S ∴ OK

DESIGN TUBE BEARING PLATE

BOLT PRELOAD $= 12.2^{K}$



MOMENT $= 12.2^{k}(.5") = 6{,}100$ IN-LBS

TRY $1" \times 3"$ BAR

$$S = \frac{bt^2}{6} = \frac{3(1)^2}{6} = .5$$

$$f_b = \frac{M}{S} = \frac{6{,}100 \text{ IN-LBS}}{.5"} = 12{,}200 \text{ PSI} < .75F_y = 27{,}000 \text{ PSI}$$

SUBJECT	CBI OFFICE DDG		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 42 OF 48
	DATE 3/7/94	DATE 4/6/94	DATE	DATE	10.42

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CHECK TUBE FOR CONCENTRATED LOADS

P_{MAX} = (BOLT AREA) x (BOLT YIELD STRESS)

$P_{MAX} = (.785\,IN^2)(36{,}000\,PSI) = 28{,}275^{\#}$

(AISC K1.3)

$$\frac{R}{t\,(N+5k)} \le 0.66F_y = 23{,}760\,PSI$$

4x4x3/8 TUBE OK

$R = 28{,}275^{\#}$ $t = 0.375''$ $N = 3''$ $k = 2(.375'') = .75''$

$$\frac{R}{t(N+5k)} = \frac{28{,}275^{\#}}{.375''(3''+5(.75''))} = 11{,}170\,PSI < .66F_y \therefore OK$$

(AISC K1.4)

$$R = 67.5\,t_w^2\left[1+3\left(\frac{N}{d}\right)\left(\frac{t_w}{t_f}\right)^{1.5}\right]\sqrt{F_{yw}\,(t_f/t_w)}$$

$$R = (67.5)(.375)^2\left[1+3\left(\frac{3}{4}\right)\left(\frac{.375}{.375}\right)^{1.5}\right]\sqrt{(36\,KSI)(.375/.375)}$$

$R = 185^k > 28.275^k \therefore$ 4x4x3/8 TUBE OK

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 43 OF 48
	DATE 3/7/94	DATE 4/6/94	DATE	DATE	10.43

BASE PLATE DESIGN

P_{MAX} ON 1" SLOTTED PLATE

↙ DUE TO ECCENTRIC LOADS (SEE A.B. CALC SHEET)

$$P_{MAX} = 2(1600^{\#}) + \frac{6064^{\#}}{2} = 6232^{\#}$$

LET ALLOWABLE BEARING ON CONCRETE = 750 PSI

$$\text{AREA REQ'D} = \frac{6232^{\#}}{750} = 8.31 \text{ IN}^2$$

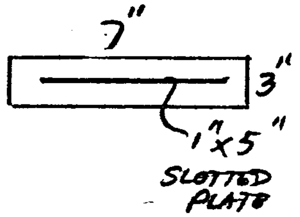
BASE WIDTH = 5" MIN.

$$\text{PLATE LENGTH} = \frac{8.31 \text{ IN}^2}{5"} = 1.66"$$

CHECK PUNCHING ON 4" SLAB OF CONCRETE

(ACI 318-89 11.12)

ASSUME 1" WIDE BASE PL ALL AROUND



$\beta = 7/3 = 2.33$ $\qquad f'_c = 3000 \text{ PSI}$

$$V_c = (2 + 4/\beta)\sqrt{f'_c}\, b_o d$$

$b_o = 2(7+3) = 20"$ $\qquad d = 4"$

$$V_c = 3.71\sqrt{3000}\,(20)(4) = 16,274^{\#}$$

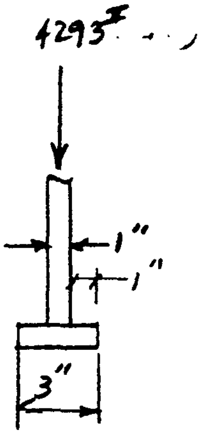
$$V_n = \phi V_c = .85(16,274^{\#}) = 13,833^{\#}$$

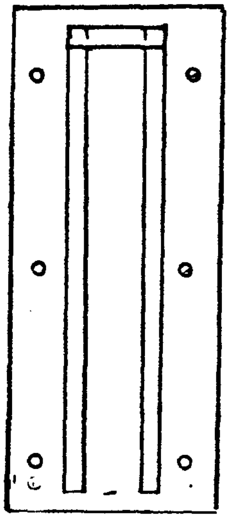
$$U = (6232^{\#})(1.7) = 10,594^{\#} < V_n \quad \therefore \quad OK$$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 93021N
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 44 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	10.44

BASE PLATE THICKNESS

VERTICAL DOWN LOAD





$$w = \frac{6232^{\#}}{(7")(3")} = 297\,PSI$$

$$M = \frac{wL^2(5)}{2} = \frac{297(1")^2(5)}{2} = 743\text{ IN-LBS}$$

$$\sigma = M/S = \frac{6M}{t^2 b} \leq 0.75F_y$$

$$\sigma = \frac{6(743\text{ IN-LBS})}{t^2(5)} \leq 27{,}000\text{ PSI}$$

$$t' = 0.182"$$

PULL OUT LOAD

MAX. ALLOWABLE PULLOUT LOAD OF EXPANSION ANCHOR = 3290#

ACTUAL PULL OUT LOAD = 1341#

$$M = 1.5"(3290^{\#}) = 4{,}935\text{ IN-LBS}$$

ASSUME 3" OF BASE PLATE RESISTS BENDING $S = \frac{t^2 3}{6} = \frac{t^2}{2}$

$$t = \sqrt{\frac{2M}{.75F_y}} = \sqrt{\frac{2(4935)}{27000}} = 0.605"$$

USE 5/8" PLATE (MIN)

SUBJECT	CBI OFFICE NDE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 45 OF 48
	DATE 2/23/94	DATE 4/6/94	DATE	DATE	10.45

Printed In USA

GO 64 REV SEP 84

WELD DESIGN

LUGS TO RING

$P_{max} \approx 6000^{\#}$

ALLOWABLE LOAD PER INCH OF WELD FOR 1/16" WELD

$f_{WA} = 600 \,{}^{\#}/IN$

ASSUME 4 WELDS @ 3" EA.

$f_W = 6000^{\#}/12'' = 500^{\#}/IN$

USE MIN. SIZE WELDS 3/16"

VERTICAL TUBE TO HORIZONTAL TUBE

$P_{MAX} = 6000^{\#}$ USE 3/16" ALL AROUND

$F = 16''(600^{\#})(3) = 28,800^{\#}$

LONGITUDINAL LUG ON BEAM TUBE WALL TO LONGIT. GUSSET

$P = 5300^{\#}$ $L = 18''$

$P/L = \frac{5300^{\#}}{18} = 294^{\#}/IN$ USE 1/8" WELD

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 46 OF 48
	DATE 2/24/94	DATE 4/6/94	DATE	DATE	10.46

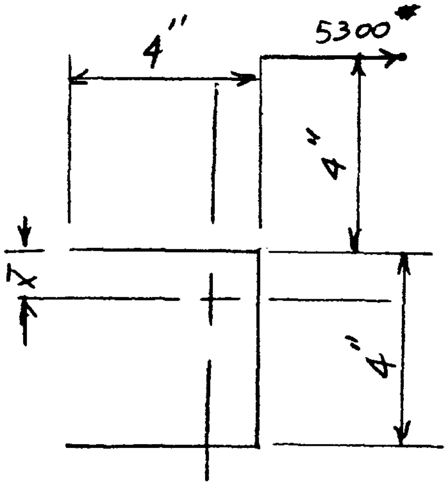
Printed In USA

GO 64 REV SEP 84

HORIZONTAL RESTRAINT TO HORIZONTAL TUBE

$M_x = 5''(5300^{\#}) = 26{,}500$ in-lbs $M_y = 4''(600^{\#}) = 2400$ in lbs

$V = 5300^{\#}$ $V = 600^{\#}$



WELD OUTLINE

$L_w = (12'')(2) = 24''$

$J_w = (58.7\,in^3)(2) = 117.3\,in^3$

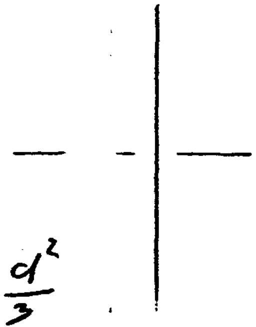
$f_{w_B} = \frac{V}{L_w} - \frac{(M_x)(2'')}{J_w}$, $f_{w_T} = \frac{V}{L_w} + \frac{M_x(2')}{J_w}$

$f_{w_T} = \frac{5300}{24} + \frac{(26{,}500)(2')}{117.3} = 673$ #/in

$f_{w_B} = \frac{5300}{24} - \frac{26{,}500(2)}{117.3} = -231$ #/in

$SIZE = \frac{673^{\#}/in}{(9600^{\#}/in/in)\left(\frac{19.2}{30}\right)} = 0.110''$

USE 3/16" FILLETS



$f_{wy} = \frac{V}{L_w} + \frac{M_y}{S}$

$f_{wy} = \frac{600}{6''} + \frac{2400}{6\,in^2} = 500$ #/in

3/16" FILLETS OK

$S = \frac{d^2}{3}$

$S = \frac{6^2}{6} = 6\,in^2$

$L_w = 6''$

SUBJECT	CBI OFFICE NOE	REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 47 OF 48
	DATE 2/28/94	DATE 4/6/94	DATE	DATE	10.47

DESIGN SUPPORT LUG ASSEMBLY WELDS

MAX BOLT LOAD ON ONE 1" ℞ = 12,200#

ASSUME 4" OF ℞ & WELD RESIST LOAD

$f_w = \frac{12200\#}{4} = 3050.\ \#/in$

SIZE IN 1/16" $= \frac{3050}{600} = 5.1\left(\frac{1}{16}\text{THS}\right)$

USE 3/8" WELD ONE SIDE

GUSSET ℞S TO BASE ℞

$V = 5300\#/2 = 2650\#$ $P = 6000\#$

$M = 59000$ IN-LBS LAT. LOAD $= 600\#$

$S_w = \frac{24^2}{3} = 192$ $L_w = 2(24") = 48"$

$$f_w = \sqrt{\left(\frac{P}{L_w} + \frac{M}{S_w}\right)^2 + \left(\frac{V}{L_w}\right)^2 + \left(\frac{\text{LAT LOAD}}{L_w}\right)^2}$$

$f_w = 436\ \#/in$

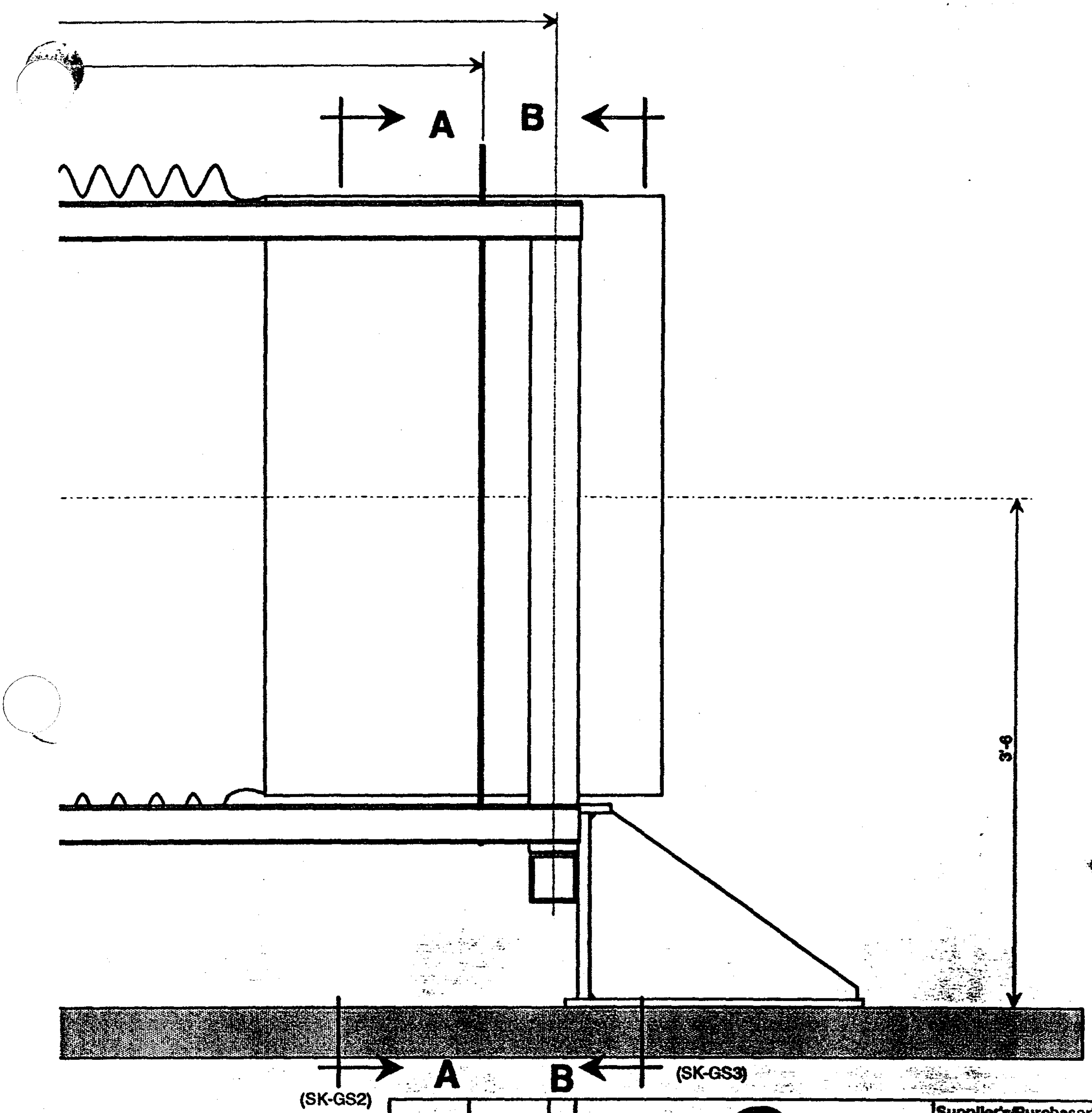
SIZE IN 1/16" $= \frac{436}{600} = .727$

USE 5/16" ONE SIDE

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 48 OF 48
	DATE 2/25/94	DATE 4/6/94	DATE	DATE	10.48

Printed In USA

GO 64 REV SEP 84



VIEW

▷ indicates change from previous issue

By	Chkd	Date	By	Chkd	Date	Revisions

Remarks

Supplier's/Purchaser's No

CBI

BEAM TUBEGUIDED SUPPORT
ELEVATION VIEW
LIGO

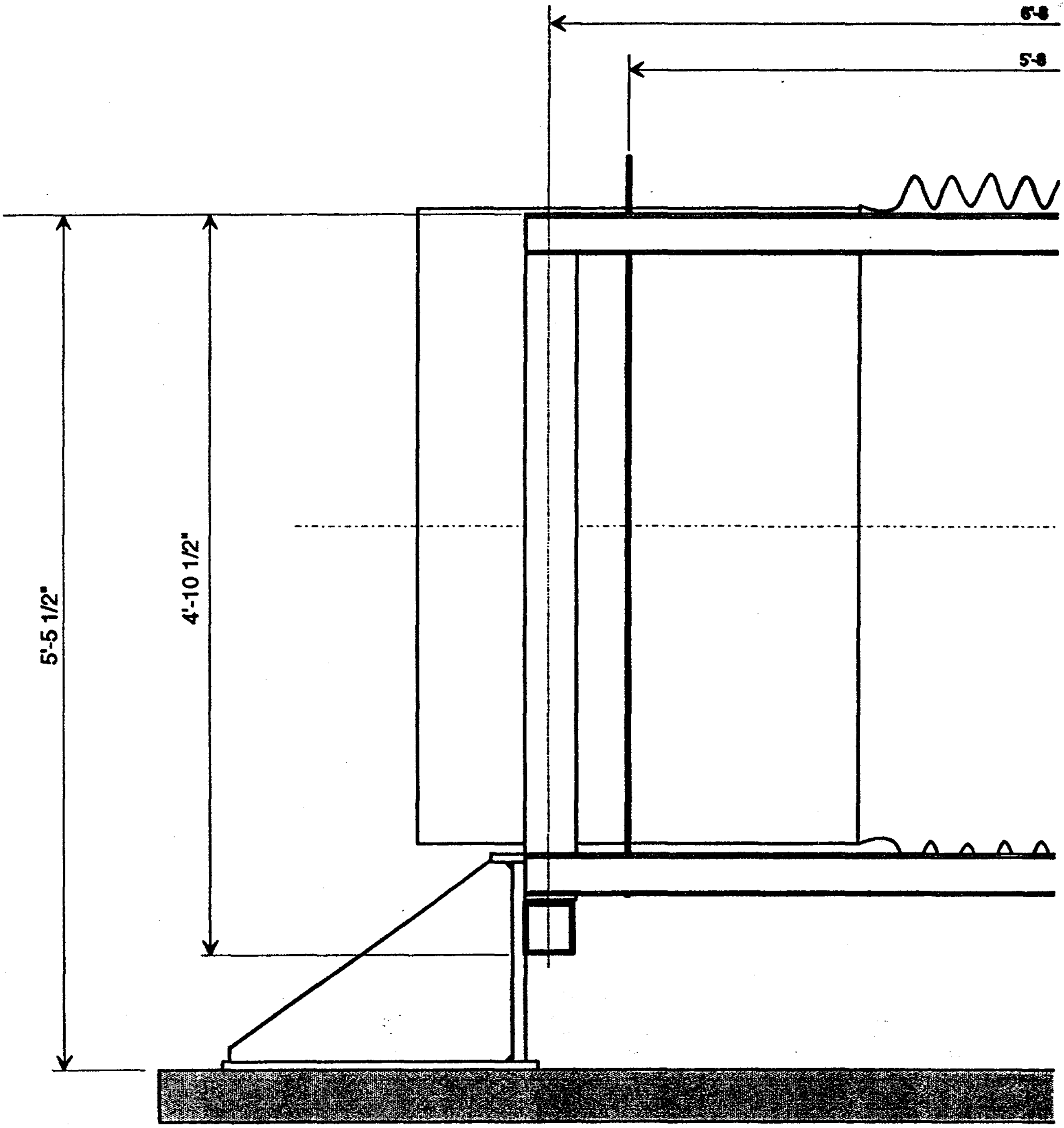
Customer's No.
By MRS Chkd DDG Date 3/3/94

Engineering Supervisor

Contract No. 930212

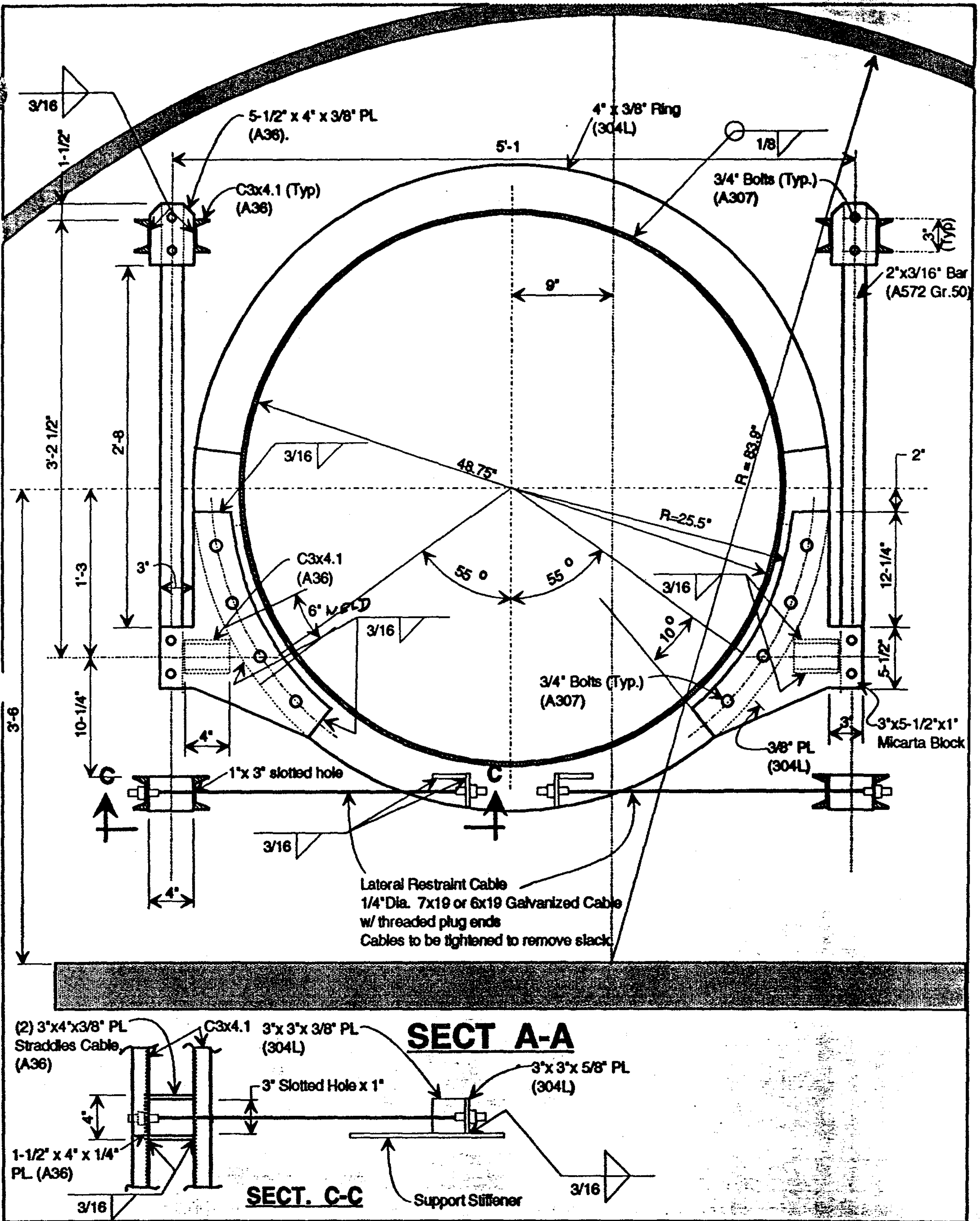
Drawing No. SK-GS1

Rev.



ELEVATION

SK-GS1



SUBJECT

HANGER ASSEMBLY
BEAM TUBE GUIDED SUPPORT
LIGO

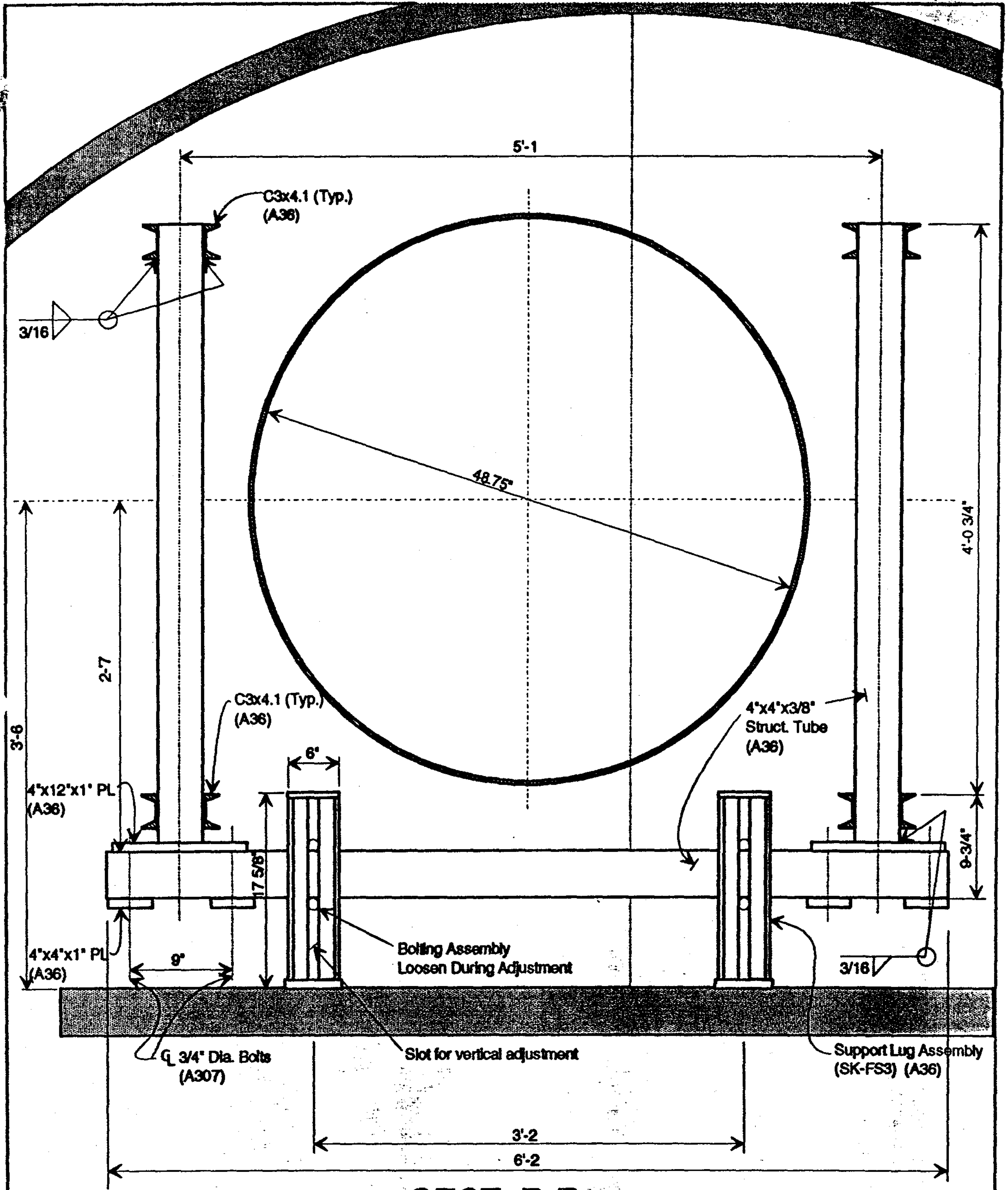
CBI **OFFICE**

REVISION: 1

REFERENCE NO. 930212

MADE	**CHK'D**	**MADE**	**CHK'D**	**SHT** 3 **OF** 35
MRS	DDG	MRS	DDG	
DATE	**DATE**	**DATE**	**DATE**	**SK - GS2**
3/3/94	4/6/94	3/7/94	4/6/94	

11.3



SECT B-B

SUBJECT	CBI OFFICE		REVISION:		REFERENCE NO. 930212
OUTER FRAME ASSEMBLY BEAM TUBE GUIDED SUPPORT LIGO	MADE MRS	CHK'D DDG	MADE MRS	CHK'D DDG	SHT 4 OF 35
	DATE 3/3/94	DATE 4/6/94	DATE 3/8/94	DATE 4/6/94	SK - GS3

Load Case	Guided Support Loads, Total	Magnitude		Direction	Comments
1	DL (Metal Wt + Insul'n)	5,100	lbs	down	(per RISA-2D analysis for continuous beam system)
2	Axial Seismic Load	0	lbs	axial	(assumes fixed support takes all axial loads
3	Lateral Seismic Load	1,130	lbs	lateral	(~ 18% * 90 plf * 65 ft), assumes guided support takes lateral loads
4	Axial BakeOut Load	0	lbs	axial	(assumes taken by fixed support)
5	Axial Contraction Load	0	lbs	axial	(assumes taken by fixed support)
6	Axial Extension Load	0	lbs	axial	(assumes taken by fixed support)
7	Vertical Stability Load	600	lbs	down	(assumed)
8	Lateral Stability Load	600	lbs	lateral	(assumes guided support takes lateral loads)

Comb'n	Load Combination	Vert Load	Axial Load	Lateral Load	Stress Increase
1	DL + Vertical Stability	5,700	0	0	1.000
2	DL + Axial EQ + Axial Ext'n + Vert Stability + Lat Stability	5,700	0	600	1.333
3	DL + Lat EQ + Axial Ext'n + Vert Stability + Lat Stability	5,700	0	1,730	1.333
4	DL + Axial BakeOut + Vert Stability + Lat Stability	5,700	0	600	1.000

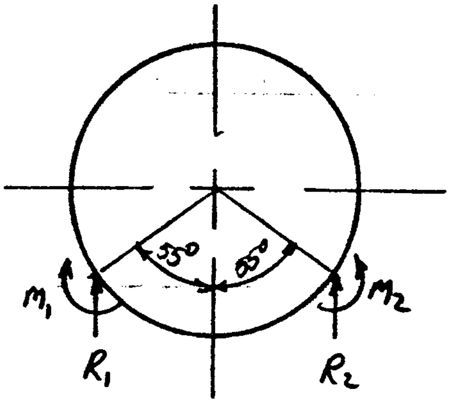
AXIAL MOVEMENT - 3.25 EXP. JT. CONTRACTION

1.63 EACH HANGER

11.5

SHELL RING DESIGN

LOAD COMBINATION #1



VERTICAL LOAD = 5700# ACTING 9.5" OUTSIDE RING CENTROID @ θ = 55°

$R_1 = R_2 = \frac{5700^{\#}}{2} = 2850^{\#}$

$M_1 = M_2 = 2850^{\#}(9.5'') = 27,075$ IN-LBS

RADIAL LOAD (P) = $R \cos 55° = 2850^{\#}(.5736) = 1635^{\#}$

TANGENT LOAD (T) = $R \sin 55° = 2850^{\#}(.8192) = 2335^{\#}$

$M/R = \frac{27,075 \text{ IN-LBS}}{26.07''} = 1038.6^{\#}$

USE SAME RING AS FIXED SUPPORT 4" x 3/8"

$A = 1.897 \text{ IN}^2$ $C_1 = 1.695''$ $C_2 = 2.432''$ $R = 26.07''$

$I = 3.34 \text{ IN}^4$ $S_1 = 1.97 \text{ IN}^3$ $S_2 = 1.37 \text{ IN}^4$

OUTPUT PROGRAM E0405A
@ 55°

$V = (899.4 \text{ PSI})(1.897 \text{ IN}^2) = 1,706^{\#}$

$T = (918.45 \text{ PSI})(1.897 \text{ IN}^2) = -1,743^{\#}$

$M = 22,155$ IN-LBS

SUBJECT LIGO BEAM TUBE GUIDED SUPPORT DESIGN	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 6 OF 35
	DATE 3/1/94	DATE 4/6/94	DATE	DATE	11.6

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PROGRAM E0405A (STD 9110-1-2)  [ IBM RS/6000 ]
STRESS AND STRAIN COEFFICIENTS FOR CIRCULAR RINGS
REVISION 11 - JANUARY 7, 1992


S     TANDARDS 9110-1-1 AND 9110-1-2

GUIDE SUPPORT LOAD COMBINATION #1 - 2 PT. AT 55 DEG.


