

New Folder Name Beam Tube Design

- 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% Maximum Differential Settlements	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	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 = $19.501 \text{ in}^2 = \text{PI}() * (\text{Do}^2 - \text{Di}^2) / 4$
 Section Modulus, S = $237.7 \text{ in}^3 = \text{PI}() * (\text{Do}^4 - \text{Di}^4) / 32 / \text{Do}$
 Moment of inertia, I = $5823 \text{ in}^4 = \text{PI}() * (\text{Do}^4 - \text{Di}^4) / 64$
 Radius of gyration, rg = $17.281 \text{ in} = (I / A)^{0.5}$

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

Number of support stiffeners, Nss = 1.5 Per section

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

Weight per vacuum stiffener = $14.987 \text{ lbs} = \text{PI}() * ((\text{Do} + 2 * \text{ws})^2 - \text{Do}^2) / 4 * \text{Ts} * 495 / 12^3$
 Weight per support stiffener = $71.550 \text{ lbs} = \text{PI}() * ((\text{Do} + 2 * \text{wss})^2 - \text{Do}^2) / 4 * \text{Tss} * 495 / 12^3$
 Stiffener weight per section = $482.01 \text{ lbs} = \text{Weight Vacuum} * \text{Ns} + \text{Weight support} * \text{Nss}$
 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 = $\text{Deni} * L$

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

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

- Allowable Stresses @ 300 Degrees F.

Yield Stress, $F_y = \underline{19,200}$ psi Table Y1
 Tensile Allowable, $S_h = \underline{13000}$ psi Table 1A
 Joint Efficiency, $E_t = \underline{0.7}$
 Compression Allowable UG 23(b)
 $A = 0.000648 = 0.125 / (Ro/t)$
 $B = \underline{5900}$ psi per Figure HA 3, interpolate to 300 degrees F.
 Where $B = F_a = F_{bx} = F_{by} = F_{bxy}$, local buckling stress
 See below for column buckling

- Allowable Stresses @ Ambient (100 degrees F)

Yield Stress = $\underline{25,000}$ psi Table Y1
 Tensile Allowable, $S_a = \underline{16,300}$ psi Table 1A
 Compression Allowable UG 23(b)
 $A = 0.000648 = 0.125 / (Ro/t)$
 $B = \underline{7800}$ psi per Figure HA 3, 100 degrees F.
 Where $B = F_a = F_{bx} = F_{by} = F_{bxy}$

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

- Allowable Axial Stress, Column Buckling per AISC

$$k = \underline{1}$$

$$L = \underline{746} \text{ in} = L_{sp} * 12$$

$$r = \underline{17.28069} \text{ in} = r_g$$

$$kL / r = 43.16958$$

$$C_c = 166.6081 = (2 * \pi)^2 * E_b * 1000 / F_y^{0.5}$$

$$F_a = 10533 \text{ psi} = \frac{(1 - (kL/r)^2 / 2 / C_c^2) * F_y}{(5/3 + 3 * (kL/r) / 8 / C_c - (kL/r)^3 / 8 / C_c^3)}$$

$F_a > B$, Thus use $B = 5900$ psi

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- 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	

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- CALCULATE SEISMIC LOAD PER UBC (Livingston, LA)

$$V = Z * I * C / R_w * W$$

$$Z = \frac{0}{1}$$

$$I = \frac{1.0}{1}$$

$$C = \frac{2.75}{1}$$

$$R_w = \frac{3}{1}$$

$$C/R_w = 0.916667 > 0.075 \text{ use: } 0.91667$$

$$W = 91.00 \text{ lbs/ft} = \text{DL} + \text{Insulation}$$

$$V = 0.0500W = 0.05W \text{ minimum per ASCE 7-88, 9.11.2}$$

$$V = 4.55 \text{ Lbs/ft}$$

$$V = 295.8 \text{ Lbs per section}$$

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

$$V = Z * I * C / R_w * W$$

$$Z = \frac{0.2}{1}$$

$$I = \frac{1.0}{1}$$

$$C = \frac{2.75}{1}$$

$$R_w = \frac{3}{1}$$

$$C/R_w = 0.916667 > 0.075 \text{ use: } 0.91667$$

$$W = 91.00 \text{ lbs/ft} = \text{DL} + \text{Insulation}$$

$$V = 0.1833W$$

$$V = 16.68 \text{ Lbs/ft} = \text{wseis}$$

$$V = 1084.4 \text{ Lbs per section}$$

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

$$P_f = 15.12 = 0.7 * C_e * C_t * I * P_g$$

$$C_e = \frac{0.9}{1} \text{ Little shelter assumed}$$

$$C_t = \frac{1.2}{1} \text{ Unheated}$$

$$I = \frac{1}{1} \text{ Category 1}$$

$$P_g = \frac{20}{1} \text{ psf}$$

Eq 5a

Table 18

Table 19

Table 20

Figure 6

$$P_s = 9.828 = C_s * P_f$$

$$C_s = \frac{0.65}{1} \text{ Angle is 35 degrees, } 90 - (180 - 70) / 2, \text{ Figure 8b}$$