   N(R)    N(T)    N(M)    DATA SHEET NO.    PLOT CODE
     2       2       2           1               0


  RADIUS     MOD-ELAS     MOM-INER       AREA        C(1)        C(2)
   26.07 28000000.00       3.34        1.90        1.70        2.43

EQUILIBRIUM LOADS        FV         FH         M/R
           INPUT  5700.000       .000       .000
        COMPUTED  5701.035       .000       .000

INPUT LOADS AND THEIR LOCATIONS

RADIAL LOADS AND ANGLES

     LOADS          1635.00    1635.00
     ANGLES           55.00     305.00

TANGENTIAL LOADS AND ANGLES

     LOADS         -2335.00    2335.00
     ANGLES           55.00     305.00

MOMENT LOADS/R AND ANGLES

     LOADS          1038.60   -1038.60
     ANGLES           55.00     305.00

UNIT STRESS VALUES FOR CIRCULAR RINGS

PRINTOUT AT EQUAL ANGLE INCREMENTS

     X      V/A         T/A      M(FORCE-LG)    THETA          DR          DC
    .00  0.0000E+00 -1.1100E+02 -5.6890E+03  0.0000E+00  1.4832E-02  0.0000E+00
   5.00  9.5688E+00 -1.0694E+02 -5.6682E+03 -1.3823E-04  1.4619E-02 -1.2882E-03    5
  10.00  1.8431E+01 -9.4822E+01 -5.6074E+03 -2.7545E-04  1.3981E-02 -2.5391E-03   10
  15.00  2.5889E+01 -7.4812E+01 -5.5112E+03 -4.1076E-04  1.2926E-02 -3.7161E-03   15
  20.00  3.1267E+01 -4.7206E+01 -5.3870E+03 -5.4336E-04  1.1468E-02 -4.7834E-03   20
  25.00  3.3918E+01 -1.2403E+01 -5.2452E+03 -6.7271E-04  9.6254E-03 -5.7065E-03   25
  30.00  3.3237E+01  2.9088E+01 -5.0990E+03 -7.9852E-04  7.4192E-03 -6.4527E-03   30
  35.00  2.8665E+01  7.6659E+01 -4.9639E+03 -9.2088E-04  4.8745E-03 -6.9915E-03   35
  40.00  1.9701E+01  1.2961E+02 -4.8579E+03 -1.0403E-03  2.0180E-03 -7.2944E-03   40
  45.00  5.9105E+00  1.8714E+02 -4.8008E+03 -1.1576E-03 -1.1228E-03 -7.3355E-03   45
  50.00 -1.3070E+01  2.4840E+02 -4.8144E+03 -1.2744E-03 -4.5209E-03 -7.0910E-03   50
  55.00 -8.9941E+02 -9.1845E+02  2.2155E+04 -1.3926E-03 -8.1512E-03 -6.5397E-03   55
  60.00 -8.1898E+02 -9.2305E+02  1.8447E+04 -8.9948E-04 -1.1277E-02 -5.6833E-03   60
      ) -7.3862E+02 -9.1699E+02  1.5086E+04 -4.9232E-04 -1.3295E-02 -4.6037E-03   65
      0 -6.5923E+02 -9.0087E+02  1.2070E+04 -1.6271E-04 -1.4375E-02 -3.3902E-03   70
  75.00 -5.8166E+02 -8.7540E+02  9.3929E+03  9.7666E-05 -1.4677E-02 -2.1174E-03   75
  80.00 -5.0669E+02 -8.4139E+02  7.0455E+03  2.9696E-04 -1.4347E-02 -8.4686E-04   80
  85.00 -4.3503E+02 -7.9972E+02  5.0147E+03  4.4302E-04 -1.3516E-02  3.7207E-04   85
  90.00 -3.6731E+02 -7.5132E+02  3.2848E+03  5.4338E-04 -1.2303E-02  1.5010E-03   90
  95.00 -3.0407E+02 -6.9721E+02  1.8378E+03  6.0513E-04 -1.0814E-02  2.5114E-03   95
                                                         -8.1400E-03  3.3831E-03  100
```

11.7

```
110.00 -1.4529E+02 -5.1116E+02 -1.0185E+03  6.2252E-04 -5.5369E-03  4.6663E-03 110
115.00 -1.0357E+02 -4.4487E+02 -1.5535E+03  5.9087E-04 -3.7282E-03  5.0703E-03 115
120.00 -6.7658E+01 -3.7828E+02 -1.9209E+03  5.4829E-04 -1.9762E-03  5.3186E-03 120
125.00 -3.7529E+01 -3.1244E+02 -2.1458E+03  4.9857E-04 -3.1486E-04  5.4178E-03 125
130.00 -1.3075E+01 -2.4840E+02 -2.2530E+03  4.4485E-04  1.2308E-03  5.3770E-03 130
1[illegible]0  5.9058E+00 -1.8715E+02 -2.2665E+03  3.8971E-04  2.6429E-03  5.2069E-03 135
[illegible]0  1.9697E+01 -1.2961E+02 -2.2095E+03  3.3515E-04  3.9098E-03  4.9199E-03 140
1[illegible].00  2.8661E+01 -7.6664E+01 -2.1035E+03  2.8261E-04  5.0250E-03  4.5289E-03 145
150.00  3.3234E+01 -2.9094E+01 -1.9684E+03  2.3304E-04  5.9858E-03  4.0474E-03 150
155.00  3.3916E+01  1.2397E+01 -1.8222E+03  1.8693E-04  6.7921E-03  3.4887E-03 155
160.00  3.1264E+01  4.7200E+01 -1.6805E+03  1.4435E-04  7.4460E-03  2.8664E-03 160
165.00  2.5887E+01  7.4806E+01 -1.5563E+03  1.0502E-04  7.9502E-03  2.1935E-03 165
170.00  1.8429E+01  9.4815E+01 -1.4600E+03  6.8402E-05  8.3077E-03  1.4831E-03 170
175.00  9.5682E+00  1.0694E+02 -1.3992E+03  3.3702E-05  8.5210E-03  7.4773E-04 175
180.00  0.0000E+00  1.1100E+02 -1.3784E+03  0.0000E+00  8.5919E-03  0.0000E+00 180
180.00  0.0000E+00  1.1100E+02 -1.3784E+03  0.0000E+00  8.5919E-03  0.0000E+00 180

PRINTOUT AT LOAD AND/OR MOMENT POINTS

 55.00 -8.9941E+02 -9.1845E+02  2.2155E+04 -1.3926E-03 -8.1512E-03 -6.5397E-03  55
 54.99 -3.7469E+01  3.1231E+02 -4.9212E+03 -1.3924E-03 -8.1438E-03 -6.5411E-03  55
305.00  3.7524E+01  3.1244E+02 -4.9215E+03  1.3926E-03 -8.1512E-03  6.5397E-03 305
304.99  8.9925E+02 -9.1847E+02  2.2147E+04  1.3916E-03 -8.1587E-03  6.5382E-03 305

PRINTOUT OF MAXIMUM AND MINIMUM VALUES OF SHEAR, THRUST, AND MOMENT
VALUES TAKEN FROM BOTH OF THE TABLES ABOVE

MAXIMUM V/A=             8.9925E+02   AT  304.99  DEGREES
MINIMUM V/A=            -8.9941E+02   AT   55.00  DEGREES
MAXIMUM T/A=             3.1244E+02   AT  305.00  DEGREES
MINIMUM T/A=            -9.2305E+02   AT   60.00  DEGREES
[illegible]UM M(FORCE-LG)=   2.2155E+04   AT   55.00  DEGREES
[illegible]UM M(FORCE-LG)=  -5.6890E+03   AT     .00  DEGREES


PRINTOUT OF MAXIMUM AND MINIMUM (AXIAL + BENDING) STRESSES FOR MOMENT
ARMS OF C1 AND C2 - VALUES TAKEN FROM BOTH OF THE TABLES ABOVE

MAXIMUM STRESS (C1)=   1.0325E+04   AT   55.00  DEGREES
MINIMUM STRESS (C1)=  -2.9981E+03   AT     .00  DEGREES
MAXIMUM STRESS (C2)=   4.0314E+03   AT     .00  DEGREES
MINIMUM STRESS (C2)=  -1.7050E+04   AT   55.00  DEGREES
STOP [SYSIN]
```

DDG 4/6/94

11.8

USING $4" \times 3/8"$ STIFFENER RING

MAXIMUM STRESS IN SHELL = 10,325 PSI @ 55°

MINIMUM STRESS IN SHELL = -2,998 PSI @ 0°

MAXIMUM STRESS IN STIFFENER BAR = 4,031 PSI @ 0°

MINIMUM STRESS IN STIFFENER BAR = -17,050 PSI @ 55°

TRY INCREASING THE RING TO 6" WIDE $\times 3/8"$

$A = 2.647 \text{ IN}^2$ $\quad I = 9.92 \text{ IN}^4$ $\quad C1 = 2.668"$

$C2 = 3.459"$ $\quad S_1 = 3.72 \text{ IN}^3$ $\quad S_2 = 2.87 \text{ IN}^3$

$16t = 16(.375") = 6"$

$$f = \frac{T}{A} \pm M/S$$

$$f_{@55°} = \frac{-1743^{\#}}{2.647"} - \frac{22{,}155 \text{ IN-LBS}}{287 \text{ IN}^3} = 658 + 7{,}720$$

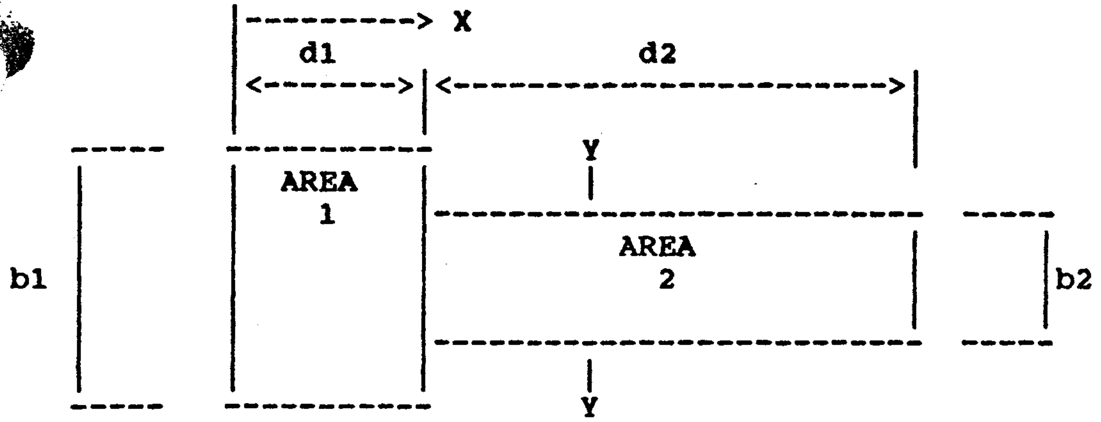
$f = 8{,}378$ PSI

$FA = .6F_y = .6(25{,}000 \text{ PSI}) = 15{,}000$ PSI

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 9 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.9

Printed in USA GO 84 REV SEP 84

MOMENT OF INERTIA CALCULATION



	1	2	3	4	5	6	7
d	0.127	6					
b	3.125	0.375					
X	0.0635	3.1270	6.1270	6.1270	6.1270	6.1270	6.1270
THETA	0	0	0	0	0	0	0

	AREA	X	AX	AX^2	Io
1	0.397	0.064	0.03	0.00	0.00
2	2.250	3.127	7.04	22.00	6.75
3	0.000	6.127	0.00	0.00	0.00
4	0.000	6.127	0.00	0.00	0.00
5	0.000	6.127	0.00	0.00	0.00
6	0.000	6.127	0.00	0.00	0.00
7	0.000	6.127	0.00	0.00	0.00
	2.647		7.06	28.75	

TOTAL DEPTH = 6.1270 in.

CENTROID $(\bar{X})$ = SUM(AX)/SUM(AREA) = 2.668 in.

I(total)= $[\mathrm{SUM}(AX^2)+\mathrm{SUM}(Io)]-(\mathrm{AREA})(\bar{X})^2$ = 9.92 $\mathrm{in.}^4$

C1 = $\bar{X}$ = 2.668 in. C2 = DEPTH - $\bar{X}$ = 3.459 in.

Sy1 = I/C1 = 3.72 $\mathrm{in.}^3$ Sy2 = I/C2 = 2.87 $\mathrm{in.}^3$

Radius of gyration (r) = $(I/A)^{1/2}$ = 1.936 in.

Torsional constant (J) = in^4

BJECT TION PROPERTIES 6" X 3/8" STIFFENER FIXED SUPPORT SHELL RING LIGO BEAM TUBE	MADE BY: MRS CHKD BY: DDG DATE: 3/01/94	R E V	MADE BY: CHKD BY: DATE:	REFERENCE NO. 93021✓ SHT 10 OF 35

CHECK 4" x 3/8" RNG @ 90°

$T/A = -751$ PSI

$M = 3{,}285$ IN-LBS

$$f = -751\text{ PSI} - \frac{3{,}285\text{ IN-LBS}}{1.37\text{ IN}^3} = -3{,}149\text{ PS}$$

$F_A = 19{,}000$ PSI

CHECK 4 x 3/8 RNG @ 40°

$T/A = 130$ PSI

$M = -4858$ IN-LBS

$f_1 = T/A + M/S_1 \qquad f_2 = T/A - M/S_2$

$$f_1 = 130 + \frac{-4858}{1.97} = -2336\text{ PSI}$$

$$f_2 = 130 - \frac{-4858}{1.37} = 3{,}676\text{ PSI}$$

$F_A = 15{,}000$ PSI

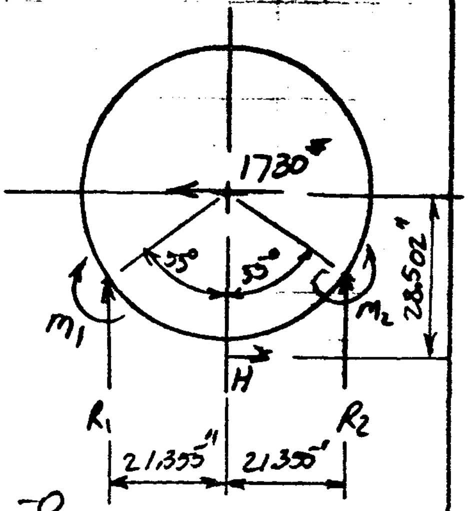
SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 93-0212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 11 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.11

LOAD COMBINATION #3

VERTICAL LOAD = 5700#

LATERAL LOAD = 1,730#

$H = 1730^{\#}$



VERTICAL LOADS DUE TO SEISMIC

$\sum M_{@H} = 0$

$(1730^{\#})(28.502") - (21.355")R_1 + (21.355")R_2 - m_1 + m_2 = 0$

$m_1 = 9.5\,R_1 \qquad m_2 = 9.5\,R_2$

$R_2 = -R_1$

$R_1 = R_2 = 799^{\#}$

VERTICAL LOAD DUE TO DL + VERT. STABILITY

$R_1 = R_2 = \frac{5700^{\#}}{2} = 2850^{\#}$

$R_1 = 2850^{\#} + 799^{\#} = 3649$

$R_2 = 2850^{\#} - 799^{\#} = 2051$

$m_1 = (3649)(9.5") = 34,666$ IN-LBS

$m_2 = (2051)(9.5") = 19,485$ IN-LBS

MOMENT AT INVERT $(M_0) = (4.127" - 1.695")(1730^{\#}) = 4,208$ IN-LBS

SUBJECT	OFFICE		REVISION		REFERENCE NO.
	CBI NOE				930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 12 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.12

Printed in USA

GO 64 REV SEP 84

INPUT INTO CBI COMPUTER PROGRAM E0405A

2 RADIAL LOADS AT 55° & 305°

$P_{55} = (3649^{\#}) \cos 55^\circ = 2,093^{\#}$

$P_{305} = (2051^{\#}) \cos 55^\circ = 1176^{\#}$

3 TANGENT LOADS @ 0°, 55° & 305°

$T_0 = 1730^{\#}$

$T_{55} = (-3649) \sin 55^\circ = -2989^{\#}$

$T_{305} = (2051) \sin 55^\circ = 1680^{\#}$

3 MOMENT LOADS @ 0°, 55° & 305°

$M_0/R = \frac{-4208 \text{ IN-LBS}}{26.07''} = -161.4^{\#}$

$\frac{M_{55}}{R} = \frac{34,666 \text{ IN-LBS}}{26.07''} = 1330^{\#}$

$M_{305}/R = \frac{-19,485 \text{ IN-LBS}}{26.07''} = -747^{\#}$

4" x 3/8" RING

$R = 26.07''$ $E = 28,000,000 \text{ PSI}$ $I = 3.39 \text{ IN}^4$

$A = 1.897 \text{ IN}^2$ $C_1 = 1.695''$ $C_2 = 2.432''$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 13 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.13

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PROGRAM E0405A (STD 9110-1-2)  [ IBM RS/6000 ]
STRESS AND STRAIN COEFFICIENTS FOR CIRCULAR RINGS
REVISION 11 - JANUARY 7, 1992


S    STANDARDS 9110-1-1 AND 9110-1-2

GUIDE SUPPORT LOAD COMBINATION #3 - 2 PT. AT 55 DEG.


   N(R)    N(T)    N(M)    DATA SHEET NO.    PLOT CODE
    2       3       3            1               0


  RADIUS    MOD-ELAS    MOM-INER       AREA        C(1)        C(2)
   26.07 28000000.00       3.34        1.90        1.70        2.43

EQUILIBRIUM LOADS        FV         FH          M/R
          INPUT  5700.000   1730.000         .000
       COMPUTED  5699.642   1730.351         .600

INPUT LOADS AND THEIR LOCATIONS

RADIAL LOADS AND ANGLES

    LOADS          2093.00    1176.00
    ANGLES           55.00     305.00

TANGENTIAL LOADS AND ANGLES

    LOADS          1730.00   -2989.00    1680.00
    ANGLES             .00      55.00     305.00

MOMENT LOADS/R AND ANGLES

    LOADS          -161.40    1330.00    -747.00
    ANGLES             .00      55.00     305.00

UNIT STRESS VALUES FOR CIRCULAR RINGS
                                                                 11.14
PRINTOUT AT EQUAL ANGLE INCREMENTS

   X      V/A         T/A      M(FORCE-LG)    THETA         DR          DC
   .00  2.7303E+02  3.4510E+02 -7.7916E+03 -3.5152E-04  1.4830E-02 -4.3481E-03
  5.00  2.4291E+02  3.4595E+02 -6.6782E+03 -5.2726E-04  1.3391E-02 -5.5832E-03   5
 10.00  2.1250E+02  3.5161E+02 -5.6953E+03 -6.7749E-04  1.1481E-02 -6.6716E-03  10
 15.00  1.8140E+02  3.6214E+02 -4.8450E+03 -8.0543E-04  9.1667E-03 -7.5752E-03  15
 20.00  1.4916E+02  3.7751E+02 -4.1312E+03 -9.1433E-04  6.5145E-03 -8.2616E-03  20
 25.00  1.1537E+02  3.9759E+02 -3.5598E+03 -1.0076E-03  3.5835E-03 -8.7041E-03  25
 30.00  7.9635E+01  4.2218E+02 -3.1382E+03 -1.0887E-03  4.2769E-04 -8.8805E-03  30
 35.00  4.1566E+01  4.5096E+02 -2.8758E+03 -1.1616E-03 -2.9057E-03 -8.7736E-03  35
 40.00  8.1767E-01  4.8353E+02 -2.7833E+03 -1.2300E-03 -6.3768E-03 -8.3694E-03  40
 45.00 -4.2922E+01  5.1941E+02 -2.8730E+03 -1.2984E-03 -9.9542E-03 -7.6575E-03  45
 50.00 -8.9916E+01  5.5804E+02 -3.1584E+03 -1.3714E-03 -1.3616E-02 -6.6296E-03  50
 55.00 -1.2437E+03 -9.7685E+02  3.1019E+04 -1.4538E-03 -1.7349E-02 -5.2791E-03  55
 60.00 -1.1563E+03 -1.0248E+03  2.5839E+04 -7.6301E-04 -2.0237E-02 -3.6266E-03  60
     0 -1.0652E+03 -1.0595E+03  2.1044E+04 -1.9355E-04 -2.1540E-02 -1.7931E-03  65
     0 -9.7173E+02 -1.0810E+03  1.6648E+04  2.6409E-04 -2.1514E-02  9.4271E-05  70
 75.00 -8.7693E+02 -1.0897E+03  1.2658E+04  6.1972E-04 -2.0401E-02  1.9302E-03  75
 80.00 -7.8191E+02 -1.0861E+03  9.0788E+03  8.8328E-04 -1.8431E-02  3.6300E-03  80
 85.00 -6.8771E+02 -1.0708E+03  5.9081E+03  1.0647E-03 -1.5817E-02  5.1284E-03  85
 90.00 -5.9534E+02 -1.0445E+03  3.1402E+03  1.1740E-03 -1.2754E-02  6.3776E-03  90
 95.00 -5.0571E+02 -1.0080E+03  7.6545E+02  1.2207E-03 -9.4176E-03  7.3463E-03  95
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10.00 -2.6135E+02 -8.4737E+02 -4.1545E+03  1.0776E-03  7.3607E-04  8.4844E-03 110
15.00 -1.9027E+02 -7.8025E+02 -5.1269E+03  9.6427E-04  3.8173E-03  8.2627E-03 115
20.00 -1.2529E+02 -7.0826E+02 -5.8056E+03  8.3073E-04  6.5652E-03  7.8072E-03 120
25.00 -6.6759E+01 -6.3262E+02 -6.2176E+03  6.8397E-04  8.9432E-03  7.1277E-03 125
30 00 -1.4947E+01 -5.5451E+02 -6.3915E+03  5.3015E-04  1.0910E-02  6.2583E-03 130
    0  2.9986E+01 -4.7518E+02 -6.3565E+03  3.7470E-04  1.2442E-02  5.2361E-03 135
   00  6.7986E+01 -3.9581E+02 -6.1426E+03  2.2234E-04  1.3528E-02  4.0997E-03 140
   00  9.9101E+01 -3.1758E+02 -5.7796E+03  7.7050E-05  1.4172E-02  2.8879E-03 145
50.00  1.2348E+02 -2.4162E+02 -5.2969E+03 -5.7891E-05  1.4390E-02  1.6386E-03 150
55.00  1.4137E+02 -1.6902E+02 -4.7231E+03 -1.7993E-04  1.4205E-02  3.8811E-04 155
60.00  1.5311E+02 -1.0079E+02 -4.0855E+03 -2.8717E-04  1.3651E-02 -8.2987E-04 160
65.00  1.5912E+02 -3.7880E+01 -3.4098E+03 -3.7839E-04  1.2767E-02 -1.9848E-03 165
70.00  1.5990E+02  1.8868E+01 -2.7197E+03 -4.5296E-04  1.1598E-02 -3.0499E-03 170
75.00  1.5602E+02  6.8691E+01 -2.0364E+03 -5.1077E-04  1.0190E-02 -4.0021E-03 175
80.00  1.4813E+02  1.1094E+02 -1.3787E+03 -5.5224E-04  8.5917E-03 -4.8228E-03 180
80.00  1.4813E+02  1.1094E+02 -1.3787E+03 -5.5224E-04  8.5917E-03 -4.8228E-03 180

RINTOUT AT LOAD AND/OR MOMENT POINTS

  .00  2.7303E+02  3.4510E+02 -7.7916E+03 -3.5152E-04  1.4830E-02 -4.3481E-03
 -.01  2.7293E+02 -5.6686E+02 -3.5862E+03 -3.5134E-04  1.4833E-02 -4.3455E-03
55.00 -1.2437E+03 -9.7685E+02  3.1019E+04 -1.4538E-03 -1.7349E-02 -5.2791E-03  55
54.99 -1.4028E+02  5.9871E+02 -3.6529E+03 -1.4536E-03 -1.7341E-02 -5.2821E-03  55
05.00 -6.5192E+01  2.6036E+01 -6.1908E+03  1.3312E-03  1.0495E-03  7.7991E-03 305
04.99  5.5458E+02 -8.5950E+02  1.3279E+04  1.3305E-03  1.0420E-03  7.7993E-03 305

RINTOUT OF MAXIMUM AND MINIMUM VALUES OF SHEAR, THRUST, AND MOMENT
ALUES TAKEN FROM BOTH OF THE TABLES ABOVE

AXIMUM V/A=            5.5458E+02   AT  304.99  DEGREES
INIMUM V/A=           -1.2437E+03   AT   55.00  DEGREES
  IUM T/A=             5.9871E+02   AT   54.99  DEGREES
  IUM T/A=            -1.0897E+03   AT   75.00  DEGREES
AXIMUM M(FORCE-LG)=    3.1019E+04   AT   55.00  DEGREES
INIMUM M(FORCE-LG)=   -7.7916E+03   AT     .00  DEGREES


RINTOUT OF MAXIMUM AND MINIMUM (AXIAL + BENDING) STRESSES FOR MOMENT
RMS OF C1 AND C2 - VALUES TAKEN FROM BOTH OF THE TABLES ABOVE

AXIMUM STRESS (C1)=    1.4765E+04   AT   55.00  DEGREES
INIMUM STRESS (C1)=   -3.7981E+03   AT  130.00  DEGREES
AXIMUM STRESS (C2)=    6.0185E+03   AT     .00  DEGREES
INIMUM STRESS (C2)=   -2.3563E+04   AT   55.00  DEGREES
TOP [SYSIN]
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DDG 4/6/94

11.15

E0405A OUTPUT

4"x 3/8" RING

σ_{MAX} = 14,765 PSI IN SHELL @ 55°
σ_{MIN} = -3798 PSI IN SHELL @ 130°

σ_{MAX} = 6019 PSI IN STIFF. @ 0°
σ_{MIN} = -23,563 PSI IN STIFF. @ 55°

TRY 6"x 3/8" SECTION @ 55°

$A = 2.647 \text{ IN}^2$ $I = 9.92 \text{ IN}^4$ $c_1 = 2.668"$ $C_2 = 3.459"$

$S_1 = 3.72 \text{ IN}^3$ $S_2 = 2.87 \text{ IN}^3$

$f = T/A \pm M/S$

$T/A = (-977 \text{PSI})\left(\frac{1.897 \text{IN}^2}{2.697 \text{IN}^2}\right) = -700 \text{ PSI}$ @ 55°

$M = 31,019$ IN-LBS @ 55°

$f_{SHELL} = -700 + \frac{31,019}{3.72 \text{IN}^3} = 7,638 \text{ PSI}$

$f_{STIFF} = -700 + \frac{-31,019}{2.87} = 11,508 \text{ PSI}$

$F_A = .6F_y = .6(25,000 \text{PSI})(1.33) = 19,950 \text{ PSI}$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930612
	MADE BY MRS	CHKD BY DDS	MADE BY	CHKD BY	SHT 16 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.16

Printed in USA GO 84 REV SEP 84

LOAD COMBINATION #4

ADDITIONAL LOAD DUE TO THRUST MOMENT

VERTICAL LOAD = 5,700# + 102# = 5,802#

LATERAL LOAD = 600# = H

PER SKETCH & METHODS FOR LOAD COMBINATION #3

FOR LATERAL FORCES

$\Sigma M_{@H} = 0$

$(600^{\#})(28.502'') - (21.355'')R_1 + (21.355'')R_2 - M_1 + M_2 = 0$

$M_1 = 9.5''\ R_1 \qquad M_2 = 9.5''\ R_2$

$R_2 = -R_1$

$R_1 = R_2 = 277^{\#}$

DUE TO VERT LOADS

$R_1 = R_2 = \frac{5802}{2} = 2901^{\#}$

$R_1 = 2901 + 277 = 3,178^{\#}$

$R_2 = 2901 - 277 = 2,624^{\#}$

$M_1 = 3178^{\#}(9.5'') = 30,191^{\#} \qquad M_2 = 2,624^{\#}(9.5'') = 24,928^{\#}$

$M_{@\ INVERT} = M_0 = (4.127'' - 1.695'')(600^{\#}) = 1459$ IN-LBS

SUBJECT

CBI OFFICE NOE

REVISION

REFERENCE NO. 930212

MADE BY MRS
CHKD BY DDG
MADE BY
CHKD BY

SHT 17 OF 35

DATE 3/2/94
DATE 4/6/94
DATE
DATE

11.17

Printed In USA
GO 64 REV SEP 84

E0405A INPUT

$P_{55} = (3178^{\#}) \cos 55^\circ = 1823^{\#}$

$P_{305} = (2624) \cos 55^\circ = 1505^{\#}$

$T_0 = 600^{\#}$

$T_{55} = (-3178) \sin 55^\circ = -2603^{\#}$

$T_{305} = (2624) \sin 55^\circ = 2149^{\#}$

$M_0/R = \frac{-1459}{26.07} = -56^{\#}$

$M_{55}/R = \frac{30{,}191}{26.07} = 1{,}158^{\#}$

$M_{305}/R = \frac{-24{,}928}{26.07} = -956^{\#}$

$4'' \times 3/8''$ RING

$R = 26.07''$ $E = 27{,}000{,}000 \text{ PSI} @ 300^\circ F$ $I = 3.34 \text{ in}^4$

$A = 1.8971 \text{ in}^2$ $C_1 = 1.695''$ $C_2 = 2.432''$

$F_y = 19{,}200 \text{ PSI} @ 300^\circ F$

SUBJECT	OFFICE		REVISION		REFERENCE NO.
	CBI NOE				930212
	MADE BY	CHKD BY	MADE BY	CHKD BY	SHT 18 OF 35
	MLS	DDG			
	DATE	DATE	DATE	DATE	
	3/2/94	4/6/94			11.18

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ROGRAM E0405A (STD 9110-1-2)  [ IBM RS/6000 ]
TRESS AND STRAIN COEFFICIENTS FOR CIRCULAR RINGS
EVISION 11 - JANUARY 7, 1992


  TANDARDS 9110-1-1 AND 9110-1-2

UIDE SUPPORT LOAD COMBINATION #4 - 2 PT. AT 55 DEG.


    N(R)     N(T)     N(M)    DATA SHEET NO.    PLOT CODE
      2        3        3            1               0


   RADIUS     MOD-ELAS     MOM-INER        AREA         C(1)          C(2)
    26.07 27000000.00         3.34         1.90         1.70          2.43

QUILIBRIUM LOADS           FV          FH         M/R
             INPUT   5802.000     600.000        .000
          COMPUTED   5801.473     600.087        .000

NPUT LOADS AND THEIR LOCATIONS

ADIAL LOADS AND ANGLES

     LOADS           1823.00     1505.00
     ANGLES            55.00      305.00

ANGENTIAL LOADS AND ANGLES

     LOADS            600.00    -2603.00     2149.00
     ANGLES              .00       55.00      305.00

OMENT LOADS/R AND ANGLES

     LOADS            -56.00     1158.00     -956.00
     ANGLES              .00       55.00      305.00

UNIT STRESS VALUES FOR CIRCULAR RINGS
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11. 19

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PRINTOUT AT EQUAL ANGLE INCREMENTS

     X       V/A          T/A       M(FORCE-LG)     THETA          DR           DC           X
    .00   9.4730E+01   4.5107E+01 -6.5208E+03 -1.2648E-04  1.5657E-02 -1.5641E-03          .
   5.00   9.0713E+01   4.8128E+01 -6.1205E+03 -2.8590E-04  1.4991E-02 -2.9049E-03         5.
  10.00   8.6124E+01   5.8227E+01 -5.7386E+03 -4.3545E-04  1.3859E-02 -4.1669E-03        10.
  15.00   8.0348E+01   7.5306E+01 -5.3789E+03 -5.7563E-04  1.2292E-02 -5.3111E-03        15.
  20.00   7.2783E+01   9.9162E+01 -5.0477E+03 -7.0708E-04  1.0324E-02 -6.3007E-03        20.
  25.00   6.2853E+01   1.2948E+02 -4.7541E+03 -8.3063E-04  7.9870E-03 -7.1022E-03        25.
  30.00   5.0008E+01   1.6585E+02 -4.5094E+03 -9.4736E-04  5.3164E-03 -7.6850E-03        30.
  35.00   3.3745E+01   2.0775E+02 -4.3273E+03 -1.0587E-03  2.3465E-03 -8.0214E-03        35.
  40.00   1.3605E+01   2.5458E+02 -4.2237E+03 -1.1664E-03 -8.8995E-04 -8.0868E-03        40.
  45.00  -1.0811E+01   3.0563E+02 -4.2160E+03 -1.2726E-03 -4.3623E-03 -7.8592E-03        45.
  50.00  -3.9838E+01   3.6013E+02 -4.3236E+03 -1.3800E-03 -8.0439E-03 -7.3193E-03        50.
  55.00  -1.0347E+03  -9.5492E+02  2.5622E+04 -1.4919E-03 -1.1913E-02 -6.4498E-03        55.
  60.00  -9.5045E+02  -9.7465E+02  2.1338E+04 -9.0030E-04 -1.5126E-02 -5.2595E-03        60.
      )  -8.6497E+02  -9.8260E+02  1.7420E+04 -4.1219E-04 -1.6999E-02 -3.8488E-03        65.
      0  -7.7929E+02  -9.7924E+02  1.3872E+04 -1.8256E-05 -1.7742E-02 -2.3254E-03        70.
  75.00  -6.9437E+02  -9.6518E+02  1.0693E+04  2.9083E-04 -1.7552E-02 -7.7934E-04        75.
  80.00  -6.1112E+02  -9.4112E+02  7.8762E+03  5.2430E-04 -1.6613E-02  7.1621E-04        80.
  85.00  -5.3038E+02  -9.0785E+02  5.4141E+03  6.9121E-04 -1.5095E-02  2.1034E-03        85.
  90.00  -4.5291E+02  -8.6627E+02  3.2936E+03  8.0034E-04 -1.3149E-02  3.3384E-03        90.
  95.00  -3.7940E+02  -8.1733E+02  1.4991E+03  8.6013E-04 -1.0913E-02  4.3900E-03        95.
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 10.00 -1.8813E+02 -6.3680E+02 -2.1258E+03  8.2083E-04 -3.0812E-03  6.2717E-03 110.
 15.00 -1.3550E+02 -5.6905E+02 -2.8200E+03  7.5802E-04 -1.2222E-03  6.5005E-03 115.
 20.00 -8.8867E+01 -4.9941E+02 -3.3020E+03  6.8037E-04  9.8540E-04  6.5096E-03 120.
 25.00 -4.8355E+01 -4.2901E+02 -3.5959E+03  5.9300E-04  2.9970E-03  6.3343E-03 125.
 30.00 -1.3980E+01 -3.5897E+02 -3.7282E+03  5.0030E-04  4.7803E-03  5.9932E-03 130.
[illegible]  1.4338E+01 -2.9036E+02 -3.7252E+03  4.0603E-04  6.3140E-03  5.5072E-03 135.
[illegible]  3.6769E+01 -2.2424E+02 -3.6129E+03  3.1326E-04  7.5865E-03  4.8988E-03 140.
[illegible]  5.3576E+01 -1.6159E+02 -3.4160E+03  2.2445E-04  8.5945E-03  4.1908E-03 145.
 50.00  6.5100E+01 -1.0333E+02 -3.1580E+03  1.4142E-04  9.3414E-03  3.4064E-03 150.
 55.00  7.1763E+01 -5.0323E+01 -2.8611E+03  6.5434E-05  9.8362E-03  2.5678E-03 155.
 60.00  7.4057E+01 -3.3159E+00 -2.5449E+03 -2.7767E-06  1.0092E-02  1.6966E-03 160.
 65.00  7.2536E+01  3.7021E+01 -2.2273E+03 -6.2959E-05  1.0125E-02  8.1285E-04 165.
 70.00  6.7807E+01  7.0123E+01 -1.9234E+03 -1.1527E-04  9.9538E-03 -6.4693E-05 170.
 75.00  6.0521E+01  9.5532E+01 -1.6457E+03 -1.6023E-04  9.5959E-03 -9.1900E-04 175.
 80.00  5.1367E+01  1.1291E+02 -1.4037E+03 -1.9861E-04  9.0704E-03 -1.7346E-03 180.
 80.00  5.1367E+01  1.1291E+02 -1.4037E+03 -1.9861E-04  9.0704E-03 -1.7346E-03 180.

RINTOUT AT LOAD AND/OR MOMENT POINTS

   .00  9.4730E+01  4.5107E+01 -6.5208E+03 -1.2648E-04  1.5657E-02 -1.5641E-03
  -.01  9.4683E+01 -2.7118E+02 -5.0617E+03 -1.2622E-04  1.5658E-02 -1.5614E-03
 55.00 -1.0347E+03 -9.5492E+02  2.5622E+04 -1.4919E-03 -1.1913E-02 -6.4498E-03  55.
 54.99 -7.3669E+01  4.1713E+02 -4.5663E+03 -1.4917E-03 -1.1905E-02 -6.4519E-03  55.
 05.00  2.5003E+00  2.1855E+02 -5.4495E+03  1.4480E-03 -5.2950E-03  7.3567E-03 305.
 04.99  7.9570E+02 -9.1428E+02  1.9467E+04  1.4470E-03 -5.3028E-03  7.3557E-03 305.

RINTOUT OF MAXIMUM AND MINIMUM VALUES OF SHEAR, THRUST, AND MOMENT
ALUES TAKEN FROM BOTH OF THE TABLES ABOVE

AXIMUM V/A=           7.9570E+02    AT  304.99  DEGREES
INIMUM V/A=          -1.0347E+03    AT   55.00  DEGREES
[illegible]UM T/A=            4.1713E+02    AT   54.99  DEGREES
[illegible]UM T/A=           -9.8260E+02    AT   65.00  DEGREES
AXIMUM M(FORCE-LG)=   2.5622E+04    AT   55.00  DEGREES
INIMUM M(FORCE-LG)=  -6.5208E+03    AT     .00  DEGREES


RINTOUT OF MAXIMUM AND MINIMUM (AXIAL + BENDING) STRESSES FOR MOMENT
RMS OF C1 AND C2 - VALUES TAKEN FROM BOTH OF THE TABLES ABOVE

AXIMUM STRESS (C1)=   1.2048E+04    AT   55.00  DEGREES
INIMUM STRESS (C1)=  -3.2641E+03    AT     .00  DEGREES
AXIMUM STRESS (C2)=   4.7932E+03    AT     .00  DEGREES
INIMUM STRESS (C2)=  -1.9612E+04    AT   55.00  DEGREES
OP [SYSIN]
```

DDG 4/6/94

11.20

E0405A OUTPUT

$4 \times 3/8$ RING

σ_{MAX} (SHELL) = 12,048 PSI @ 55°

σ_{MIN} (SHELL) = -3264 PSI @ 0°

σ_{MAX} (STIFF) = 4793 PSI @ 0°

σ_{MIN} (STIFF) = -9,612 PSI @ 55°

TRY $6'' \times 3/8''$ SECTION @ 55°

$A = 2.647 \text{ IN}^2$ $I = 9.92 \text{ IN}^4$ $C_1 = 2.668''$ $C_2 = 3.459''$

$S_1 = 3.72 \text{ IN}^3$ $S_2 = 2.87 \text{ IN}^3$

$f = T/A \pm M/S$

@ 55° $T/A = (-955 \text{ PSI})\left(\frac{1.897 \text{ IN}^2}{2.647 \text{ IN}^2}\right) = -685 \text{ PSI}$

$M = 25,622 \text{ IN-LBS}$

$f_{SHELL} = -685 \text{ PSI} + \frac{25,622}{3.72 \text{ IN}^3} = 6,203 \text{ PSI}$

$f_{STIFF} = -685 \text{ PSI} - \frac{25,622}{2.87} = -9,613 \text{ PSI}$

$F_A = .6F_Y = .6(19,200) = 11,520 \text{ PSI}$

SUBJECT	OFFICE	REVISION	REFERENCE NO.
	CBI NOE		930212

MADE BY	CHKD BY	MADE BY	CHKD BY	SHT 21 OF 35
MRS	DDG			
DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.21

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GO 64 REV SEP 84

RING HANGER LUG DESIGN

$V_{max} = 3650^{\#}$ LOAD COMBINATION #3

CHECK BENDING OF LUG

2" FROM HANGER CENTERLINE

$M = 2''(3650^{\#}) = 7300$ IN-LBS

PLATE $t = 3/8''$ WIDTH $= 5\frac{1}{2}''$ $S = \frac{(5.5)^2(.375)}{6} = 1.89 \text{ in}^3$

$\sigma_{bx} = \frac{7300 \text{ in-LBS}}{1.89 \text{ in}^3} = 3862$ PSI

7" FROM HANGER ℄

$M = 7''(3650^{\#}) = 25,550$ IN-LBS

ASSUME LUG WIDTH $= 5.5'' + 2(3'') = 11.5''$ $S = 8.26 \text{ in}^3$

$\sigma_{bx} = \frac{25,550 \text{ in-LBS}}{8.26 \text{ in}^3} = 3,093$ PSI $< F_b = .6(19,200) = 11,520$ PSI

A-

SHEAR ON LUG

$V = 3650^{\#}$ $A = 5.5''(.375'') = 2.06 \text{ in}^2$

$f_v = V/A = 1772$ PSI $< .4F_y = .4(19,200 \text{ PSI}) = 7,680$ PSI

SUBJECT	CBI OFFICE NDE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 22 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.22

TORSION ON LUG

$$T = V\left[\frac{(t_1 + t_2)}{2} + 1''\right] = 3650\left[\frac{(.375 + .1875)}{2} + 1''\right) = 4677 \text{ IN-LBS}$$

$$\text{TORSIONAL RESISTANCE } (R) = \frac{bd^3}{3} = \frac{(5.5'')(.375)^3}{3} = 0.10$$

$$\theta = \frac{TL}{E_S R} \quad (\text{RAD}) \qquad \tau = \frac{T}{bd^2/3} \quad (\text{PSI})$$

$$E_S = 12{,}000{,}000 \text{ PSI}$$

$$@ L = 2''$$

$$\theta = \frac{(467.2 \text{ IN-LBS})(2'')}{(12{,}000{,}000)(0.10)} = 0.0078 \text{ RAD} = .447^\circ$$

$$\tau = \frac{4677}{(5.5)(.375)^2/3} = 18{,}141 \text{ PSI} > .4F_y$$

ATTACH A CHANNEL TO STIFFEN AGAINST TORSION

TRY 3 X 4.1

$$\tau = \frac{T}{2[A]t_s}$$

$$[A] = (3 + .273)\left(1.41 + .17/2 + \frac{.375}{2}\right) = 4.12 \text{ IN}^2$$

$$\tau = \frac{4677}{2[4.12](.17'')} = 3{,}335 \text{ PSI} < .4F_y = 7{,}680 \text{ PSI}$$

SUBJECT

CBI OFFICE NOE

REVISION

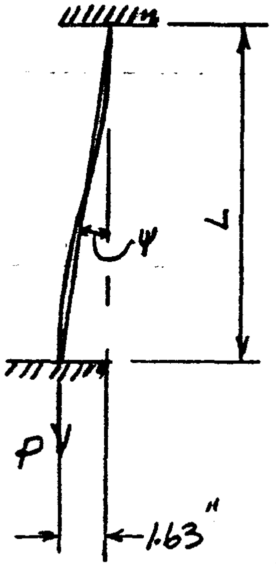
REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY
MRS	DDG		
DATE 3/2/94	DATE 4/6/94	DATE	DATE

SHT 23 OF 35

11.23

HANGER STRAP DESIGN



USING THE SLOPE - DEFLECTION METHOD

$$M_{TOP} = \frac{2EI}{L}\left[2\theta_{TOP} + \theta_{BOT} - 3\psi\right]$$

$$M_{BOT} = \frac{2EI}{L}\left[2\theta_{B} + \theta_{T} - 3\psi\right]$$

LET ROTATION @ TOP $(\theta_{TOP}) = 0$
ROTATION @ BOTTOM $(\theta_{BOT}) = 0$

$$M_{TOP} = M_{BOT} = \frac{-6EI}{L}\psi$$

USE A572 GR. 50 MATERIAL FOR STRAPS $F_y = 50{,}000$ PSI

TRANSLATION = 1.63" $P_{MAX} = 3178^{\#}$ (BAKE-OUT) ⇐ GOVERNS

$P_{MAX} = 3649^{\#}$ (SEISMIC)

TRY 2" x 3/16" STRAP

$A = 2(.1875") = .375\ IN^2$ $I = \frac{2(.1875)^3}{12} = 0.0011\ IN^4$ $S = \frac{2(.1875)^2}{6} = 0.0117\ IN^3$

$E = 29{,}000{,}000$ PSI

LET $L = 32"$ $\therefore \psi = \frac{1.63}{32} = 0.05094$ RAD. $= 2.919°$

SUBJECT	OFFICE CBI NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 24 OF 25
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.24

$$M_{TOP} = \frac{6EI}{L}\psi$$

$$= \frac{6(29,000,000)(.0011)}{32''}(.05094)$$

$$= 305 \text{ IN-LBS}$$

$$f_a = P/A = \frac{3178^{\#}}{0.375 \text{ in}^2} = 8,475 \text{ PSI}$$

$$f_b = M/S = \frac{305 \text{ IN-LBS}}{0.0117 \text{ in}^3} = -26,068 \text{ PSI}$$

$$F_a = 0.6F_y = .6(50,000) = 30,000 \text{ PSI}$$

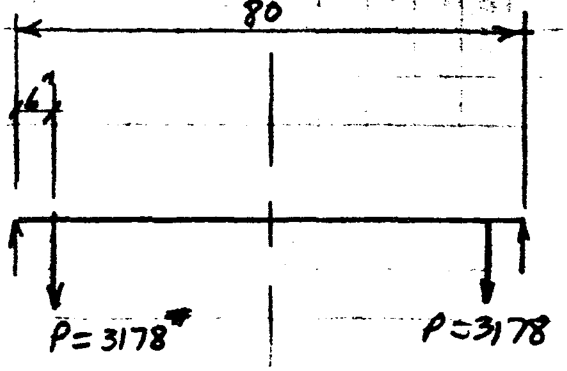
$$F_b = 0.75F_y = .75(50,000) = 37,500 \text{ PSI}$$

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1.0$$

$$\frac{8475}{30,000} + \frac{26,068}{37,500} = 0.28 + 0.70 = 0.98 < 1.0 \therefore \text{OK}$$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 25 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.25

DESIGN OVERHEAD BEAM



$M = 6''(3178^{\#}) = 19,068$ IN-LBS

TRY 2 C3x4.1

$A = 2.42 \text{ IN}^2$ $\quad S = 2(1.10) = 2.20 \text{ IN}^3$ $\quad d/A_f = 7.78$

$$f_b = M/S = \frac{19,068}{2.20} = 8,667 \text{ PSI}$$

(AISC F3)

$$F_b = \frac{12000\, C_b}{l\, d/A_f}$$

$C_b = 1.0$ $\quad l = 80''$

$$F_b = \frac{12000}{80\,(7.78)} = 19.28 \text{ KSI}$$

$f_b < F_b$ $\therefore$ OK

SUBJECT	OFFICE CBI NOE		REVISION	REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY / CHKD BY	SHT 26 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE / DATE	11.26

COLUMN DESIGN

$P = 3178^{\#}$ MAX (BAKE OUT CONTROLS)

TRY ☐ TUBE $4 \times 4 \times \frac{3}{8}$

$A = 5.08\ \text{in}^2$ $I = 10.7\ \text{in}^4$ $S = 5.35\ \text{in}^3$ $r = 1.45''$

LET $K = 2.1$ (CANTELEVER)

$L = 50''$

$$KL/r = \frac{(2.1)(50)}{1.45} = 72.4$$

$F_a = 16{,}120$ PSI

$$f_a = \frac{3178^{\#}}{5.08\ \text{in}^2} = 626\ \text{PSI} < F_a \therefore \text{OK}$$

BENDING IN COLUMN DUE TO LONGITUDINAL LOAD

$P_L = P \sin 2.919° = 3178(0.0509) = 162^{\#}$

$m = 50''(162^{\#}) = 8100$ in-lbs

$$f_b = \frac{8100\ \text{in-lbs}}{5.35\ \text{in}^3} = 1514\ \text{PSI}$$

$$\Delta = \frac{PL^3}{3EI} = \frac{(162^{\#})(50)^3}{3(29{,}000{,}000)(10.7)} = 0.022''$$

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY mRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 27 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.27

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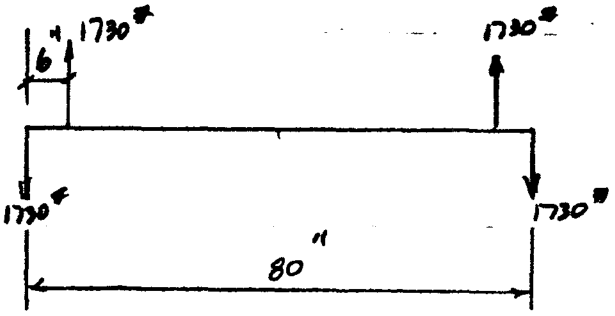
GO 64 REV SEP 84

DESIGN LOWER LONGITUDINAL BEAM

MAXIMUM LATERAL LOAD = 1730# SEISMIC , 600# STABILITY



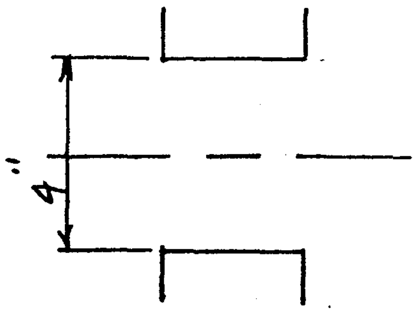
$M_{MAX} = 6''(1730^{\#}) = 10,380$ IN-LBS

TRY 2-C3x4.1# (BACK TO BACK)

$A = 2(1.21) = 2.42$ IN²

$I = 2(.197) + 2(1.21)(2'' + .436'')^2 = 14.75$ IN⁴

$S = I/c = \frac{14.75 \text{ IN}^4}{2 + 1.41''} = 4.32$ IN³



$f_b = M/S = \frac{10,380 \text{ IN-LBS}}{4.32 \text{ IN}^3} = 2,403$ PSI

$F_b = 1.33(.6F_y) = 28,800$ PSI

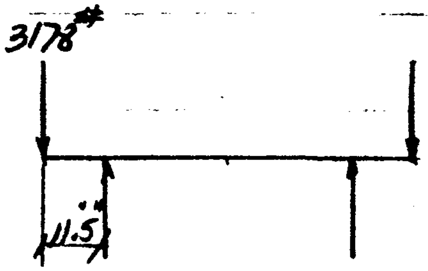
TRY 4x4x3/8 STRUCTURAL TUBE

$A = 5.08$ IN² $I = 10.7$ IN⁴ $S = 5.35$ IN³

TUBE IS OK BY INSPECTION

SUBJECT	OFFICE CBI NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 29 OF 35
	DATE 3/2/94	DATE 4/6/94	DATE	DATE	11.28

DESIGN TRANSVERSE BEAM



$M = 3178(11.5") = 36,547$ IN-LBS

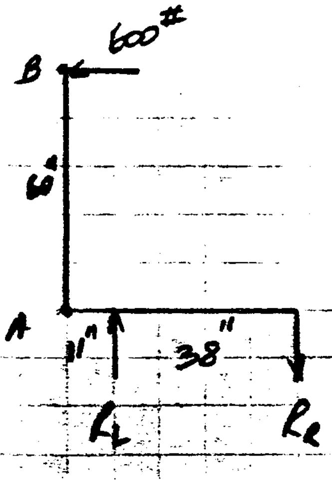
TRY 4×4×3/8" TUBE

$S = 5.35$ IN^3

$f_b = \frac{36,547}{5.35} = 6,831$ PSI

CHECK FLEXIBILITY OF COLUMN

APPLY 600# LOAD @ TOP OF COLUMN.



$M @ R_L = 60(600) = 36,000$ IN-LBS

$\theta @ A = \frac{ML}{3EI} = \frac{36,000(38")}{3(29,000,000)(10.7)}$

$\theta = .00147$ RAD

$\Delta_B = 60(.00147) = .0882$

$\Delta'_B = \frac{WL^3}{3EI} = \frac{600(60)^3}{3(29000000)(10.7)} = 0.139"$

$\Delta_{TOTAL} = .139 + .088 = 0.227$

SUBJECT	OFFICE		REVISION		REFERENCE NO.
	CBI NOE				93,212
	MADE BY	CHKD BY	MADE BY	CHKD BY	SHT 29 OF 35
	mbs	DDG			
	DATE	DATE	DATE	DATE	11.29
	3/3/94	4/6/94			

SUPPORT LUG DESIGN

USE SAME LUG AS THE FIXED SUPPORT

HANGER BOLT DESIGN

$P_{max} = 3650^{\#}$ (SEISMIC)

USE 2 BOLTS IN SINGLE SHEAR

ALLOWABLE SHEAR PER BOLT $= 4.4^{K}$

TOTAL $= 8.8^{K} > 3.65^{K} \therefore$ OK

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY mRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 30 OF 35
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LATERAL RESTRAINT CABLES

LATERAL LOADS = 1730# (SEISMIC)
= 600# (NORMAL)

LONGITUDINAL PIPE MOVEMENT = 1.63" MAX

TRY 1/4"ϕ 7x19 OR 6x19 IPS IWRC GALVANIZED CABLE*

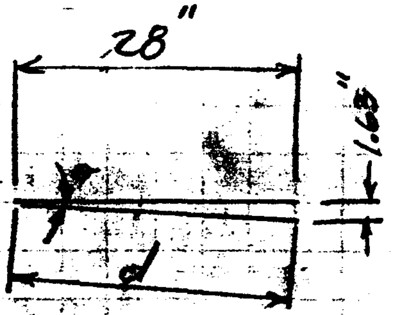
MIN. BREAKING STRENGTH = 7000# (CATELOG NO. 11, SAVA INDUSTRIES, INC)

FACTOR OF SAFETY (FS) = $\frac{7000}{600\#}$ = 11.7 (NORMAL)

FACTOR OF SAFETY (FS) = $\frac{7000}{1730\#}$ = 4.0 (SEISMIC)

ADDITIONAL LOAD DUE TO BAKE-OUT

L = 28"



$d = \sqrt{(28)^2 + (1.63)^2} = 28.0474''$

$\theta = 3.3317° = .05815$ RAD

E = 13,000,000 PSI (WIRE ROPE ENGINEERING HANDBOOK)

$\Delta = 0.0474''$ WIRE METAL AREA = 0.0341 IN² 1/4"ϕ

$P = \frac{AE\Delta}{L} = \frac{(.0341\,IN^2)(13,000,000\,PSI)(.0474'')}{28''} = 1750\#$

$FS = \frac{7000\#}{1350\#} = 5.2$ (BAKE OUT)

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 93021
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 31 OF 35
	DATE 3/4/94	DATE 4/6/94	DATE	DATE	11.31

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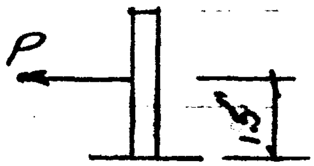
GO 64 REV SEP 84

RESTRAINT LUG DESIGN

$P = 1730^{\#}$ (SEISMIC)



$P = (600^{\#} + 750^{\#}) = 1350^{\#}$ (BAKE-OUT)

$M = (1730^{\#})(2'') = 3460^{\#}$

TRY $3'' \times 3'' \times \frac{5}{8}''$ PL $\qquad S = \frac{(.625)^2(3)}{6} = 0.195\,\text{in}^3$

$f_b = \frac{3460}{.195} = 17{,}744$ PSI

PUT 3/8" GUSSET TO SUPPORT MOMENT

SUBJECT	OFFICE CBI NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 30 OF 35
	DATE 3/4/94	DATE 4/6/94	DATE	DATE	11.32

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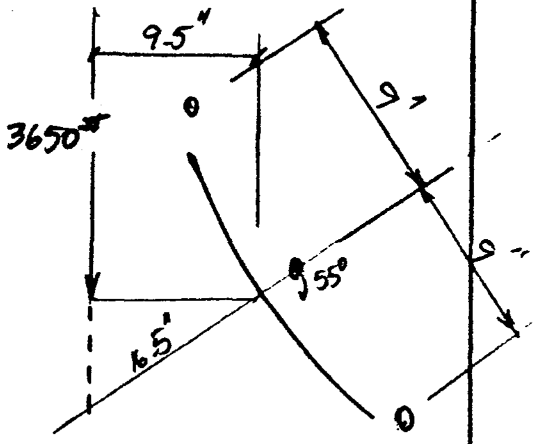
DESIGN BOLTED RING LUG CONNECTION

TRY 3 BOLTS

$f_{vm} = (3650^{\#})(9.5'')/9'' = 3,853^{\#}$



$f_v = \frac{3650}{3} = 1217^{\#}$

$f_{vT} = \sqrt{f_{vm}^2 + f_v^2}$

$f_{vT} = 4,041^{\#}$ /BOLT

ALLOWABLE LOAD = $4,400^{\#}$ /BOLT

TRY 4 - 3/4"φ BOLTS

PER AISC TABLE XI, PG 4-62

$P = C \times r_v$ $n=4$ $l = 9''$

$r_v = 4400^{\#}$ $C = 1.21$

$P = 1.21(4400^{\#}) \leq 5,324^{\#} > 4041^{\#}$ ∴ OK

SUBJECT	CBI OFFICE NOE	REVISION	REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY	SHT 33 OF 35
MRS	DDG			
DATE 3/8/94	DATE 4/6/94	DATE	DATE	11.33

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DESIGN OUTER FRAME VERTICAL BOLTED CONNECTION

ASSUME 600# LATERAL LOAD @ TOP OF COLUMN

$M = (600^{\#})(58.5'') = 35,100^{\#-IN.}$

TRY 2 BOLTS @ 9" APART

$P_{BOLT} = \frac{35,100 \text{ IN-LBS}}{9''} = 3900^{\#}/BOLT$

PER AISC 3/4" ϕ BOLT $P_{ALLOW} = 8.8^{K} > P \therefore OK$

BASE PLATE

$e = 2.5''$

$M = 2.5''(3649^{\#}) = 9,123$ IN-LBS   USE 10,000 IN-LBS

$S_{REQD} = \frac{M}{.75F_y} = \frac{10,000}{.75(36,000)} = .371 \text{ IN}^3$

$S = \frac{bt^2}{6}$

$.371 \text{ IN}^3 = \frac{(4'')t^2}{6}$

$t = 0.746''$

USE 1" PL

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 34 OF 35
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CHECK TUBE WALL FOR BOLT LOAD

CHECK. TUBE WALL FOR BOLT YIELD LOAD

$$P = A_b F_y = (0.4418 \text{ IN}^2)(36{,}000 \text{ PSI}) = 15{,}905^{\#}$$

REF. "FORMULAS FOR STRESS & STRAIN", ROARK 4TH ED., PG 226, CASE 38

ASSUME 4" SQ. PLATE @ 1" LOAD AREA

$a = b = 4"$ $a_1 = b_1 = 1"$

$b_1/b = .25$ $a_1/b = .25$

$\beta = 1.18$

3/8" WALL t

$$S_b = \beta \frac{W}{t^2} = 1.18 \frac{16{,}000^{\#}}{(.375)^2} = 134{,}260 \text{ PSI}$$

SOLVE FOR t @ $S_{ALLOW} = .75F_y = 27{,}000$ PSI

$$27000 = 1.18 \frac{(16{,}000)}{t^2}$$

$t_{REQ'D} = 0.837"$

USE 4"x4"x1" SQ. WASHER PLATES

SUBJECT	CBI OFFICE NOE		REVISION		REFERENCE NO. 930212
	MADE BY MRS	CHKD BY DDG	MADE BY	CHKD BY	SHT 35 OF 35
	DATE 3/8/94	DATE 4/6/94	DATE	DATE	11.35

CBI

Location NOE - A

Thermal Analysis of Ligo Supports

Prepared for

Ligo Beam Tube Design and

Qualification Test - CalTech

by

CBI Technical Services Company

Plainfield, Illinois

CBI Contract Number 930212

March 1994

SUBJECT Ligo Heat Transfer Analysis	MADE BY DEP	CHKD BY KAD	REV	BY		CHARGE NO. 930212
CalTech	DATE 3/30/94	DATE 3/31/94		CHKD		
				DATE		SHT OF

CBI

Location NOE - A

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SUBJECT Ligo Heat Transfer Analysis	MADE BY DEP	CHKD BY KAD	REV	BY	CHARGE NO. 930212
CalTech	DATE 3/30/94	DATE 3/31/94		CHKD	SHT i OF
				DATE	

List of Figures

List of Tables

I. INTRODUCTION:

This report documents the finite element heat transfer analysis of the Ligo tube system, near the fixed supports. This thermal analysis determines the temperature drop of the Ligo tube near the fixed supports during bake-out conditions.

The Ligo structure consists of a tube approximately four kilometers in length. A current within the tube wall maintains a tube temperature of 284.0^{O}F away from the supports, during bake-out. While heating of the tube occurs, the supports act as a heat sink. This analysis determines the minimum tube wall temperature, due to the sink effects of the supports; this tube wall temperature determines the acceptability of the insulation system at the supports. The minimum acceptable tube wall temperature is 266.0^{O}F.

Included in this report is a description of model geometry, finite element modelling of the same, material properties, thermal loads, thermal boundary conditions, and temperature distribution results.

II. SUMMARY OF RESULTS:

Figures 1 through 4 show the support details. Separate finite element models determine the tube wall temperature at the transfer lug and column supports. The minimum tube wall temperatures occur at these locations. The minimum tube wall temperatures at these locations are greater than the specified minimum value of 266.0^{O}F.

The minimum tube wall temperature occurs at the column support. While not shown in the attached figures, two inches of duct wrap insulation covering the plates, micarta, and column is required to meet the minimum tube wall temperature requirement. The transfer lug support detail shown in the attached figures is adequate.

III. METHOD OF ANALYSIS:

A. Rationale of Separate Point Support Models

Figure 1 shows a typical three point fixed support for the Ligo tube. Both the Ligo tube and supports are symmetric about the x=0 plane shown in Figure 1. Two distinct heat sinks exist due to the presence of the support, one at the transfer lug location, and one at the column support location. Since the supports are about twenty-five inches apart along the circumference of the tube, these heat sinks are assumed to act independently of each other. This analysis uses separate finite element models, called the transfer lug model and column support model, respectively, to analyze each location. Figures 5 and 6 show the geometry of the transfer lug and column support models, respectively.

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B. Rationale of Axisymmetric Analysis

Both finite element models are axisymmetric, with the z-direction the axis of symmetry. The main path of heat flow from the tube is through the transfer lug or column support, the horizontal structure tube, and the support lug assembly to the concrete foundation. The axisymmetric modelling of the non-axisymmetric support components utilizes smearing of the thermal conductivities based on cross sectional area of the component versus modelled cross sectional area along the flow path. Similarly, axisymmetric modelling of convective film coefficients utilizes smearing based on exposed surface area ratios.

C. Axisymmetric Analysis of a Concentrated Heat Sink

The transfer lug and column support models determine which of the two locations produces the minimum tube wall temperature, and also the total heat flux through this governing heat sink. The governing total heat flux is then used in an additional axisymmetric model to more accurately determine the minimum tube wall temperature. Figure 7 shows the concentrated heat sink model geometry.

D. Acceptance Criteria

The maximum temperature in the tube is 284.0°F. The minimum tube temperature is 266.0°F. This is a pure temperature requirement, not a requirement based on a maximum temperature drop in the tube.

E. Computer Programs

The ADINA-T computer program determines the temperature distribution in the tube, insulation, stiffener, and support components. ADINA-T (Automatic Dynamic Incremental Non-linear Analysis of Temperatures) is a general purpose, commercially available computer program for the solution of linear or non-linear, steady-state or transient, finite element analysis of heat transfer and field problems. ADINA R&D, Inc., of Watertown, Massachusetts developed and maintains the ADINA-T program.

PATRAN Plus software generates the finite element models and presents the analysis results. PATRAN Plus is a pre- and post- processing software package developed and maintained by PDA Engineering of Costa Mesa, California. PATRAN is an open-ended (solver independent), general purpose, commercially available, engineering software package that utilizes interactive graphics to generate finite element models and evaluate and present analysis results.

F. Assumptions

The analysis uses the assumptions shown below.

- Steady state heat transfer analysis. The analysis assumes no transient effects.
- No thermal gradient exists at the model end away from the support.

- Symmetry exists along the z=0 plane for both models.
- No thermal gradient exists across the plane of symmetry.
- Smearing of thermal conductivities used to reflect true material cross sectional area of non-axisymmetric support components.
- Smearing of convective film coefficients used to reflect true exposed surface area of non-axisymmetric support components.
- Transfer lug and column support heat sinks act independently of each other.
- Free convection acts on all exposed surfaces. Analysis includes support insulation if initial results require refinement.
- Convective film coefficients are a function of temperature.
- Thermal conductivity of micarta is constant. Other thermal conductivities are a function of temperature.
- Tube wall thickness intentionally modelled as 0.125 inches. The actual thickness of the tube wall is 0.127 inches.
- Ambient temperature used for prescribed temperature of concrete.
- Analysis does not include the teflon fabric.

IV. FINITE ELEMENT MODEL DESCRIPTION:

A. Geometry

Figures 1 through 4 show the geometry of a typical fixed support. Figures 5 and 6 show the geometries used for the transfer lug and column support models, respectively. The dimensions shown in Figures 1 through 4, along the heat flow path and beyond the micarta insulation (foundation side of the support), are used to establish the smeared geometry used in the axisymmetric modelling.

The extents of the tube and duct wrap insulation modelled away from the support is sixty inches. Boundary condition effects at this location have no effect on the temperature distribution at the support.

Figure 7 shows the geometry of the concentrated heat sink model. This model includes sixty inches of tube and insulation.

B. Finite Element Mesh

Figures 8 through 10 show the finite element mesh of the transfer lug, column support, and concentrated heat sink models, respectively. All models use eight-noded axisymmetric elements. The figures show the materials used for the respective analyses.

C. Material Properties

Table 1 shows the base thermal conductivities for the materials used in the analysis. With the exception of micarta, all thermal conductivities are a function of temperature. Table 2 shows the smearing factors used in the analyses. The thermal conductivities of the analyses are the base values times the smearing factors. Appendix A contains the calculations of the conductivity smearing factors for the transfer lug and column support analyses.

D. Thermal Loads

The lone heat source in all models is an applied distributed heat flux which simulates the effect of the electric current in the tube. Away from the support, the temperature of the tube is 284.0^{O}F. Appendix B contains the calculations used to determine the approximate required value of this heat source, given an insulation thickness and free convection to ambient conditions. This calculation considers one constant thermal conductivity value of the insulation per iteration; therefore, this calculation is approximate. The required heat source is about 20.05 BTU/hr-in, or 15,640 BTU/hr for each sixty-five foot section of tube.

E. Thermal Boundary Conditions

Both models have prescribed temperatures assigned at the support lug end, where it attaches to the concrete foundation. The temperature value is the same used for the ambient conditions. In the analyses, the ambient temperature is 70^{O}F.

Free convection to ambient air is assigned to all exposed surfaces. Figures 1 through 4 do not include insulation details for the supports. The analyses consider support insulation details only if the conservative non-insulated approximation yields unacceptable results. The base convective film coefficients are a function of temperature and are shown in Table 3. Table 4 shows the smearing factors used in the analyses. The convective film coefficients used in the analyses are the base values times the smearing factors. Appendix A contains the calculations of the convective film coefficient smearing factors for the transfer lug and column support analyses. Appendix B contains the calculation used to determine the convective film coefficients shown in Table 3.

The concentrated heat sink model includes distributed heat flow out of the model at the heat sink location. The results from the transfer lug and column support models determine the magnitude of this heat sink. This model contains no prescribed nodal temperatures.

V. INITIAL RESULTS AND ANALYSIS REFINEMENT:

A. Transfer Lug Model - Initial Minimum Tube Wall Temperature

Figure 11 shows an isotherm plot of the temperature distribution in the tube, stiffener, and support components. The plot shows that the minimum temperature in the tube exceeds the minimum requirement of 266.0°F. The calculated minimum temperature of the tube wall is 280.3°F.

B. Transfer Lug Model - Analysis Refinement

An axisymmetric analysis assumes that no heat flow occurs in the circumferential direction. Some heat flow occurs in the Ligo structure circumferentially around the stiffener, between the column support and transfer lug. The distance between these supports is about twenty-five inches around the circumference of the pipe. Between these supports, a location exists where no heat flow occurs circumferentially; the maximum temperature between the supports occurs at this location. It is reasonable to assume that this maximum occurs about half way between the supports.

From the temperature distribution shown in Figure 11, the tube wall temperature about twelve and one-half inches away from the support is about 282.5°F. To conservatively estimate the effect of potential interaction of the heat sink supports, the heat flow input is revised, such that the maximum pipe temperature is reduced from 284.0°F to 282.5°F. This assumption is conservative, since the maximum tube wall temperature of 284.0°F occurs in the Ligo structure along the length of the tube, as well as the top of the tube.

C. Transfer Lug Model - Refined Analysis Results

Figure 12 shows an isotherm plot of the revised temperature distribution in the tube, stiffener, and support components. The plot shows that the minimum temperature in the tube exceeds the minimum requirement of 266.0°F. The calculated minimum temperature of the tube wall is 279.2°F.

D. Column Support Model - Initial Minimum Tube Wall Temperature

Figure 13 shows an isotherm plot of the temperature distribution in the tube, stiffener, and support components. The plot shows that the minimum temperature in the tube is below the minimum requirement of 266.0°F. The calculated minimum temperature of the tube wall is 257.9°F.

E. Column Support Model - Analysis Refinement

Since the minimum temperature of the tube wall does not meet the minimum temperature requirement, the model refinement includes two inches of duct wrap insulation covering horizontal and vertical plates, micarta, and column support. This refinement uses equivalent convective film coefficients considering both conduction through the insulation and free convection to ambient air. Appendix C contains this calculation.

F. Column Support Model - Refined Analysis Results

Figure 14 contains an isotherm plot of the refined analysis. Figure 14 shows that the minimum temperature in the tube exceeds the minimum requirement of 266.0°F. The calculated minimum temperature of the tube wall is 271.2°F.

An additional one degree temperature drop is assumed due to interaction effects between the two supports. The resulting minimum temperature of 270.2°F is still above the required minimum value. This is verified by the concentrated heat sink model.

G. Concentrated Heat Sink Model - Initial Minimum Tube Wall Temperature

The minimum tube wall temperature occurs at the column support. Therefore, the heat loss is higher at the column support, than at the transfer lug. Appendix C contains the calculations for the heat loss at the column support, and the equivalent heat loss applied in the concentrated heat sink model.

Figure 15 contains an isotherm plot of the temperature distribution in the tube. This figure shows that the minimum temperature in the tube exceeds the minimum requirement of 266.0°F. The calculated minimum temperature of the tube wall is 270.3°F.

H. Concentrated Heat Sink Model - Analysis Refinement

The revision of the heat flow in the tube is similar to the technique used in the transfer lug analysis. The maximum tube wall temperature is 280.3°F in the revised analysis. No change is made in the heat loss rate.

I. Concentrated Heat Sink Model - Refined Analysis Results

Figure 16 contains an isotherm plot of the temperature distribution in the tube. This figure shows that the minimum temperature in the tube exceeds the minimum requirement of 266.0°F. The calculated minimum temperature of the tube wall is 266.7°F.

Since the analysis of the concentrated heat sink model yields acceptable results, the insulation detail of the column support region of the support is adequate. The heat loss is greater at the column support than at the transfer lug. The insulation detail at the transfer lug is also adequate.

VI. CONCLUSIONS:

The insulation details at the transfer lug and column support analyzed in the refined analyses are adequate. The minimum temperature in the tube wall occurs at the column support. This minimum calculated temperature is 266.7^{O}F, above the required temperature of 266.0^{O}F.

While not shown in Figures 1 through 4, two inches of duct wrap insulation covering the plates, micarta, and column is required to meet the minimum tube wall temperature requirement. The transfer lug support detail shown in the attached figures is adequate.

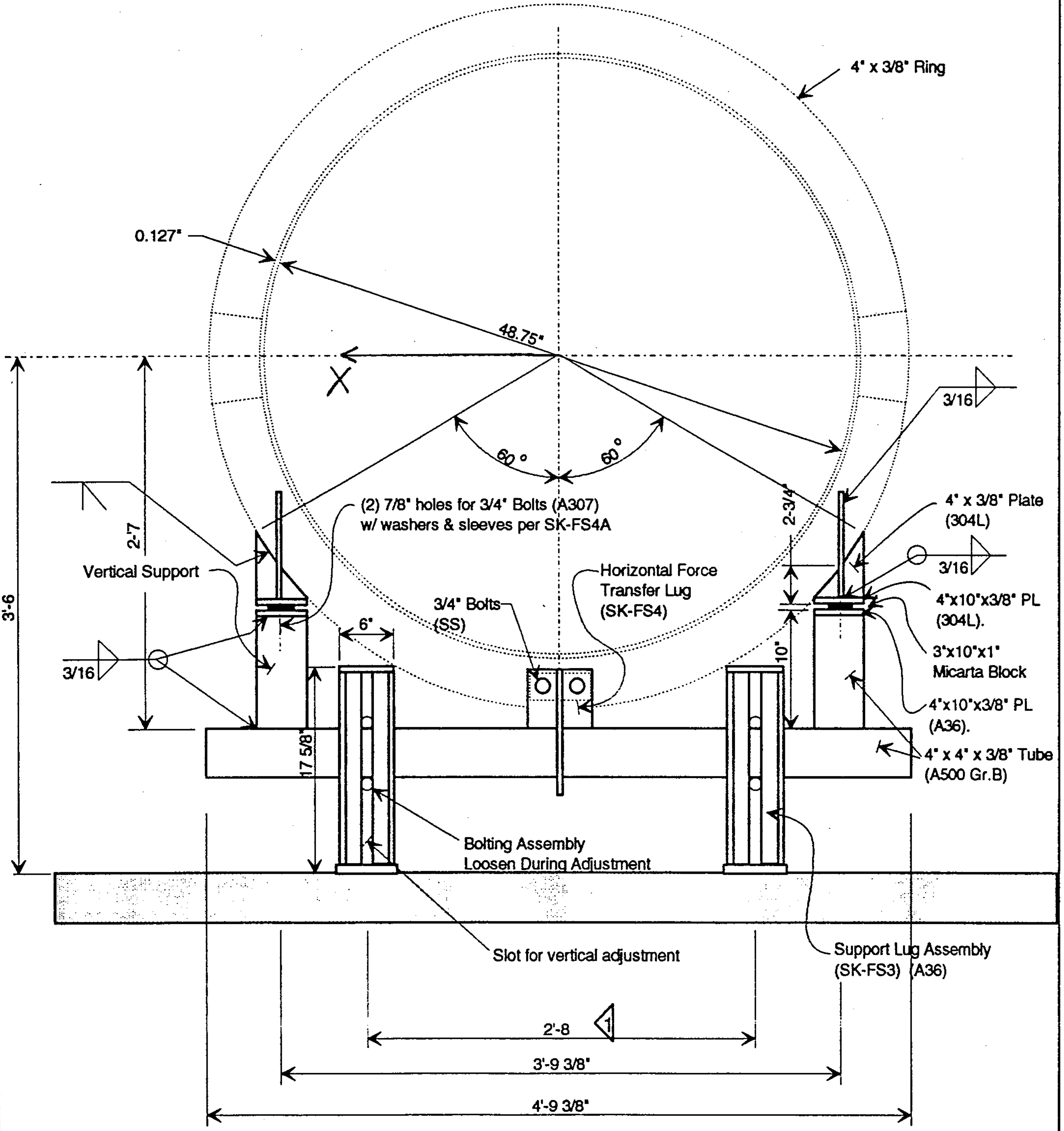
VII. REFERENCES:

1) Fundamentals of Heat Transfer, F.P. Incropera, D.P. DeWitt, John Wiley and Sons, 1981 Edition.

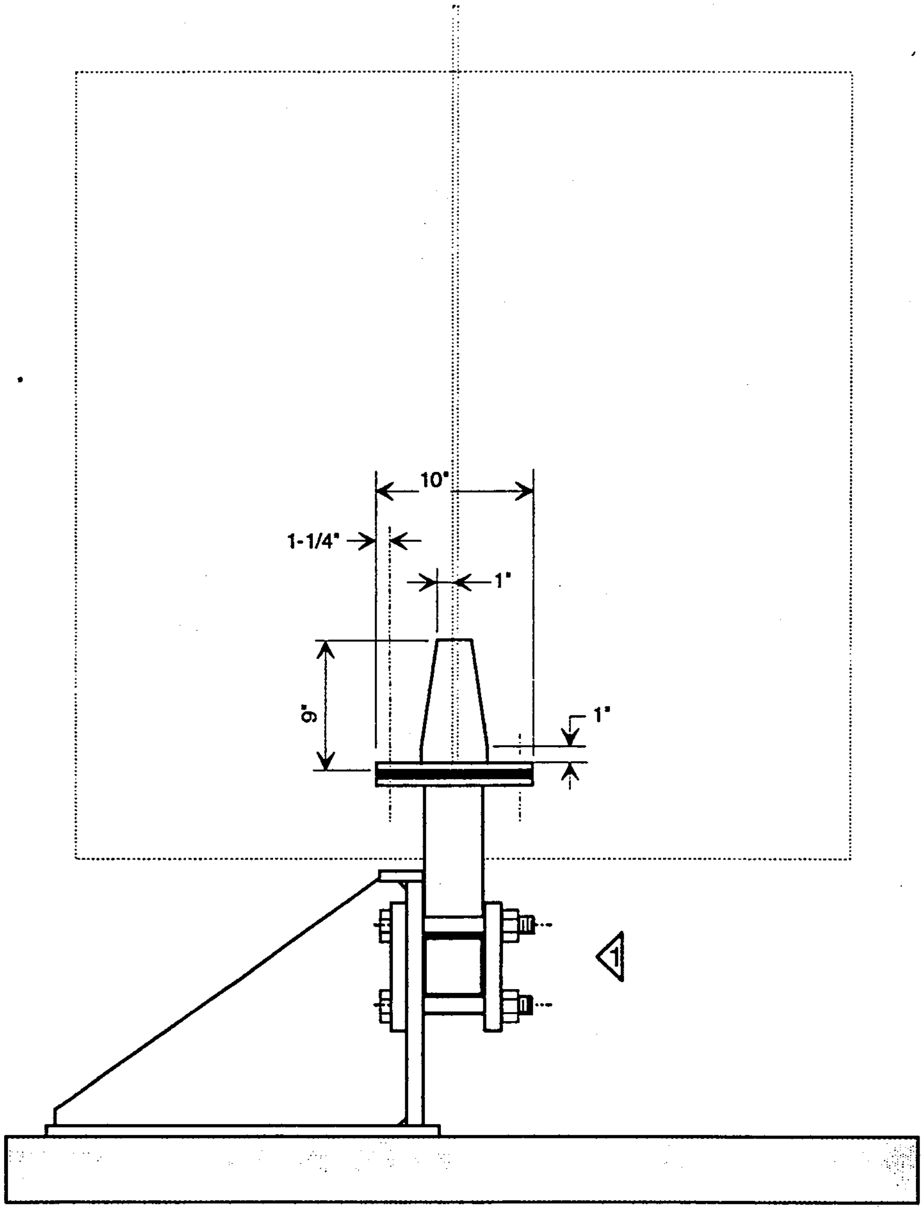
2) ASME Code, Section II, Part D, Table TCD, 1992 Edition.

3) Krauf Duct Wrap Technical Data Manual

Figure 1:
Ligo Support Geometry - Elevation View



SUBJECT	CBI OFFICE		REVISION: 1	REFERENCE NO.
LIGO BEAM TUBE FIXED SUPPORT	MADE MRS	CHK'D	MADE MRS	CHK'D WJC	SHT 8 OF__
	DATE 2/22/94	DATE	DATE 3/7/94	DATE 3-30-94	SK - FS1A



SIDE VIEW

Figure 2:
Ligo Support Geometry - Side View

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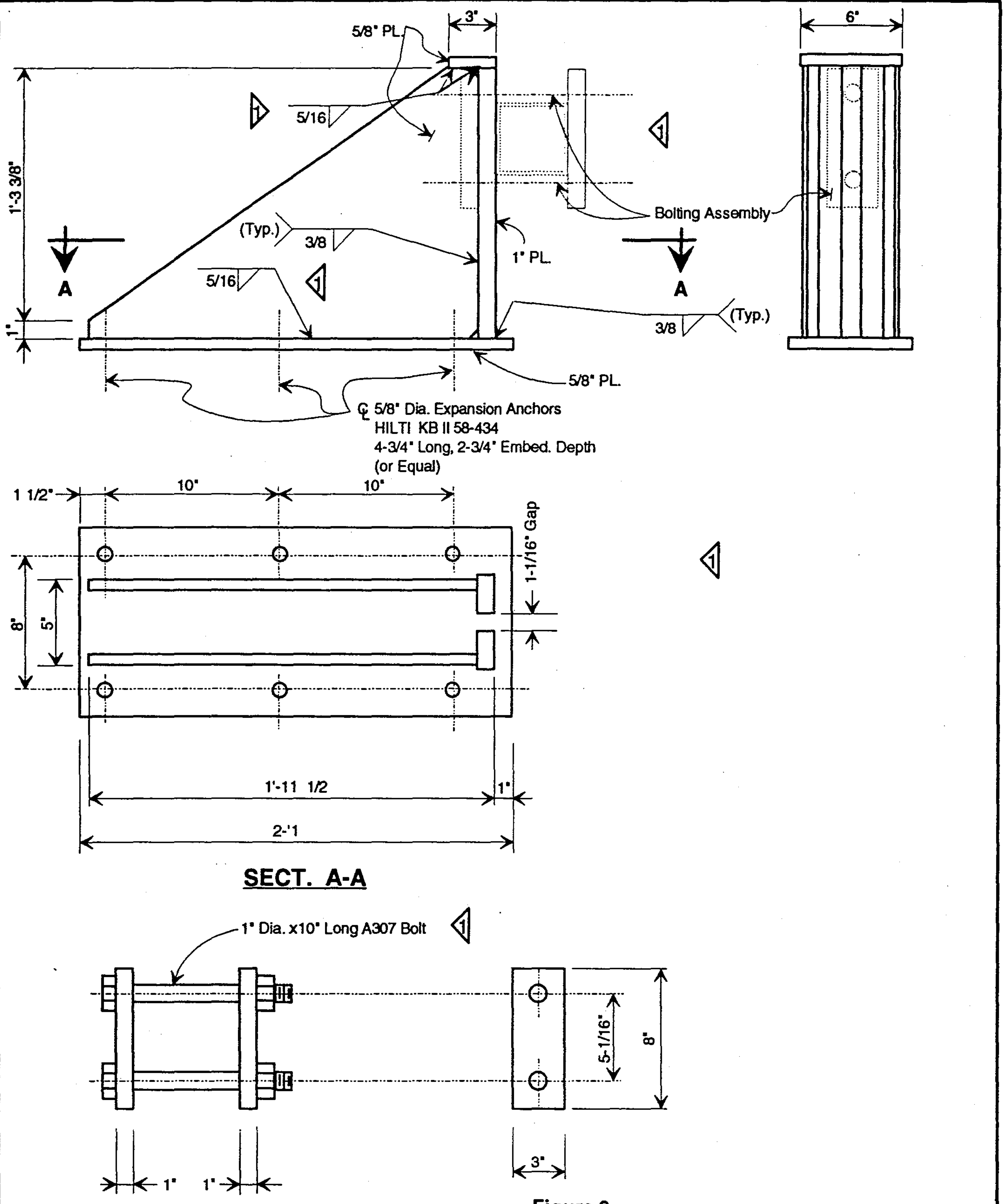
LIGO BEAM TUBE FIXED SUPPORT	**MADE** MRS	**CHK'D**	**MADE** MRS	**CHK'D** WJC	**SHT** 9 **OF**
	DATE 2/19/94	**DATE**	**DATE** 3/7/94	**DATE** 3-30-94	**SK - FS2A**



SECT. A-A

BOLTING ASSEMBLY

Figure 3:
Ligo Support Geometry - Support Lug Assembly

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SUPPORT LUG ASSEMBLY BEAM TUBE FIXED SUPPORT LIGO	MADE MRS	CHK'D	MADE MRS	CHK'D WJC	SHT 10 OF__
	DATE 2/23/94	DATE	DATE 3/7/94	DATE 3-30-94	SK - FS3A

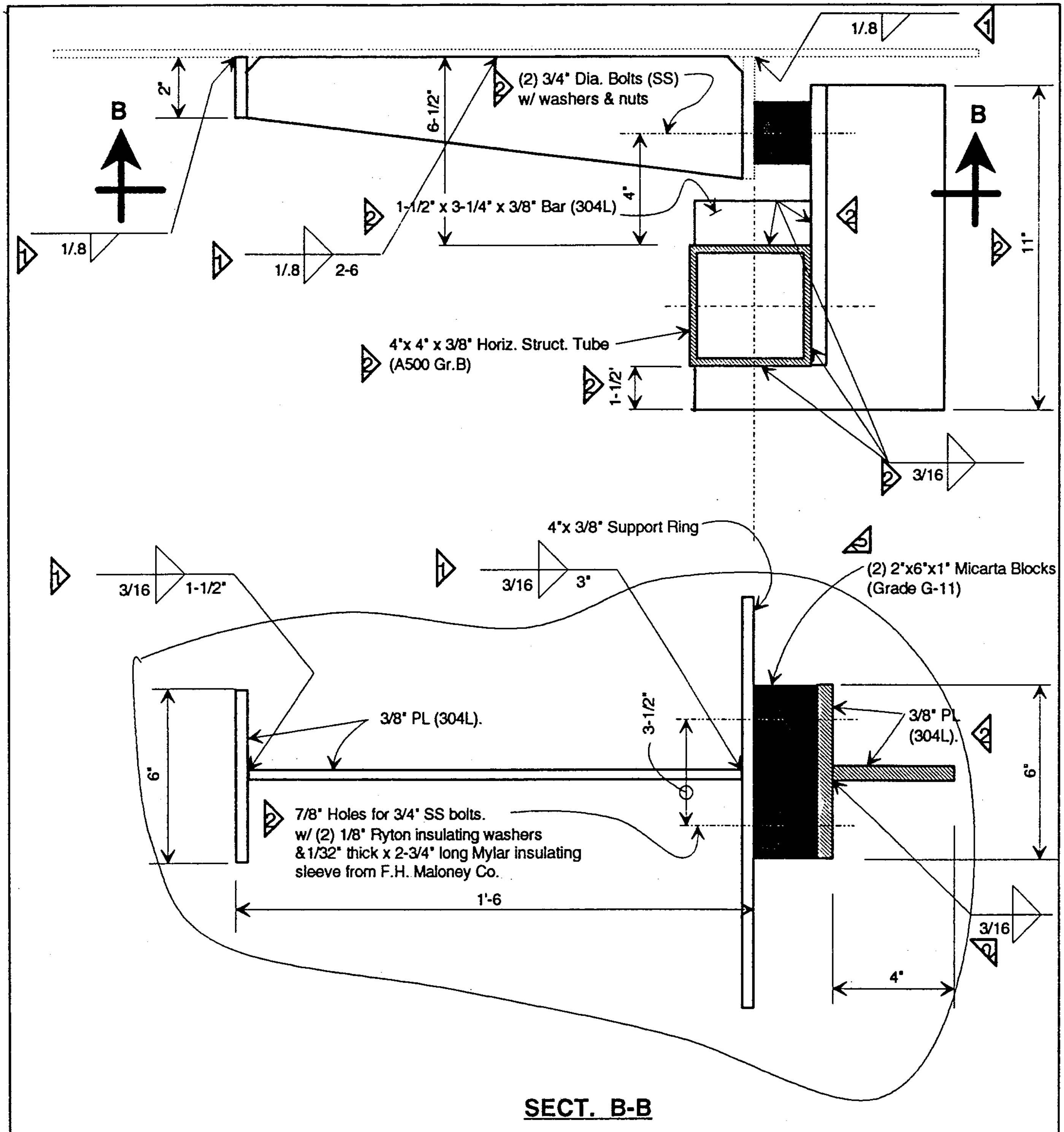

Figure 4:
Ligo Support Geometry - Transfer Lug Details

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HORIZONTAL RESTRAINT BEAM TUBE FIXED SUPPORT LIGO	**MADE** MRS	**CHK'D**	**MADE** MRS	**CHK'D** WJC	**SHT** 11 **OF**
	DATE 2/24/94	**DATE**	**DATE** 3/7/94	**DATE** 3-30-94	**SK - FS4A**

SUBJECT
LIGO HEAT TRANSFER
ANALYSIS

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OFFICE N06-A

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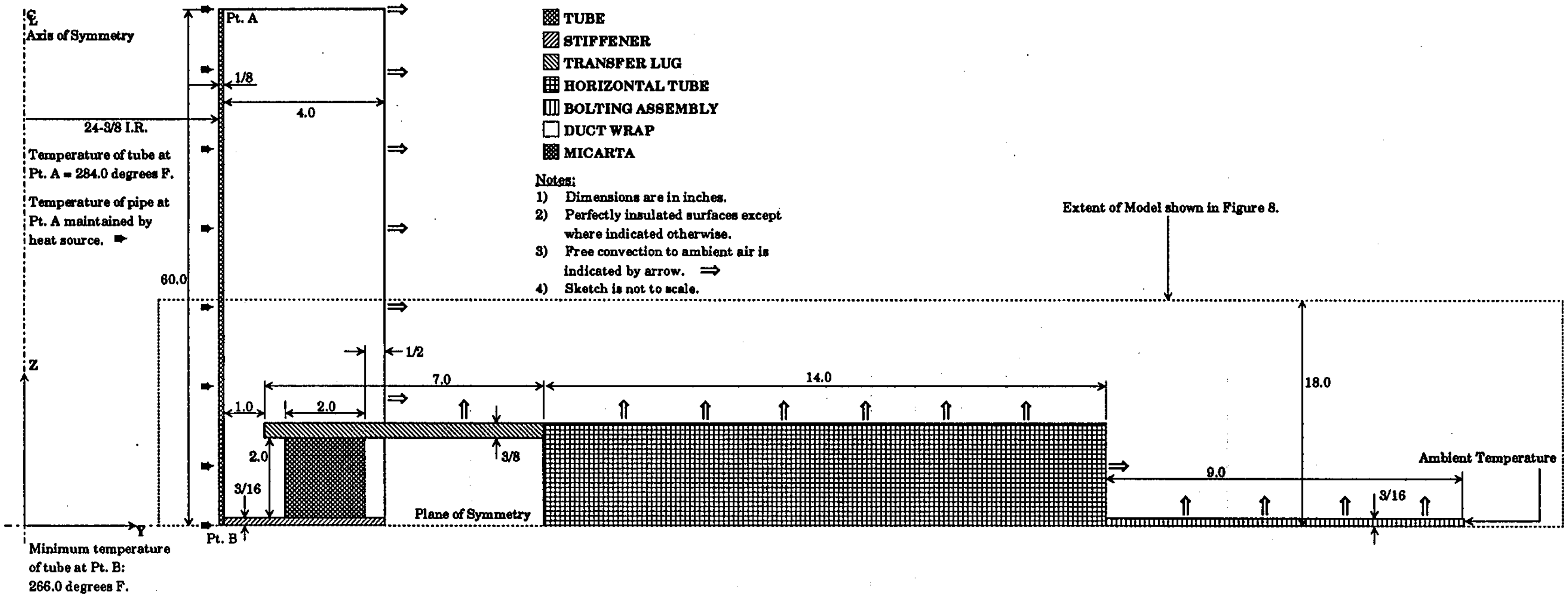

- ▩ TUBE
- ▨ STIFFENER
- ▧ TRANSFER LUG
- ▦ HORIZONTAL TUBE
- ▥ BOLTING ASSEMBLY
- ☐ DUCT WRAP
- ▩ MICARTA

Notes:
1) Dimensions are in inches.
2) Perfectly insulated surfaces except where indicated otherwise.
3) Free convection to ambient air is indicated by arrow. ⇒
4) Sketch is not to scale.

Figure 5:
Transfer Lug Model - Geometry

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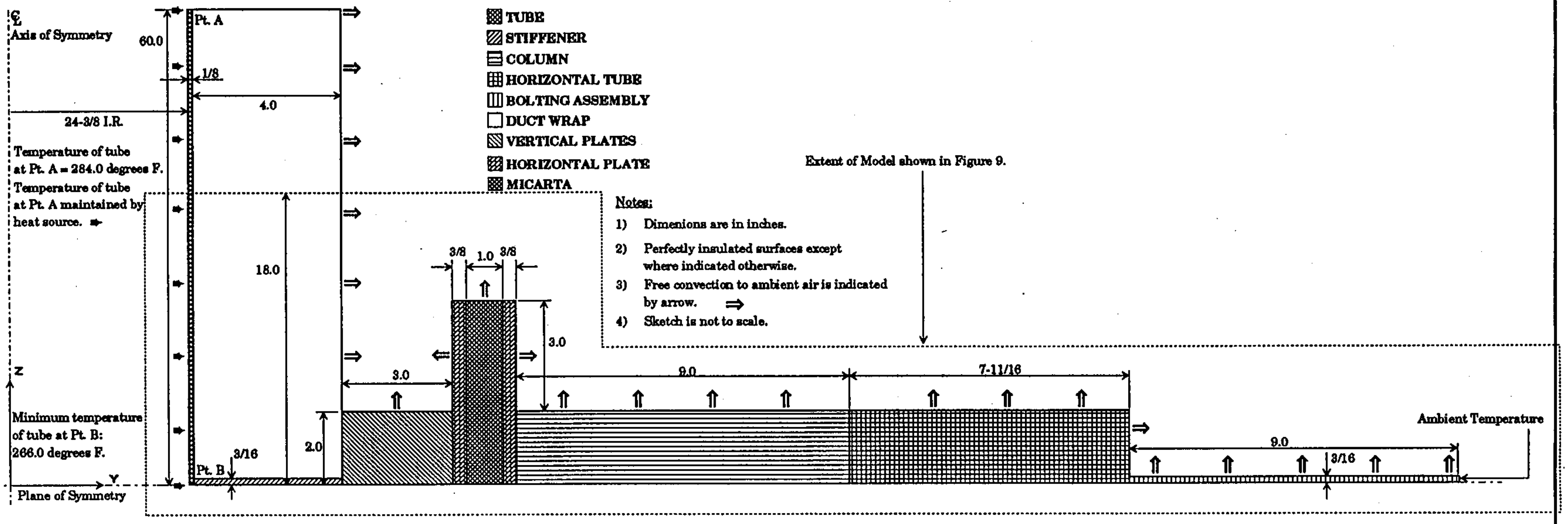

Notes:

1) Dimensions are in inches.
2) Perfectly insulated surfaces except where indicated otherwise.
3) Free convection to ambient air is indicated by arrow. ⇒
4) Sketch is not to scale.

Figure 6:
Column Support Model - Geometry

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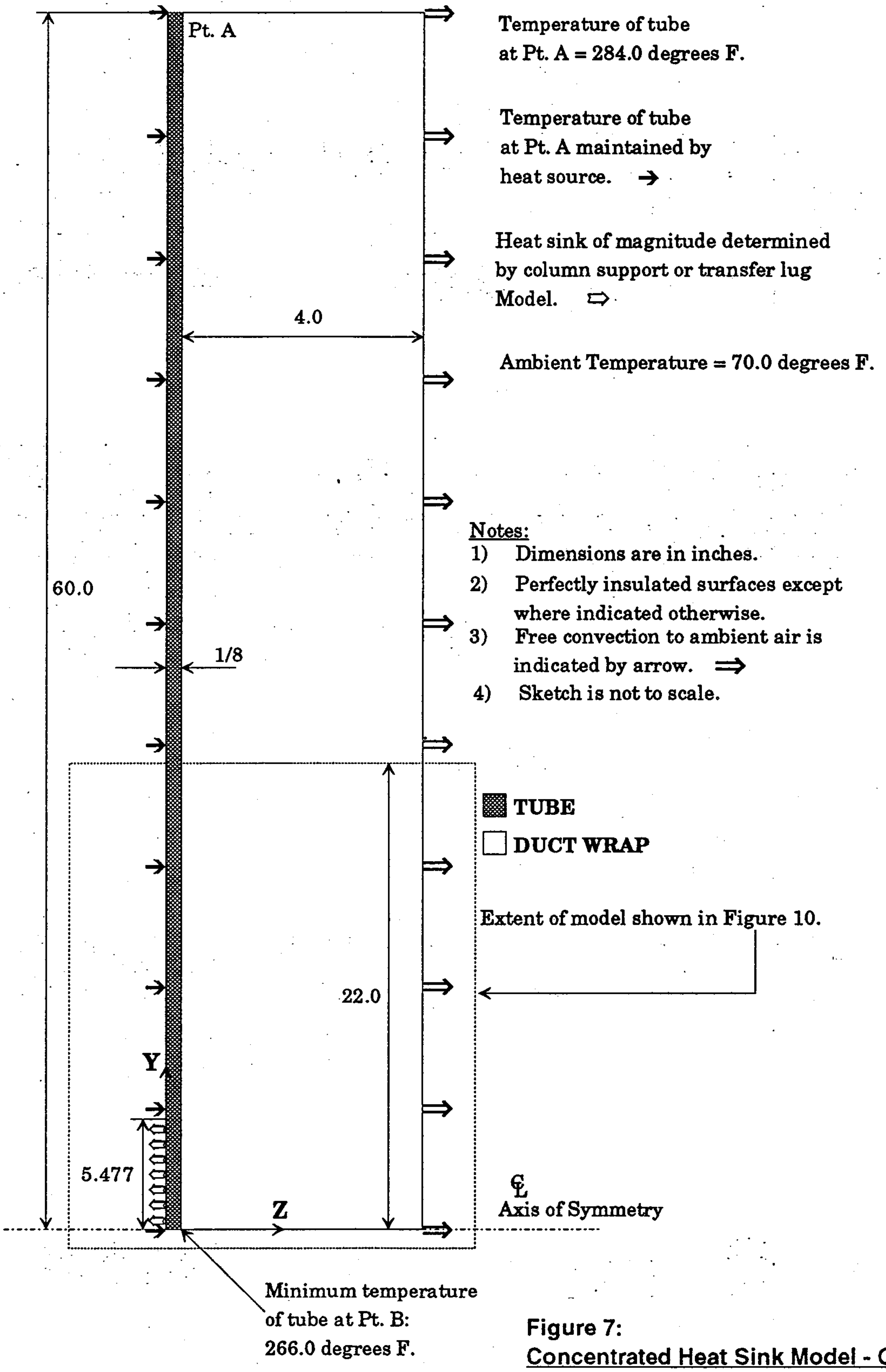

Temperature of tube at Pt. A = 284.0 degrees F.

Temperature of tube at Pt. A maintained by heat source. →

Heat sink of magnitude determined by column support or transfer lug Model. ⇨

Ambient Temperature = 70.0 degrees F.

Notes:
1) Dimensions are in inches.
2) Perfectly insulated surfaces except where indicated otherwise.
3) Free convection to ambient air is indicated by arrow. ⟹
4) Sketch is not to scale.

▨ **TUBE**

☐ **DUCT WRAP**

Extent of model shown in Figure 10.

Axis of Symmetry

Minimum temperature of tube at Pt. B: 266.0 degrees F.

Figure 7:
Concentrated Heat Sink Model - Geometry

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LIGO HEAT TRANSFER ANALYSIS

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SUBJECT

Ligo Beam Tube Design and Qualification

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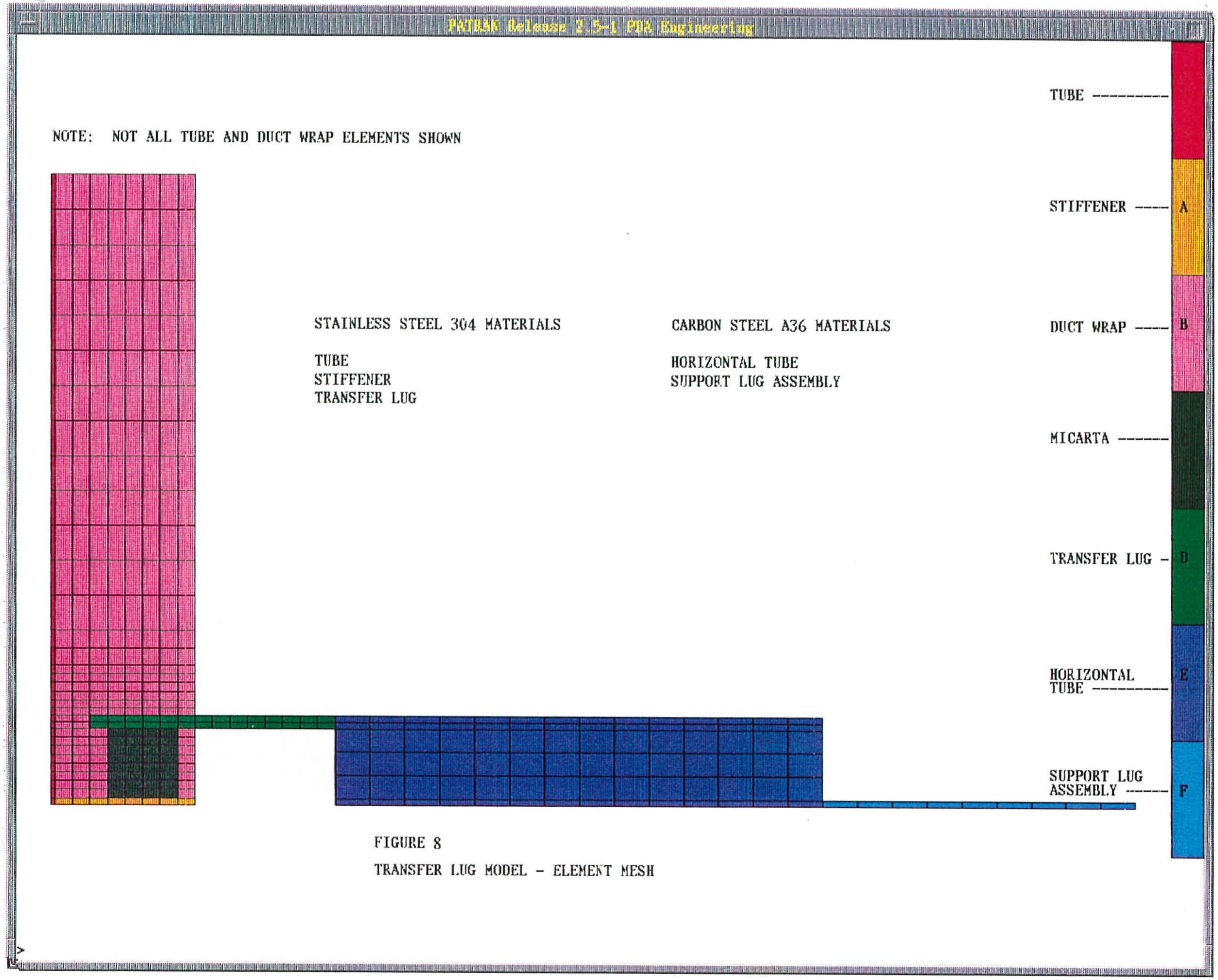


NOTE: NOT ALL TUBE AND DUCT WRAP ELEMENTS SHOWN

STAINLESS STEEL 304 MATERIALS

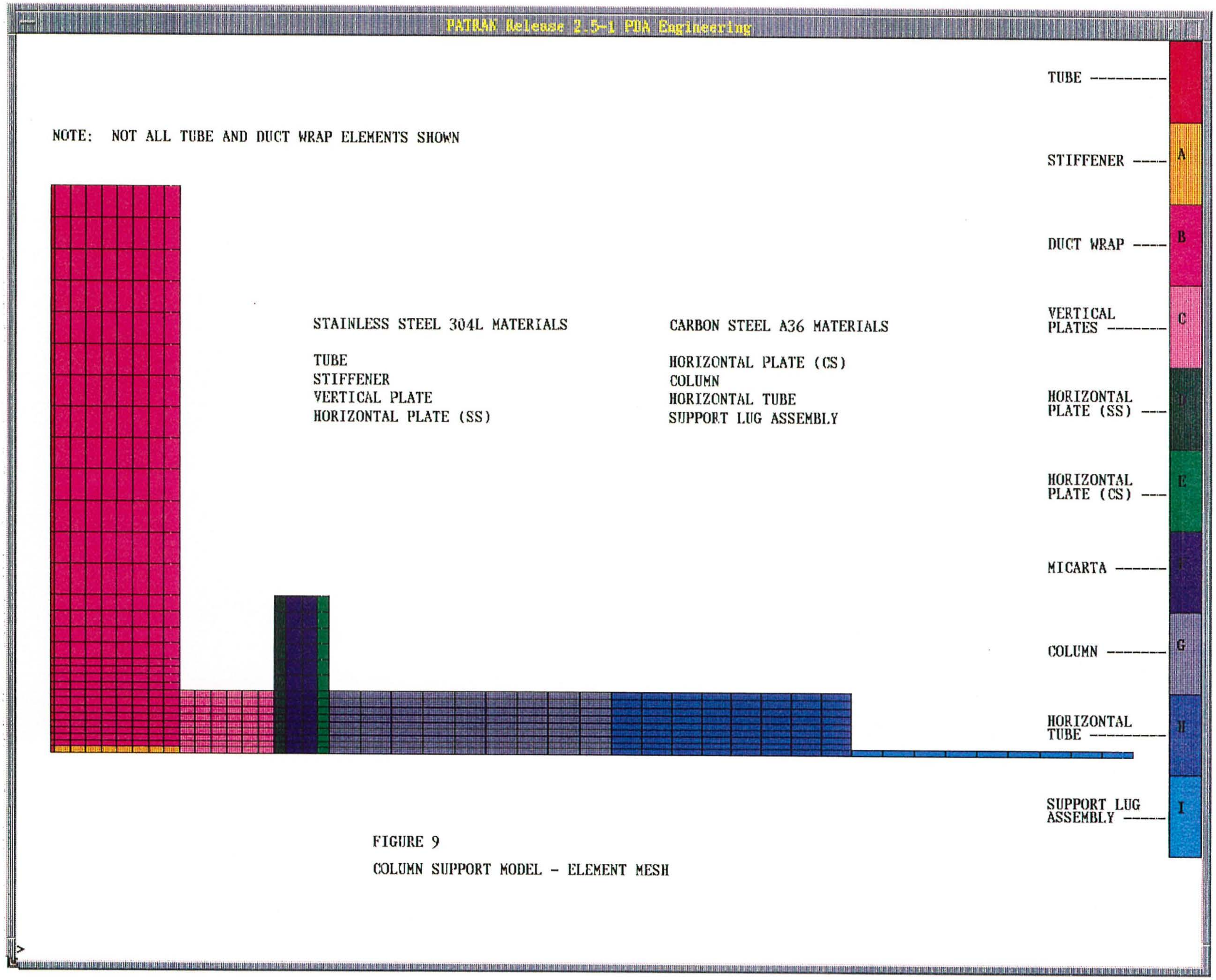
TUBE
STIFFENER
TRANSFER LUG

CARBON STEEL A36 MATERIALS

HORIZONTAL TUBE
SUPPORT LUG ASSEMBLY

FIGURE 8

TRANSFER LUG MODEL - ELEMENT MESH



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NOTE: NOT ALL TUBE AND DUCT WRAP ELEMENTS SHOWN

STAINLESS STEEL 304L MATERIALS

TUBE
STIFFENER
VERTICAL PLATE
HORIZONTAL PLATE (SS)

CARBON STEEL A36 MATERIALS

HORIZONTAL PLATE (CS)
COLUMN
HORIZONTAL TUBE
SUPPORT LUG ASSEMBLY

FIGURE 9

COLUMN SUPPORT MODEL - ELEMENT MESH

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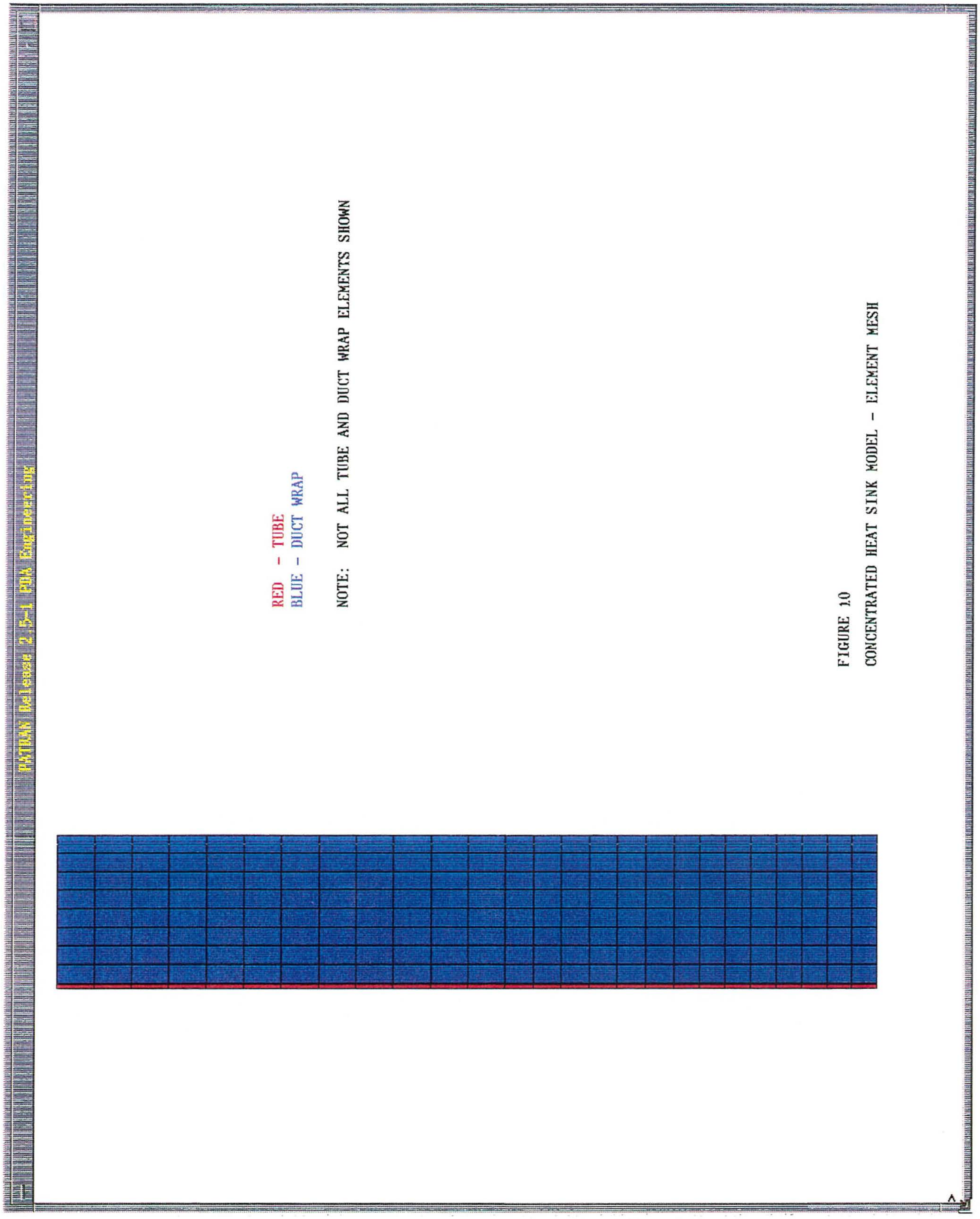

RED - TUBE
BLUE - DUCT WRAP

NOTE: NOT ALL TUBE AND DUCT WRAP ELEMENTS SHOWN

FIGURE 1.0
CONCENTRATED HEAT SINK MODEL - ELEMENT MESH

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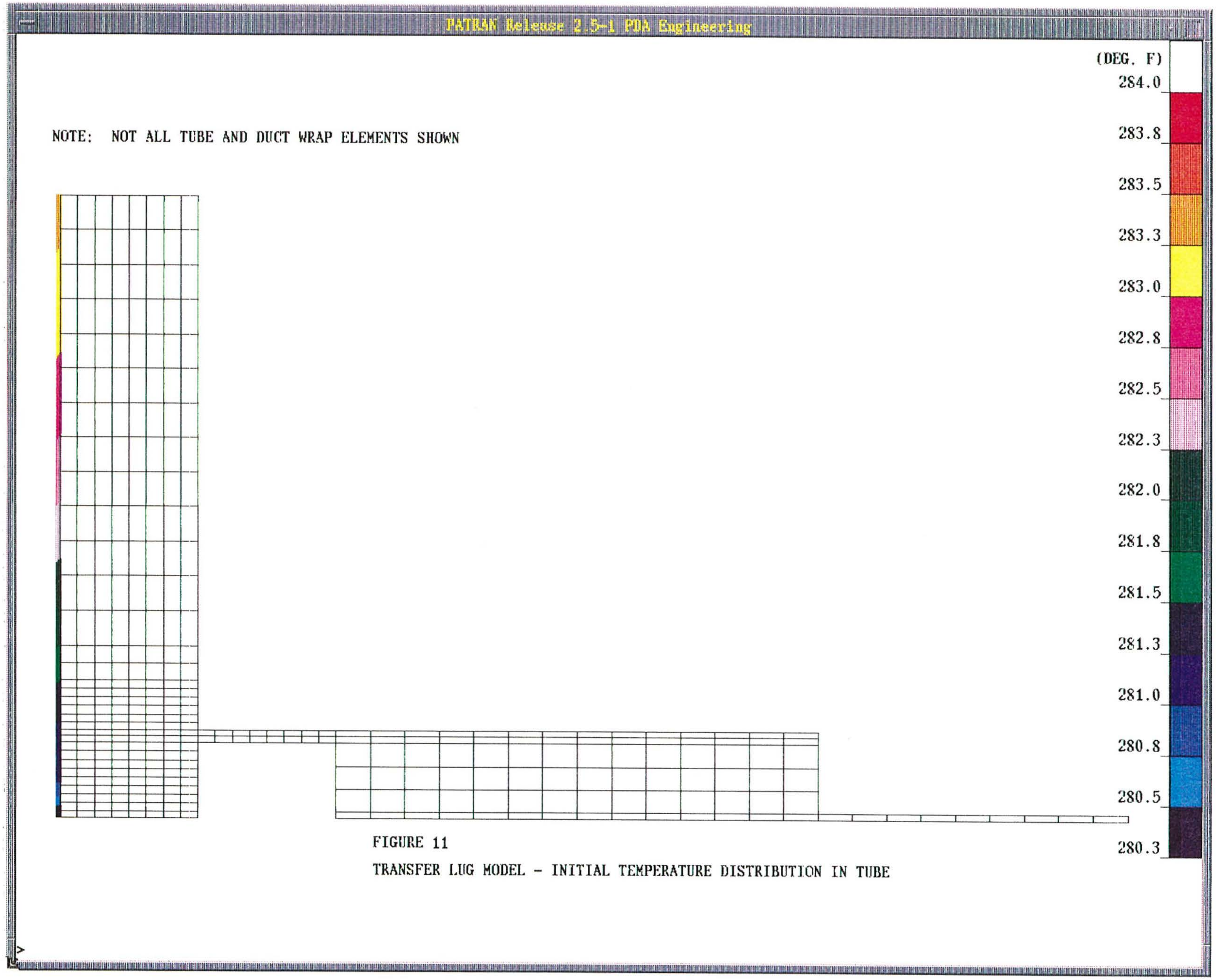

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FIGURE 11

TRANSFER LUG MODEL - INITIAL TEMPERATURE DISTRIBUTION IN TUBE

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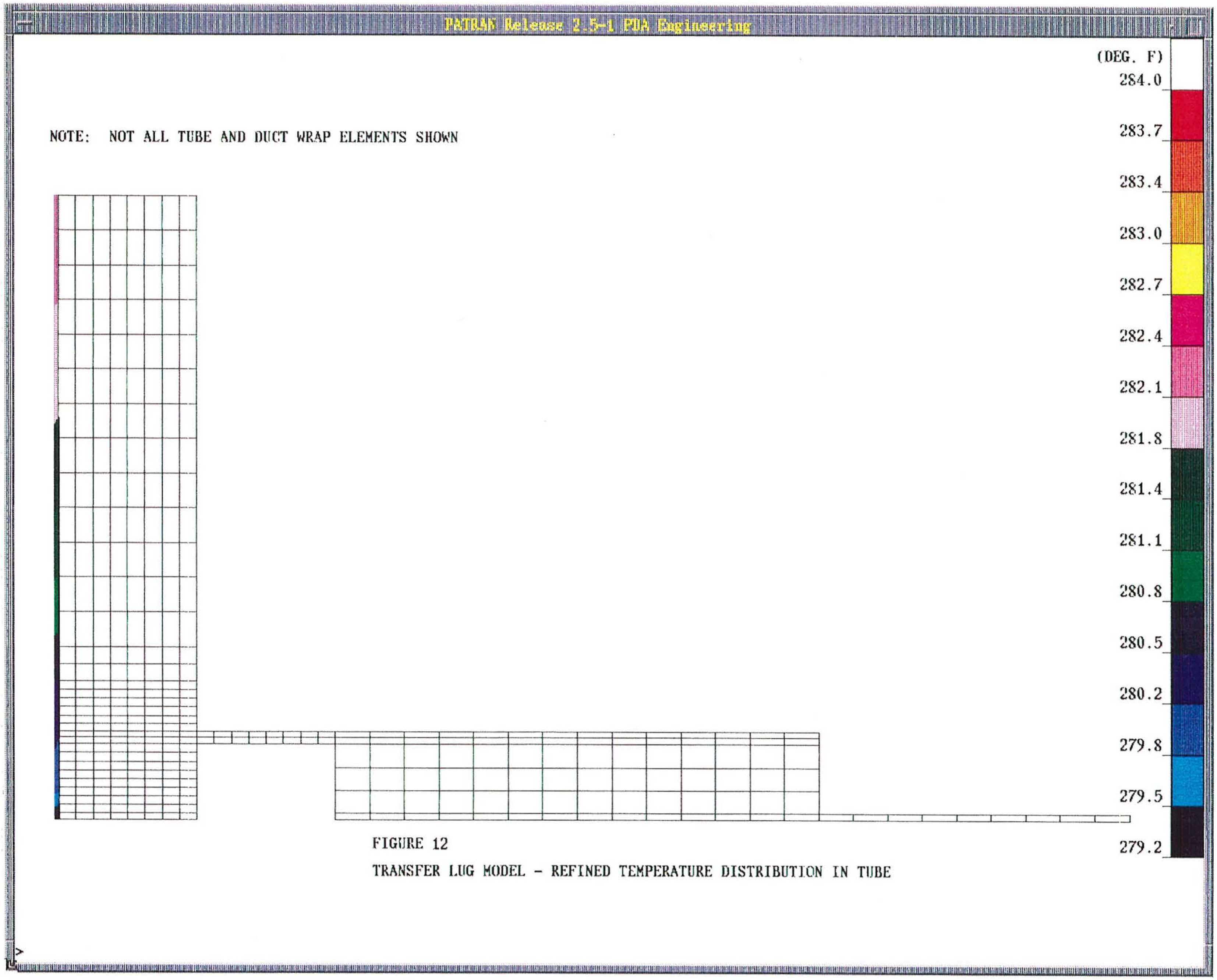
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NOTE: NOT ALL TUBE AND DUCT WRAP ELEMENTS SHOWN

FIGURE 12

TRANSFER LUG MODEL - REFINED TEMPERATURE DISTRIBUTION IN TUBE

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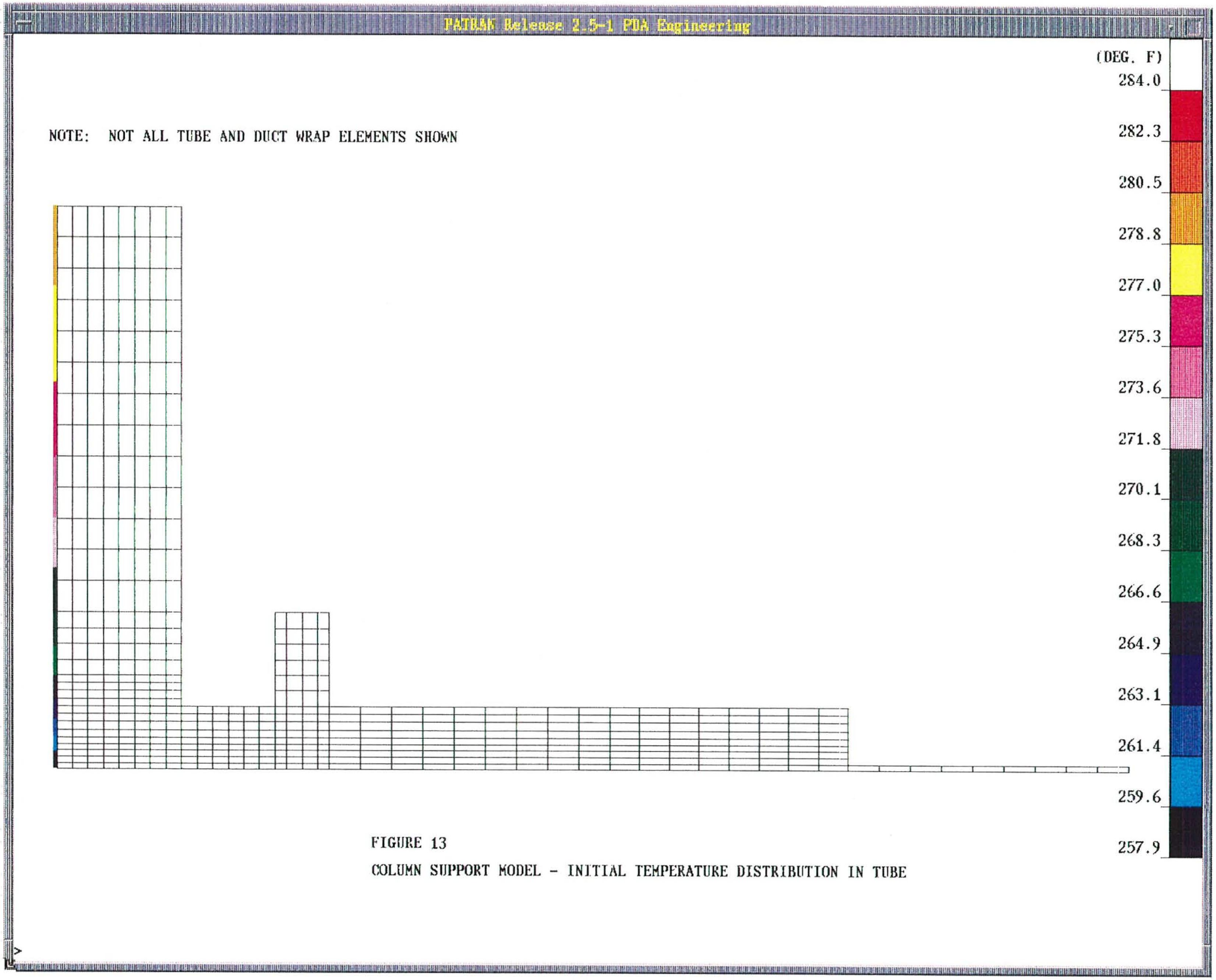

NOTE: NOT ALL TUBE AND DUCT WRAP ELEMENTS SHOWN

FIGURE 13

COLUMN SUPPORT MODEL - INITIAL TEMPERATURE DISTRIBUTION IN TUBE

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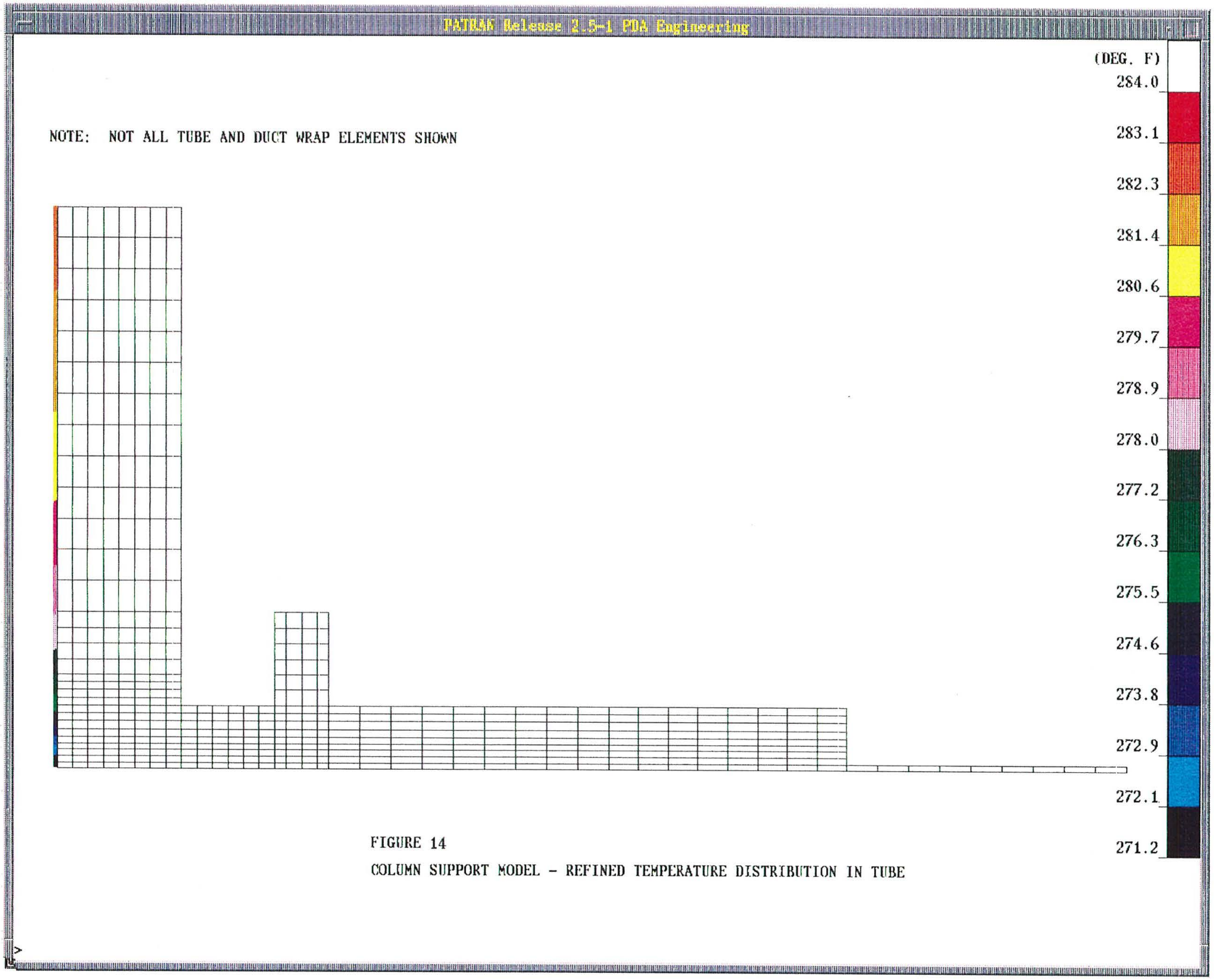

NOTE: NOT ALL TUBE AND DUCT WRAP ELEMENTS SHOWN

FIGURE 14

COLUMN SUPPORT MODEL - REFINED TEMPERATURE DISTRIBUTION IN TUBE

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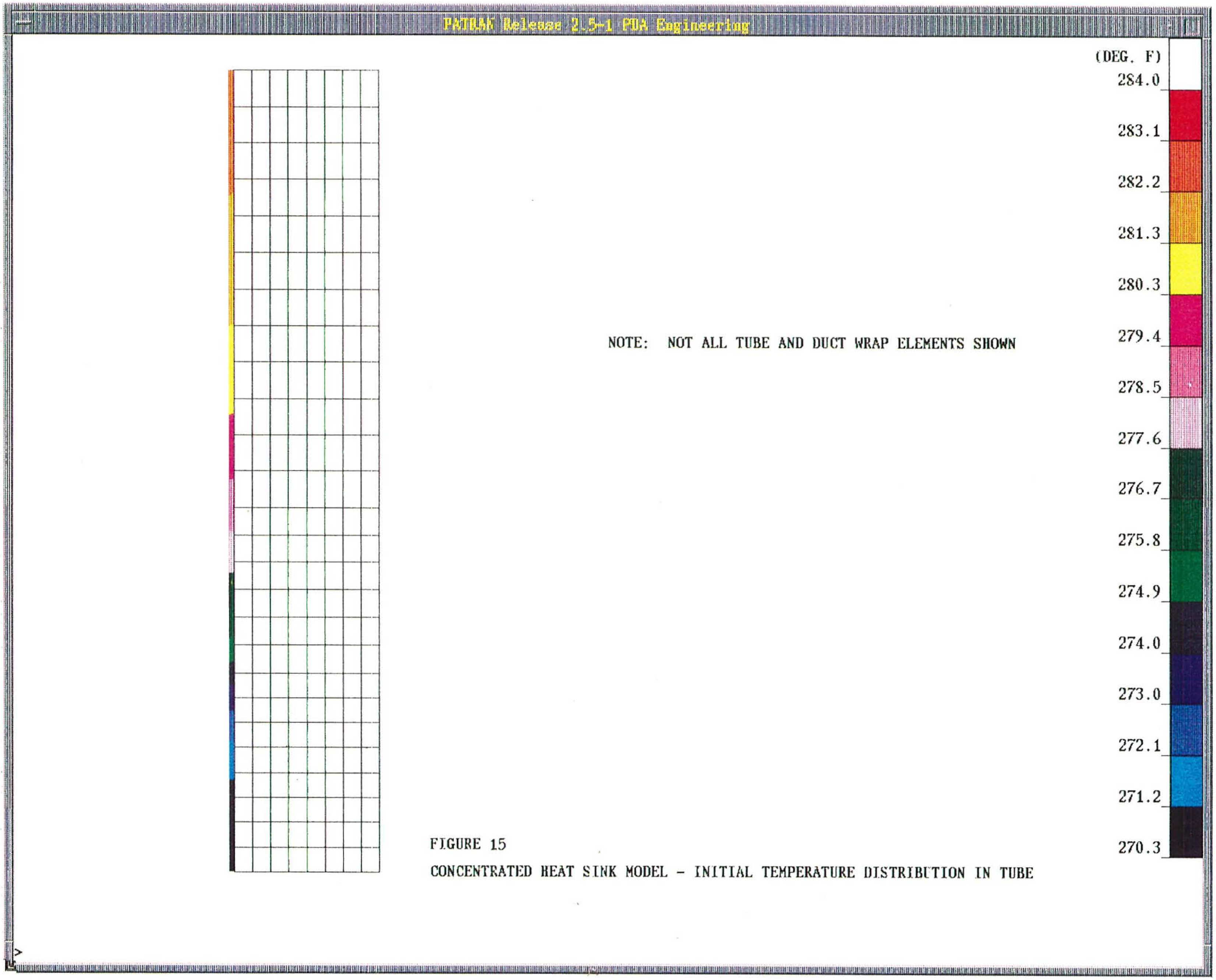

NOTE: NOT ALL TUBE AND DUCT WRAP ELEMENTS SHOWN

FIGURE 15

CONCENTRATED HEAT SINK MODEL - INITIAL TEMPERATURE DISTRIBUTION IN TUBE

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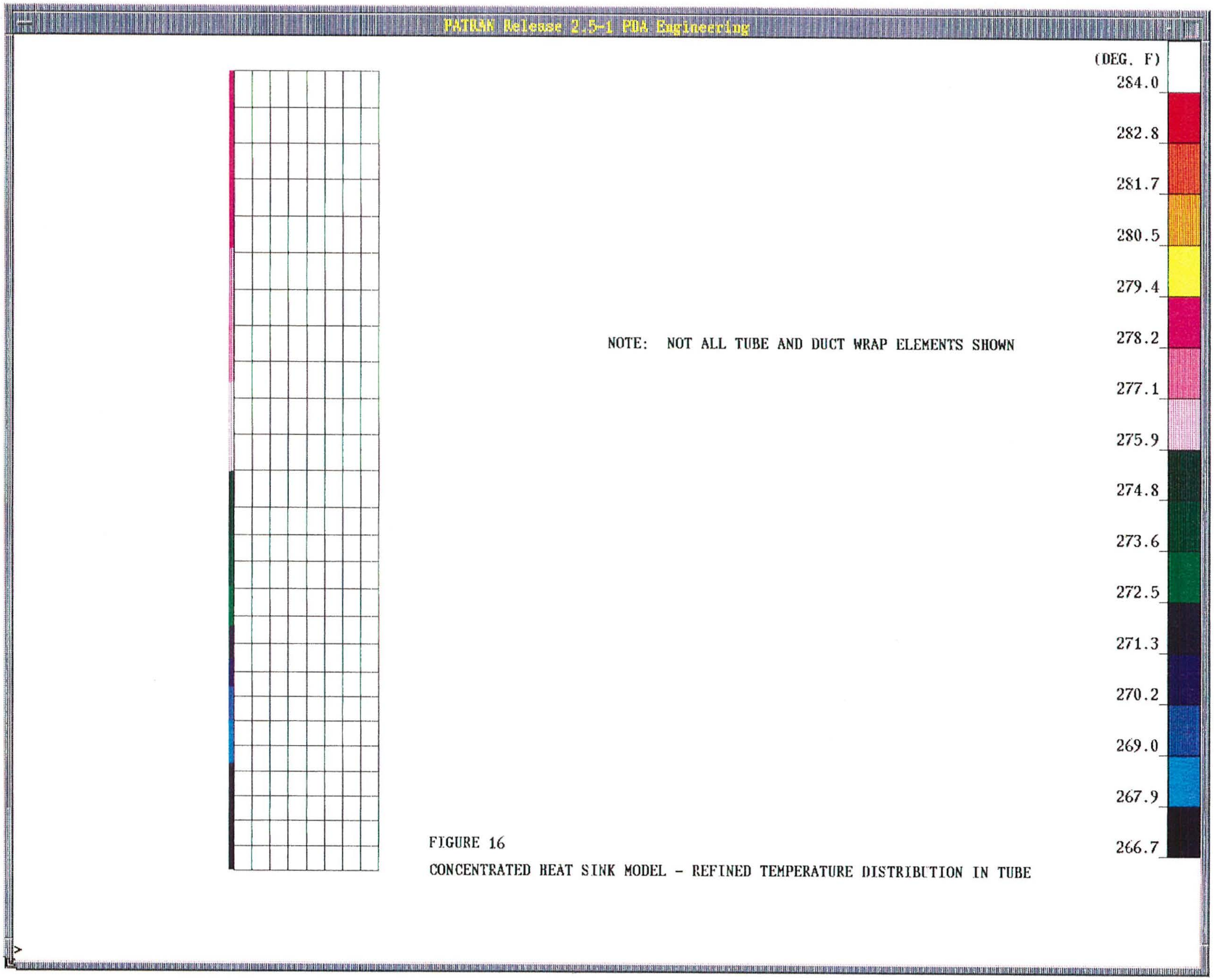

NOTE: NOT ALL TUBE AND DUCT WRAP ELEMENTS SHOWN

FIGURE 16

CONCENTRATED HEAT SINK MODEL - REFINED TEMPERATURE DISTRIBUTION IN TUBE

Table 1

Thermal Conductivities - Base Values

Temperature (Deg. F)	Stainless Steel 304L (BTU/hr in F)	Carbon Steel A36 (BTU/hr in F)	Duct Wrap (BTU/hr in F)
70.0	0.717	1.967	1.792E-03
75.0	----------	----------	1.792E-03
100.0	0.725	1.992	1.917E-03
125.0	----------	----------	2.069E-03
150.0	0.750	2.017	2.236E-03
175.0	----------	----------	2.458E-03
200.0	0.775	2.033	2.667E-03
225.0	----------	----------	2.958E-03
250.0	0.800	2.033	3.264E-03
275.0	----------	----------	3.625E-03
300.0	0.817	2.033	4.028E-03

Thermal Conductivity of Micarta

(Assumed Independent of Temperature)

k = 1.25E-02 BTU/hr in F

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Table 2

Thermal Conductivities - Smearing Factors

Transfer Lug Model

Component	Smearing Factor
Micarta	0.01768
Transfer Lug	0.03724
Horizontal Tube	0.00977
Support Lug	0.71772

Column Support Model

Component	Smearing Factor
Vertical Plates	0.01367
Horizontal Plate (SS)	0.02009
Horizontal Plate (CS)	0.01926
Micarta	0.01475
Column	0.00613
Horizontal Tube	0.00408
Support Lug	0.33447

Location NOE - A

Table 3

Convective Film Coefficients - Base Values

Free Convection to Ambient Temperature

Temperature (Deg. F)	h (BTU/hr in^2 F)
70.0	7.857E-06
75.0	2.385E-03
100.0	4.149E-03
125.0	4.957E-03
150.0	5.506E-03
175.0	5.924E-03
200.0	6.260E-03
225.0	6.541E-03
250.0	6.782E-03

Free Convection Plus Two Inches Duct Wrap Insulation

Temperature (Deg. F)	h (BTU/hr in^2 F)
70.0	----------
75.0	6.513E-04
100.0	7.786E-04
125.0	8.559E-04
150.0	9.293E-04
175.0	1.018E-03
200.0	1.099E-03
225.0	1.206E-03
250.0	1.315E-03

Table 4

Convective Film Coefficients - Smearing Factors

Transfer Lug Model

Component	Smearing Factor
Transfer Lug	0.08675
Horizontal Tube	0.06141
Support Lug	0.21955

Column Support Model

Component	Smearing Factor
Vertical Plates	0.10853
Horizontal Plate (SS)	0.00785
Horizontal Plate (CS)	0.00745
Micarta	0.06391
Column	0.03607
Horizontal Tube	0.02315
Support Lug	0.10284

CBI

Location NOE - A

Appendix A

Axisymmetric Smearing Factor Calculations

SUBJECT	MADE BY	CHKD BY	REV			CHARGE NO.
Ligo Heat Transfer Analysis	DEP	KAD		BY		930212
CalTech	DATE 3/29/94	DATE 3/29/94		CHKD		SHT A1 OF
				DATE		

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TRANSFER LUG MODEL

MICARTA

VOLUME IN SUPPORT = $V_1' = 2'' \times 6'' \times 2'' \Rightarrow V_1' = 24 \text{ in}^3$

VOLUME PER 32.50' OF LIGO = $V_1'' = V_1'/2 = 24/2 \Rightarrow V_1'' = 12 \text{ in}^3$

VOLUME IN MODEL = $V_1 = \pi(R_o^2 - R_i^2)h$

$R_i = 26''$ $R_o = 28''$ $h = 2''$

$\Rightarrow V_1 = 678.58 \text{ in}^3$

SMEARING Factor = $R = V_1''/V_1 = \frac{12}{678.58}$

$\Rightarrow \underline{\underline{R = 0.01768}}$

TRANSFER LUG

VOLUME IN SUPPORT = $V_1' = (6'' \times 3/8'' \times 9\tfrac{1}{2}'') + (4'' \times 3/8'' \times 9\tfrac{1}{2}'')$

$\Rightarrow V_1' = 35.625 \text{ in}^3$

VOLUME PER 32.50' OF LIGO = $V_1'' = V_1'/2 \Rightarrow 35.625/2$

$\Rightarrow V_1'' = 17.813 \text{ in}^3$

VOLUME IN MODEL = $V_1 = \pi(R_o^2 - R_i^2)h$

$R_i = 25.5''$ $R_o = 32.5''$ $h = 3/8''$

$\Rightarrow V_1 = 478.31 \text{ in}^3$

SMEARING Factor = $R = V_1''/V_1 = \frac{17.813}{478.31}$

$\Rightarrow \underline{\underline{R = 0.03724}}$

SUBJECT	OFFICE	REVISION		REFERENCE NO.
LIGO HEAT TRANSFER ANALYSIS - CALTECH	CBI NOE-A			930212
	MADE BY DEP	CHKD BY KAD	MADE BY	CHKD BY	SHT A2 OF
	DATE 3/29/94	DATE 3/29/94	DATE	DATE	

HORIZONTAL TUBE

VOLUME IN SUPPORT $= V_1' = A \cdot L$

$L = 2'-8'' \Rightarrow L = 32''$

$A = (4^2 - 3.25^2) \Rightarrow A = 5.4375 \text{ in}^2$

$\Rightarrow V_1' = 174.0 \text{ in}^3$

VOLUME PER 32.50' OF LIGO $= V_1'' = V_1'/2 = 174/2$

$\Rightarrow V_1'' = 87 \text{ in}^3$

VOLUME IN MODEL $= V_1 = \pi(R_o^2 - R_i^2)h$

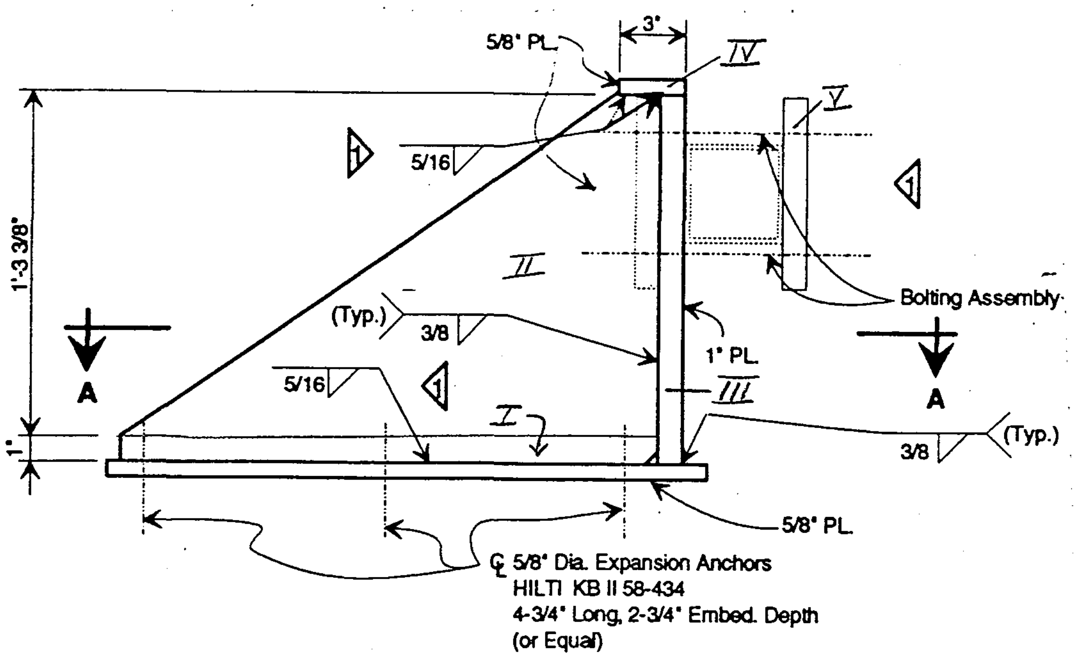
$R_i = 32.5'' \quad R_o = 46.5'' \quad h = 2\,9/16''$

$\Rightarrow V_1 = 8903.67 \text{ in}^3$

SMEARING Factor $= R = V_1''/V_1 = 87/8903.67$

$$\Rightarrow \underline{\underline{R = 0.00977}}$$

SUPPORT LUG



SUBJECT
LIGO HEAT TRANSFER
ANALYSIS - CAL TECH

CBI OFFICE NOE-A

REVISION

REFERENCE NO. 930212

MADE BY	CHKD BY	MADE BY	CHKD BY
DEP	KAD		
DATE 3/29/94	DATE 3/29/94	DATE	DATE

SHT A3 OF ___

Area of I : $1'' \times 22\tfrac{1}{2}'' \Rightarrow A_1 = 22\tfrac{1}{2} \text{ in}^2$

Area of II : $\frac{1}{2}[15\tfrac{3}{8}''][2'' + 22\tfrac{1}{2}''] \Rightarrow A_2 = 188.34375 \text{ in}^2$

Area of III : $1'' \times 16\tfrac{3}{8}'' \Rightarrow A_3 = 16.375 \text{ in}^2$

Area of IV : $3'' \times \tfrac{5}{8}'' \Rightarrow A_4 = 1.875 \text{ in}^2$

Area of V : $8'' \times 1'' \Rightarrow A_5 = 8 \text{ in}^2$

VOLUME OF SECTIONS I through V :

$t_1 = t_2 = \tfrac{5}{8}'' \qquad t_4 = 6''$

$t_3 = 1''$

$t_5 = 3''$

$$V_i = A_i \cdot t_i \Rightarrow \begin{aligned} V_1 &= 14.0625 \text{ in}^3 \\ V_2 &= 117.7148 \text{ in}^3 \\ V_3 &= 16.375 \text{ in}^3 \\ V_4 &= 11.25 \text{ in}^3 \\ V_5 &= 24 \text{ in}^3 \end{aligned}$$

VOLUME OF BOLTS : 1" DIAMETER

LENGTH (NOT INCLUDING PLATE OVERLAP)

9"

$$V_B = 9\pi \text{ in}^3 \Rightarrow V_B = 28.2743 \text{ in}^3$$

VOLUME PER 32.50' OF LIGO $= V_1'' =$

$$2 * [V_1 + V_2 + V_3 + \tfrac{1}{2}V_4 + \tfrac{1}{2}V_5 + V_B]$$

$$\Rightarrow V_1'' = 388.103 \text{ in}^3$$

VOLUME IN MODEL $= V_1''' = \pi(R_o^2 - R_i^2)h$

$R_i = 46.5'' \quad R_o = 55.5'' \quad h = \tfrac{3}{16}''$

$$\Rightarrow V_1''' = 540.75 \text{ in}^3$$

SMEARING Factor $= R = V_1''/V_1''' = \dfrac{388.103}{540.75}$

$$\Rightarrow \underline{\underline{R = 0.71772}}$$

SUBJECT LIGO HEAT TRANSFER ANALYSIS - CALTECH	CBI OFFICE NOE-A		REVISION		REFERENCE NO. 930212
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TRANSFER LUG - EXPOSED SURFACE AREA

SURFACE AREA IN SUPPORT = $E_1' =$

$2(4'' \times 9\frac{1}{2}'') + 6'' \times 9\frac{1}{2}'' \Rightarrow E_1' = 133 \text{ in}^2$

SURFACE AREA per 32.50' OF LIGO = $E_1 = E_1'/2$

$\Rightarrow E_1 = 66.5 \text{ in}^2$

SURFACE AREA IN MODEL = $E_1'' = \pi(R_o^2 - R_i^2)$

$R_i = 28.5''$ $R_o = 32.5''$

$\Rightarrow E_1'' = 766.55 \text{ in}^2$

SMEARING FACTOR = $R = E_1/E_1'' \Rightarrow \underline{\underline{R = 0.08675}}$

HORIZONTAL TUBE - EXPOSED SURFACE AREA

SURFACE AREA IN SUPPORT = $E_1' = 4[4'' \times 32'']$

$\Rightarrow E_1' = 512 \text{ in}^2$

SURFACE AREA per 32.50' OF LIGO : $E_1 = E_1'/2$

$\Rightarrow E_1 = 256 \text{ in}^2$

SURFACE AREA IN MODEL = $E_1'' = \pi(R_o^2 - R_i^2) + 2\pi(2\frac{3}{8})R_o$

$R_i = 32.5''$ $R_o = 46.5''$

$\Rightarrow E_1'' = 4168.50 \text{ in}^2$

Smearing Factor : $R = E_1/E_1'' \Rightarrow \underline{R = 0.06141}$

SUBJECT LIGO HEAT TRANSFER ANALYSIS - CALTECH	CBI OFFICE NOE-A		REVISION		REFERENCE NO. 930212
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SUPPORT LUG - EXPOSED SURFACE AREA

SURFACE AREA IN SUPPORT $= E_1' =$

$$4 \times 17\,5/8'' \times 6'' + 4\,[A_1 + A_2]$$

$A_1 = 22.5 \text{ in}^2$

$A_2 = 188.34375 \text{ in}^2$

$$\Rightarrow E_1' = 1266.375 \text{ in}^2$$

SURFACE AREA per 32.50' OF LIGO $= E_1 = E_1'/2$

$$\Rightarrow E_1 = 633.1875 \text{ in}^2$$

SURFACE AREA IN MODEL $= E_1'' = \pi(R_o^2 - R_i^2)$

$R_i = 46.5''$ $\quad R_o = 55.5''$

$$\Rightarrow E_1'' = 2883.982 \text{ in}^2$$

SMEARING Factor : $R = E_1/E_1'' \Rightarrow \underline{\underline{R = 0.21955}}$

SUBJECT LIGO HEAT TRANSFER ANALYSIS - CALTECH	CBI OFFICE NOE-A	REVISION		REFERENCE NO. 930212
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COLUMN SUPPORT MODEL

VERTICAL PLATES

VOLUME IN SUPPORT = $V_1' = 2 \times 3/16'' \times (2'' \times 1'' + 1/2 \times 7\,5/8'' \times (1''+2''))$

$+ 2 \times 3/8'' \times 4'' \times 8\,5/8''$

$\Rightarrow V_1' = 30.9141$

VOLUME per 32.50' OF LIGO = $V_1'' = V_1'/2$

$\Rightarrow V_1'' = 15.4571$

VOLUME IN MODEL = $V_1 = \pi(R_o^2 - R_i^2)h$

$R_i = 28.5''$ $R_o = 31.5''$ $h = 2.0''$

$\Rightarrow V_1 = 1130.97\ in^3$

SMEARING Factor = $R = V_1''/V_1 = \frac{15.4571}{1130.97}$

$\Rightarrow \underline{\underline{R = 0.01367}}$

HORIZONTAL PLATES

VOLUME IN SUPPORT = $V_1' = 4'' \times 10'' \times 3/8'' \Rightarrow V_1' = 15.0\ in^3$

VOLUME per 32.50' OF LIGO = $V_1'' = V_1'/2$

$\Rightarrow V_1'' = 7.50\ in^3$

VOLUME IN MODEL = $V_1 = \pi(R_o^2 - R_i^2)h$

PLATE 1: $R_i = 31.5''$ $R_o = 31\,7/8''$ $h = 5.0''$

PLATE 2: $R_i = 32\,7/8''$ $R_o = 33\,1/4''$ $h = 5.0''$

PLATE 1: $V_1 = 373.309\ in^3$

PLATE 2: $V_1 = 389.508\ in^3$

SMEARING Factor = $R = V_1/V_1''$

$\Rightarrow$ PLATE 1: $\underline{\underline{R = 0.02009}}$ PLATE 2: $\underline{\underline{R = 0.01926}}$

SUBJECT LIGO HEAT TRANSFER ANALYSIS - CAL TECH	OFFICE CBI NOE-A		REVISION		REFERENCE NO. 930212
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	DATE 3/29/94	DATE 3/29/94	DATE	DATE	

MICARTA

VOLUME IN SUPPORT $= V_1' = 3'' \times 10'' \times 1'' \Rightarrow V_1' = 30 \text{ in}^3$

VOLUME per 32.50' OF LIGO $= V_1'' = V_1'/2 \Rightarrow V_1'' = 15 \text{ in}^3$

VOLUME IN MODEL $= V_1 = \pi (R_o^2 - R_i^2) h$

$R_i = 31\,7/8''$ $R_o = 32\,7/8''$ $h = 5.0''$

$\Rightarrow V_1 = 1017.09 \text{ in}^3$

SMEARING Factor $= R = V_1''/V_1$

$$\Rightarrow \underline{\underline{R = 0.01475}}$$

COLUMN

VOLUME IN SUPPORT $= V_1' = A \cdot L$

$L = 10'' - 3/8'' \Rightarrow L = 9.625''$

$A = (4^2 - 3.25^2) \Rightarrow A = 5.4375 \text{ in}^2$

$\Rightarrow V_1' = 52.336 \text{ in}^3$

VOLUME per 32.50' OF LIGO $= V_1'' = V_1'/2$

$\Rightarrow V_1'' = 26.168 \text{ in}^3$

VOLUME IN MODEL $\Rightarrow V_1 = \pi (R_o^2 - R_i^2) h$

$R_i = 33\,1/4''$ $R_o = 42\,1/4''$ $h = 2.0''$

$\Rightarrow V_1 = 4269.424 \text{ in}^3$

SMEARING Factor $= R = V_1''/V_1 = \dfrac{26.168}{4269.42}$

$$\Rightarrow \underline{\underline{R = 0.00613}}$$

SUBJECT	CBI OFFICE	REVISION		REFERENCE NO.
LIGO HEAT TRANSFER ANALYSIS - CALTECH	NOE-A			930212
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	DATE 3/29/94	DATE 3/29/94	DATE	DATE	

HORIZONTAL TUBE

VOLUME IN SUPPORT $= V_1' = A \cdot L$

$$L = 1/2\,[(3'-9\,3/8")-(2'-8")] \Rightarrow L = 6.6875"$$

$$A = (4^2 - 3.25^2) \Rightarrow A = 5.4375"$$

$$\Rightarrow V_1' = 36.363 \text{ in}^3$$

VOLUME per 32.50' OF LIGO $= V_1'' = V_1'/2$

$$\Rightarrow V_1'' = 18.182 \text{ in}^3$$

VOLUME OF MODEL $= V_1 = \pi(R_o^2 - R_i^2)\,h$

$R_i = 42\,1/4"$ $R_o = 49\,15/16"$ $h = 2.0"$

$$\Rightarrow V_1 = 4452.839 \text{ in}^3$$

SMEARING Factor $= R = V_1''/V_1$

$$\Rightarrow \underline{\underline{R = 0.00408}}$$

SUPPORT LUG

Volume per 32.50' OF LIGO $= 1/2\ V_1''$ from Support Lug from TRANSFER LUG MODEL.

$$V_1'' = 193.052 \text{ in}^3$$

VOLUME IN MODEL $= V = \pi(R_o^2 - R_i^2)\,h$

$R_i = 49\,15/16"$ $R_o = 58\,15/16"$ $h = 3/16"$

$$\Rightarrow V = 577.194 \text{ in}^3$$

SMEARING Factor $= R = V_1''/V = \dfrac{193.052}{577.194}$

$$\Rightarrow \underline{\underline{R = 0.33447}}$$

SUBJECT LIGO HEAT TRANSFER ANALYSIS - CALTECH	CBI OFFICE NOE-A		REVISION		REFERENCE NO. 930212
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VERTICAL PLATES - EXPOSED SURFACE AREA

SURFACE AREA IN SUPPORT $= E_1'$

$$= 4\left[2'' \times 1'' + \tfrac{1}{2} \times 7\tfrac{5}{8}'' \times (2'' + 1'')\right] + 2\left[4'' \times 8\tfrac{5}{8}''\right]$$

$$\Rightarrow E_1' = 122.75 \text{ in}^2$$

SURFACE AREA per 32.50' OF LIGO $= E_1 = E_1'/2$

$$\Rightarrow E_1 = 61.375 \text{ in}^2$$

SURFACE AREA IN MODEL $= E_1'' = \pi(R_o^2 - R_i^2)$

$R_i = 28.5''$ $R_o = 31.5''$

$$\Rightarrow E_1'' = 565.487 \text{ in}^2$$

Smearing Factor $= R = E_1/E_1'' = \dfrac{61.375}{565.487}$

$$\Rightarrow \underline{\underline{R = 0.10853}}$$

HORIZONTAL PLATES - EXPOSED SURFACE AREA

SURFACE AREA IN SUPPORT $= E_1'$

$$= 2\left[4'' \times 3/8''\right] + 2\left[10'' \times 3/8''\right]$$

$$\Rightarrow E_1' = 10.50 \text{ in}^2$$

SURFACE AREA per 32.50' OF LIGO $= E_1$

$= E_1'/2 \quad \Rightarrow E_1 = 5.25 \text{ in}^2$

VOLUME IN MODEL PLATE 1: $E_1'' = \pi(R_o^2 - R_i^2) + 2\pi(3)R_i$

PLATE 2: $E_1'' = \pi(R_o^2 - R_i^2) + 2\pi(3)R_o$

PLATE 1: $R_i = 31.5''$ $R_o = 31\,7/8''$ $E_1'' = 668.423 \text{ in}^2$

PLATE 2: $R_i = 32\,7/8''$ $R_o = 33\,1/4''$ $E_1'' = 704.649 \text{ in}^2$

Smearing Factor $= R = E_1/E_1''$

$\Rightarrow$ PLATE 1: $\underline{R = 0.00785}$ PLATE 2: $\underline{R = 0.00745}$

SUBJECT LIGO HEAT TRANSFER ANALYSIS - CALTECH	OFFICE CBI NOE-A	REVISION		REFERENCE NO. 930212
	MADE BY DEP	CHKD BY KAD	MADE BY	CHKD BY	A10 SHT___OF___
	DATE 3/29/94	DATE 3/29/94	DATE	DATE	

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MICARTA - EXPOSED SURFACE AREA

SURFACE AREA IN SUPPORT $= E_1'$

$= 2[3'' \times 1''] + 2[10'' \times 1''] \Rightarrow E_1' = 26 \text{ in}^2$

SURFACE AREA per 32.50' OF LIGO $= E_1$

$= E_1'/2 \Rightarrow E_1 = 13 \text{ in}^2$

SURFACE AREA IN MODEL $= E_1'' = \pi(R_o^2 - R_i^2)$

$R_i = 31\,7/8''$ $R_o = 32\,7/8''$

$\Rightarrow E_1'' = 203.418 \text{ in}^2$

Smearing Factor $= R = E_1/E_1'' = 13/203.418$

$\Rightarrow \underline{\underline{R = 0.06391}}$

COLUMN - EXPOSED SURFACE AREA

SURFACE AREA IN SUPPORT $= E_1'$

$= 4[4'' \times 9\,5/8''] \Rightarrow E_1' = 154 \text{ in}^2$

SURFACE AREA per 32.50' OF LIGO $= E_1$

$= E_1'/2 \Rightarrow E_1 = 77 \text{ in}^2$

SURFACE AREA IN MODEL $= E_1'' = \pi(R_o^2 - R_i^2)$

$R_i = 33\,1/4''$ $R_o = 42\,1/4''$

$\Rightarrow E_1'' = 2134.712 \text{ in}^2$

Smearing Factor $= R = E_1/E_1'' = 77/2134.712$

$\Rightarrow \underline{\underline{R = 0.03607}}$

SUBJECT	CBI OFFICE	REVISION		REFERENCE NO.
LIGO HEAT TRANSFER ANALYSIS - CALTECH	NOE-A			930212
	MADE BY DEP	CHKD BY KAD	MADE BY	CHKD BY	All SHT__ OF__
	DATE 3/29/94	DATE 3/29/94	DATE	DATE	

HORIZONTAL TUBE - EXPOSED SURFACE AREA

SURFACE AREA IN SUPPORT $= E_1' = 4[4'' \times 6.6875'']$

$\Rightarrow E_1' = 107 \text{ in}^2$

SURFACE AREA per 32.50' OF LIGO $= E_1 = E_1'/2$

$\Rightarrow E_1 = 53.5 \text{ in}^2$

SURFACE AREA IN MODEL $= E_1'' = \pi(R_o^2 - R_i^2) + 1\tfrac{13}{16} R_o$

$R_i = 42\tfrac{1}{4}''$ $\qquad R_o = 49\tfrac{15}{16}''$

$\Rightarrow E_1'' = 2310.689 \text{ in}^2$

Smearing Factor $= R = E_1/E_1'' = \dfrac{53.5}{2310.689}$

$\Rightarrow \underline{\underline{R = 0.02315}}$

SUPPORT LUG - EXPOSED SURFACE AREA

SURFACE AREA per 32.50' OF LIGO: $\tfrac{1}{2} E_1$ from Support Lug from Transfer Lug model.

$\Rightarrow E_1 = 316.594 \text{ in}^2$

SURFACE Area IN MODEL $= E_1'' = \pi(R_o^2 - R_i^2)$

$R_i = 49\tfrac{15}{16}''$ $\qquad R_o = 58\tfrac{15}{16}''$

$\Rightarrow E_1'' = 3078.37 \text{ in}^2$

Smearing Factor $= R = E_1/E_1'' = \dfrac{316.594}{3078.37}$

$\Rightarrow \underline{\underline{R = 0.10284}}$

SUBJECT
LIGO HEAT TRANSFER
ANALYSIS - CALTECH

CBI OFFICE NOE-A
REVISION
REFERENCE NO. 930212

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CHKD BY
SHT A12 OF

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DATE 3/29/94
DATE
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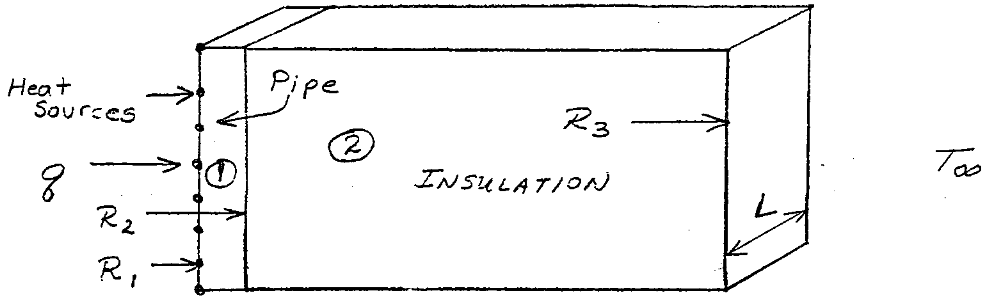
Appendix B

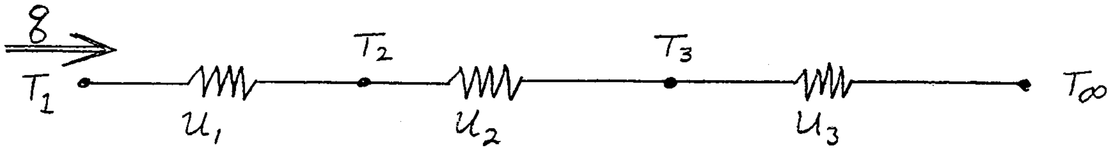
Heat Source and Free Convection Coefficient Calculations

ONE-D CALCULATION OF ELECTRICAL HEAT INPUT :



CYLINDRICAL CROSS-SECTION

ELECTRICAL ANALOGY



U_1 = Conduction through pipe
U_2 = Conduction through insulation
U_3 = Free convection from insulation

$$U_1 = \frac{\ln[R_2/R_1]}{2\pi K_1} \qquad U_2 = \frac{\ln[R_3/R_2]}{2\pi K_2}$$

$$U_3 = \frac{1}{h\, 2\pi R_3}$$

$$q = \frac{(T_1 - T_\infty) L}{U_1 + U_2 + U_3}$$

For PATRAN INPUT : $q/L = \dfrac{T_1 - T_\infty}{U_1 + U_2 + U_3}$

$$q/L = \frac{T_1 - T_3}{U_1 + U_2}$$

SUBJECT	OFFICE	REVISION		REFERENCE NO.
LIGO HEAT TRANSFER ANALYSIS - CAL TECH	CBI NOE - A			930212
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$$q/L = \frac{T_1 - T_\infty}{\frac{\ln[R_2/R_1]}{2\pi K_1} + \frac{\ln[R_3/R_2]}{2\pi K_2} + \frac{1}{h\,2\pi R_3}} \Rightarrow \textcircled{A}$$

$$q/L = \frac{T_1 - T_3}{\frac{\ln[R_2/R_1]}{2\pi K_1} + \frac{\ln[R_3/R_2]}{2\pi K_2}}$$

$$T_3 = -q/L\left[\frac{\ln[R_2/R_1]}{2\pi K_1} + \frac{\ln[R_3/R_2]}{2\pi K_2}\right] + T_1 \Rightarrow \textcircled{B}$$

IN EQUATION Ⓐ ONLY UNKNOWN IS h

K_1 and K_2 assumed independent of temperature

$$\overline{Nu}_D = \frac{hD}{K} \Rightarrow \begin{matrix} D = 2R_3 \\ K = K_3 \end{matrix} \Rightarrow h = \frac{\overline{Nu}_D K_3}{2R_3} \Rightarrow \textcircled{C}$$

K_3 for air

$$\overline{Nu}_D = \left[0.60 + \frac{0.387\,Ra_D^{1/6}}{\left[1 + (0.559/Pr)^{9/16}\right]^{8/27}}\right]^2 \quad (10^{-5} < Ra_D < 10^{12}) \Rightarrow \textcircled{D}$$

$$Ra_D = \frac{g\beta(T_3 - T_\infty)(2R_3)^3}{\nu\alpha} \Rightarrow \textcircled{E}$$

IN EQUATION Ⓔ ONLY UNKNOWN IS T_3

SOLUTION

1) ASSUME T_3
2) Solve Ⓔ for Ra_D
3) Solve Ⓓ for $\overline{Nu}_D$
4) Solve Ⓒ for h
5) Solve Ⓐ for q/L
6) Solve Ⓑ for T_3
7) Repeat 1) through 6) until convergence of T_3 is reached.

Ref: FUNDAMENTS OF HEAT TRANSFER
F.P. INCROPERA, D.P. DeWitt, 1981 Edition
Pages 80-82, 447-449

SUBJECT LIGO HEAT TRANSFER ANALYSIS - CALTECH	OFFICE CBI NOE - A		REVISION		REFERENCE NO. 930212
	MADE BY DEP	CHKD BY KAD	MADE BY	CHKD BY	SHT B3 OF
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K OF INSULATION IS A FUNCTION OF TEMPERATURE

INSULATION = 1.5 PCF

DATA FROM TECHNICAL DATA

	T (°F)	K ($\frac{BTU\ in}{hr\ ft^2\ °F}$)	K ($\frac{BTU}{in\ hr\ °F}$)
*	0	0.220	$1.528 \cdot 10^{-3}$
*	25	0.228	$1.583 \cdot 10^{-3}$
	50	0.240	$1.667 \cdot 10^{-3}$
	75	0.258	$1.792 \cdot 10^{-3}$
	100	0.276	$1.917 \cdot 10^{-3}$
	125	0.298	$2.069 \cdot 10^{-3}$
	150	0.322	$2.236 \cdot 10^{-3}$
	175	0.354	$2.458 \cdot 10^{-3}$
	200	0.384	$2.667 \cdot 10^{-3}$
*	225	0.426	$2.958 \cdot 10^{-3}$
*	250	0.470	$3.264 \cdot 10^{-3}$
*	275	0.522	$3.625 \cdot 10^{-3}$
*	300	0.580	$4.028 \cdot 10^{-3}$

* VALUES ARE EXTRAPOLATED FROM CURVE.

K OF SS304L

$250\ °F \rightarrow K = 9.6 \frac{BTU}{hr\ ft\ °F} \Rightarrow K = 0.800 \frac{BTU}{hr\ in\ °F}$

$300\ °F \rightarrow K = 9.8 \frac{BTU}{hr\ ft\ °F} \Rightarrow K = 0.817 \frac{BTU}{hr\ in\ °F}$

$K_{(284\ °F)} = 0.811 \frac{BTU}{hr\ in\ °F} \quad \therefore K_1 = 0.811 \frac{BTU}{hr\ in\ °F}$

GEOMETRY KNOWN DATA :

$R_1 = 24.375''$

$R_2 = 24.500''$

$R_3 = 28.500''$

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VISCOSITY OF AIR ν =

$T\ (K)$	$\nu \cdot 10^6\ (m^2/s)$	$T\ (°F)$	$\nu\ (in^2/hr)$
250	11.44	−9.67	63.835
300	15.89	80.33	88.666
350	20.92	170.33	116.734
400	26.41	260.33	147.368

$$1\ m^2/s = 5.58 \cdot 10^6\ in^2/hr$$

VISCOSITY OF AIR α :

$T\ (K)$	$\alpha \cdot 10^6\ (m^2/s)$	$T\ (°F)$	$\alpha\ (in^2/hr)$
250	15.90	-9.67	88.722
300	22.50	80.33	125.550
350	29.90	170.33	166.842
400	38.30	260.33	213.714

$$g = 32.2\ ft/s^2 \Rightarrow 5.007744 \cdot 10^9\ in/hr^2$$

$$\beta = \frac{1}{T} \quad (T \text{ in } °R)$$

PRANDTL NUMBER Pr : $Pr = \nu/\alpha$

CONDUCTIVITY OF AIR K_3 =

$T\ (K)$	$K \cdot 10^3\ (W/m\,K)$	$T\ (°F)$	$K_3\ (BTU/hr\ in\ °F)$
250	22.3	-9.67	$1.074 \cdot 10^{-3}$
300	26.3	80.33	$1.266 \cdot 10^{-3}$
350	30.0	170.33	$1.445 \cdot 10^{-3}$
400	33.8	260.33	$1.628 \cdot 10^{-3}$

$$1\ W/m\,K = 4.81517 \cdot 10^{-2}\ BTU/hr\ in\ °F$$

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$$T_A = \frac{T_3 + T_\infty}{2} \qquad \text{Let} \quad T_2 = T_1 \qquad T_B = \frac{T_2 + T_3}{2}$$

$$K_2 = K_{(T_B)}$$

BEGIN ITERATION PROCESS

$$T_\infty = 70\,°F \qquad T_1 = 284\,°F$$

$$\text{Let} \quad \gamma_1 = 0.387\,(Ra_D)^{1/6}$$

$$\gamma_2 = \left[1 + (0.559/Pr)^{9/16}\right]^{8/27}$$

$$\therefore \bar{N}u_D = \left[0.60 + \frac{\gamma_1}{\gamma_2}\right]^2$$

ITERATION RESULTS ON SPREADSHEET

Eq. Ⓐ = $Q = q/L$

$$Q = \frac{T_1 - T_\infty}{U_1 + U_2 + U_3}$$

Eq. Ⓑ $T_3 = -Q\left[U_1 + U_2\right] + T_1$

SUBJECT
LIGO HEAT TRANSFER ANALYSIS
- CAL TECH

CBI OFFICE NOE-A

REVISION

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Heat Source Input Calculations

Assumed Conditions

Ambient Temperature = 70.00 F

Tube Temperature T1 = 284.00 F

Initial Estimate of T3 = 100.00 F

	Iteration 1			Iteration 2			Iteration 3	
T3 =	100.00	F	T3 =	97.16	F	T3 =	97.77	F
Ta =	85.00	F	Ta =	83.58	F	Ta =	83.88	F
v =	90.122	in^2/hr	v =	89.680	in^2/hr	v =	89.774	in^2/hr
α =	127.693	in^2/hr	α =	127.041	in^2/hr	α =	127.180	in^2/hr
Pr =	0.7058		Pr =	0.7059		Pr =	0.7059	
β =	1.836E-03	1/R	β =	1.841E-03	1/R	β =	1.840E-03	1/R
RaD =	4.439E+09		RaD =	4.070E+09		RaD =	4.149E+09	
γ1 =	15.689		γ1 =	15.463		γ1 =	15.513	
γ2 =	1.205		γ2 =	1.205		γ2 =	1.205	
NuD =	185.458		NuD =	180.408		NuD =	181.520	
Tb =	192.000	F	Tb =	190.581	F	Tb =	190.883	F
K2 =	2.600E-03	BTU/hr in F	K2 =	2.588E-03	BTU/hr in F	K2 =	2.591E-03	BTU/hr in F
K3 =	1.275E-03	BTU/hr in F	K3 =	1.272E-03	BTU/hr in F	K3 =	1.273E-03	BTU/hr in F
h =	4.149E-03	BTU/hr in^2 F	h =	4.027E-03	BTU/hr in^2 F	h =	4.054E-03	BTU/hr in^2 F
U1 =	0.001	hr in F/BTU	U1 =	0.001	hr in F/BTU	U1 =	0.001	hr in F/BTU
U2 =	9.257	hr in F/BTU	U2 =	9.299	hr in F/BTU	U2 =	9.290	hr in F/BTU
U3 =	1.346	hr in F/BTU	U3 =	1.387	hr in F/BTU	U3 =	1.377	hr in F/BTU
Q =	20.181	BTU/hr in	Q =	20.024	BTU/hr in	Q =	20.059	BTU/hr in
T3 =	97.16	F	T3 =	97.77	F	T3 =	97.63	F

SUBJECT
LIGO HEAT TRANSFER
ANALYSIS - CALTECH

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Heat Source Input Calculations

Assumed Conditions

Ambient Temperature = 70.00 F

Tube Temperature T1 = 284.00 F

Initial Estimate of T3 = 100.00 F

	Iteration 4			Iteration 5			Iteration 6	
T3 =	97.63	F	T3 =	97.66	F	T3 =	97.65	F
Ta =	83.81	F	Ta =	83.83	F	Ta =	83.83	F
v =	89.753	in^2/hr	v =	89.758	in^2/hr	v =	89.756	in^2/hr
α =	127.149	in^2/hr	α =	127.156	in^2/hr	α =	127.154	in^2/hr
Pr =	0.7059		Pr =	0.7059		Pr =	0.7059	
β =	1.840E-03	1/R	β =	1.840E-03	1/R	β =	1.840E-03	1/R
RaD =	4.131E+09		RaD =	4.135E+09		RaD =	4.134E+09	
$\gamma 1$ =	15.502		$\gamma 1$ =	15.505		$\gamma 1$ =	15.504	
$\gamma 2$ =	1.205		$\gamma 2$ =	1.205		$\gamma 2$ =	1.205	
NuD =	181.271		NuD =	181.327		NuD =	181.314	
Tb =	190.815	F	Tb =	190.830	F	Tb =	190.827	F
K2 =	2.590E-03	BTU/hr in F	K2 =	2.590E-03	BTU/hr in F	K2 =	2.590E-03	BTU/hr in F
K3 =	1.273E-03	BTU/hr in F	K3 =	1.273E-03	BTU/hr in F	K3 =	1.273E-03	BTU/hr in F
h =	4.048E-03	BTU/hr in^2 F	h =	4.050E-03	BTU/hr in^2 F	h =	4.049E-03	BTU/hr in^2 F
U1 =	0.001	hr in F/BTU	U1 =	0.001	hr in F/BTU	U1 =	0.001	hr in F/BTU
U2 =	9.292	hr in F/BTU	U2 =	9.292	hr in F/BTU	U2 =	9.292	hr in F/BTU
U3 =	1.379	hr in F/BTU	U3 =	1.379	hr in F/BTU	U3 =	1.379	hr in F/BTU
Q =	20.051	BTU/hr in	Q =	20.053	BTU/hr in	Q =	20.052	BTU/hr in
T3 =	97.66	F	T3 =	97.65	F	T3 =	97.65	F

Q (Unit Length) = 20.052 BTU/hr in

Q (Per 65' Length) = 15640.0 BTU/hr

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Free Convection Coefficient Calculations

Assumed Conditions
Ambient Temperature = 70.00 F
Tube Temperature T1 = 284.00 F

T3 =	70.00	F	T3 =	75.00	F	T3 =	100.00	F
Ta =	70.00	F	Ta =	72.50	F	Ta =	85.00	F
v =	85.816	in^2/hr	v =	86.506	in^2/hr	v =	90.122	in^2/hr
α =	121.323	in^2/hr	α =	122.346	in^2/hr	α =	127.693	in^2/hr
Pr =	0.7073		Pr =	0.7071		Pr =	0.7058	
β =	1.888E-03	1/R	β =	1.879E-03	1/R	β =	1.836E-03	1/R
RaD =	0.000E+00		RaD =	8.233E+08		RaD =	4.439E+09	
γ1 =	0.000		γ1 =	11.848		γ1 =	15.689	
γ2 =	1.205		γ2 =	1.205		γ2 =	1.205	
NuD =	0.360		NuD =	108.838		NuD =	185.458	
K3 =	1.244E-03	BTU/hr in F	K3 =	1.249E-03	BTU/hr in F	K3 =	1.275E-03	BTU/hr in F
h =	7.857E-06	BTU/hr in^2 F	h =	2.385E-03	BTU/hr in^2 F	h =	4.149E-03	BTU/hr in^2 F

T3 =	125.00	F	T3 =	150.00	F	T3 =	175.00	F
Ta =	97.50	F	Ta =	110.00	F	Ta =	122.50	F
v =	94.021	in^2/hr	v =	97.919	in^2/hr	v =	101.817	in^2/hr
α =	133.428	in^2/hr	α =	139.163	in^2/hr	α =	144.898	in^2/hr
Pr =	0.7047		Pr =	0.7036		Pr =	0.7027	
β =	1.795E-03	1/R	β =	1.755E-03	1/R	β =	1.718E-03	1/R
RaD =	7.297E+09		RaD =	9.557E+09		RaD =	1.134E+10	
γ1 =	17.044		γ1 =	17.828		γ1 =	18.343	
γ2 =	1.205		γ2 =	1.205		γ2 =	1.206	
NuD =	217.303		NuD =	236.850		NuD =	250.127	
K3 =	1.300E-03	BTU/hr in F	K3 =	1.325E-03	BTU/hr in F	K3 =	1.350E-03	BTU/hr in F
h =	4.957E-03	BTU/hr in^2 F	h =	5.506E-03	BTU/hr in^2 F	h =	5.924E-03	BTU/hr in^2 F

SUBJECT
LIGO HEAT TRANSFER
ANALYSIS - CALTECH

CBI OFFICE NOE-A
REVISION
REFERENCE NO. 930212

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Free Convection Coefficient Calculations

Assumed Conditions
Ambient Temperature = 70 F
Tube Temperature T1 = 284 F

T3 =	200.00	F	T3 =	225.00	F	T3 =	250.00	F
Ta =	135.00	F	Ta =	147.50	F	Ta =	160.00	F
v =	105.716	in^2/hr	v =	109.614	in^2/hr	v =	113.512	in^2/hr
α =	150.633	in^2/hr	α =	156.368	in^2/hr	α =	162.103	in^2/hr
Pr =	0.7018		Pr =	0.7010		Pr =	0.7003	
β =	1.682E-03	1/R	β =	1.647E-03	1/R	β =	1.614E-03	1/R
RaD =	1.273E+10		RaD =	1.381E+10		RaD =	1.464E+10	
$\gamma 1$ =	18.701		$\gamma 1$ =	18.956		$\gamma 1$ =	19.141	
$\gamma 2$ =	1.206		$\gamma 2$ =	1.206		$\gamma 2$ =	1.206	
NuD =	259.557		NuD =	266.392		NuD =	271.373	
K3 =	1.375E-03	BTU/hr in F	K3 =	1.400E-03	BTU/hr in F	K3 =	1.424E-03	BTU/hr in F
h =	6.260E-03	BTU/hr in^2 F	h =	6.541E-03	BTU/hr in^2 F	h =	6.782E-03	BTU/hr in^2 F

SUBJECT
LIGO HEAT TRANSFER ANALYSIS - CALTECH

CBI OFFICE NOE-A
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Appendix C

Miscellaneous Calculations

EQUIVALENT CONVECTIVE FILM COEFFICIENTS

CONVECTION RESISTANCE $= 1/h$

CONDUCTION RESISTANCE $= L/K$

TOTAL RESISTANCE $= L/K + 1/h$

INSULATION = DUCT WRAP

@ 250 °F $K = 3.264 \times 10^{-3}$ BTU/hr in °F

Free Convection $h = 3.500 \times 10^{-3}$ BTU/hr in² °F

L = INSULATION THICKNESS

U = TOTAL RESISTANCE

$$U = 1/h + L/K = 1/H$$

H = EQUIVALENT CONVECTIVE FILM COEFFICIENT.

$$U = 1/3.500 \cdot 10^{-3} + 2/3.264 \cdot 10^{-3} \Rightarrow U = 898.459 \ \frac{hr \cdot in^2 \ °F}{BTU}$$

$$H = 1/898.4593 \Rightarrow H = 1.113016 \cdot 10^{-3} \ BTU/hr \ in^2 \ °F$$

(Thickness of Insulation = 2.0")

TABLE OF EQUIVALENT COEFFICIENTS (L = 2.0")

T (°F)	H (BTU/hr·in² °F)	T (°F)	H (BTU/hr·in² °F)
75	$6.513 \cdot 10^{-4}$	175	$1.018 \cdot 10^{-3}$
100	$7.786 \cdot 10^{-4}$	200	$1.099 \cdot 10^{-3}$
125	$8.559 \cdot 10^{-4}$	225	$1.206 \cdot 10^{-3}$
150	$9.293 \cdot 10^{-4}$	250	$1.315 \cdot 10^{-3}$

(Correction Factor R NOT INCLUDED)

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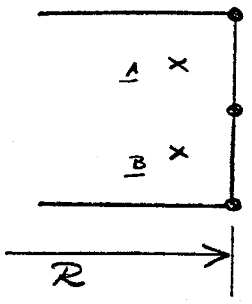
CONCENTRATED HEAT SINK CALCULATION



Heat flux results = Column Support Model

$A = q = 1.41198$ BTU/hr in²

$B = q = 1.38885$ BTU/hr in²

Average = $q = 1.40042$ BTU/hr in²

$Q = q \cdot t \cdot R \qquad t = 3/16''$

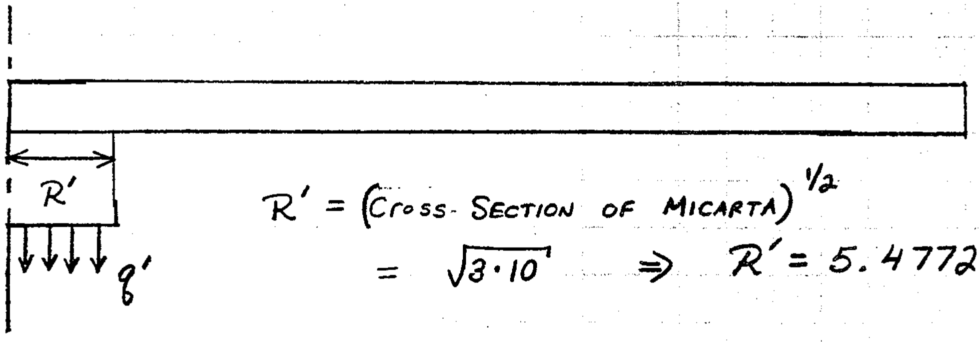
$R = 26.25''$

@ Location of Nodes.

$Q = 1.40042 \times 3/16 \times 26.25$

$\Rightarrow Q = 6.8927 \frac{BTU}{hr}$

IN CONCENTRATED HEAT SINK MODEL



$R' = (\text{Cross-Section of Micarta})^{1/2}$

$= \sqrt{3 \cdot 10} \Rightarrow R' = 5.4772$ in

$$q' = \frac{q \cdot t \cdot R}{\pi (R')^2} \Rightarrow q' = \frac{Q}{\pi (R')^2}$$

$$= \frac{6.8927}{\pi\,(30)}$$

$$\Rightarrow \underline{\underline{q' = 0.0731 \text{ BTU/hr in}^2}}$$

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