$$\text{Width} = 46.049 \text{ in} = D_o * \sin 70 \text{ Per 7.4.3, slope } > 70 \text{ no load}$$

$$\text{Snow Load per foot, } w_{sn} = 37.71 \text{ lbs/ft} = P_s * \text{Width}$$

$$\text{Snow load per section} = 2451 \text{ lbs}$$

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

SHT 5 OF 29

DATE

DATE

DATE

DATE

6.9

3/11/94

4.4.94

- 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 = $\frac{7.029}{11.849}$ kips, per RISA2D
 1/2 of guided support = $\frac{2.41}{11.849}$ 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 = $\frac{43480}{91}$ 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 = $\frac{0.079}{91}$ in
 Based on, 91 lbs/ft, DL + Insulation, used in RISA2D

True DL + Insulation = wdi = 91.00
 Estimated Deflection = 0.081 in = wdi * Lsp⁴ / 185 / Eb / I * 12³ / 1000

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

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- CASE 1: Dead Load Reactions, Stresses and Deflections

FIXED SUPPORT

Rfx1 = 0
 Rfy1 = 5774 lbs = $K_f * 2 * L * wd$
 Rfz1 = 0

GUIDED SUPPORT

Rgx1 = 0
 Rgy1 = 3959 lbs = $K_g * 2 * L * wd$

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 = $K_f * 2 * L * wdi$
 Rfz2 = 0

GUIDED SUPPORT

Rgx2 = 0
 Rgy2 = 4812 lbs = $K_g * 2 * L * wdi$

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 = $wdi * Lsp^4 / 185 / Eb / I * 12^3 / 1000 * Kd$

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

FIXED SUPPORT

Rfx3 = 0
 Rfy3 = 2908 lbs = $K_f * 2 * L * w_{sn}$
 Rfz3 = 0

GUIDED SUPPORT

Rgx3 = 0
 Rgy3 = 1994 lbs = $K_g * 2 * L * w_{sn}$

MOMENTS & BENDING STRESS

Mx3 = 18020 lb-ft = $w_{sn} * (L_{sp})^2 / 8 * K_m$
 fbx3 = 910 psi = $M_{x3} * 12 / S$

My3 = 0
 fby3 = 0 psi = $M_{y3} * 12 / S$

MIDSPAN DEFLECTION

Dely3 (amb) = 0.031 in = $w_{sn} * L_{sp}^4 / 185 / E_a / I * 12^3 / 1000 * K_d$

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

FIXED SUPPORT

Rfx4 = 1275 lbs = $w_w * 2 * L * K_f$
 Rfy4 = 0
 Rfz4 = 0

GUIDED SUPPORT

Rgx4 = 874 lbs = $w_w * 2 * L * K_g$
 Rgy4 = 0

MOMENTS & BENDING STRESS

Mx4 = 0
 fbx4 = 0 psi = $M_{x4} * 12 / S$

My4 = 7896 lb-ft = $w_w * (L_{sp})^2 / 8 * K_m$
 fby4 = 399 psi = $M_{y4} * 12 / S$

MIDSPAN DEFLECTION

Delx4 (amb) = 0.014 in = $w_w * L_{sp}^4 / 185 / E_a / I * 12^3 / 1000 * K_d$

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- 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

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- 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

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- 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 * Lsp² / 8 * Km

fbx8 = fby8 = 3579 psi = Mx8 * 12 / S

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

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

FIXED SUPPORT

$Rfx9 = 0 \text{ lbs}$
 $Rfy9 = 0$
 $Rfz9 = 5959 \text{ lbs} = 2 * Eej * Kej * x$

GUIDED SUPPORT

$Rgx9 = 0$
 $Rgy9 = 167.8 \text{ lbs} = Rfz9 * H / Lsp / 12 / 2$
 $fbx9 = fby9 = 0$
 $Delx9 = Dely9 = 0$

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

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

FIXED SUPPORT

$Rfx10 = 0 \text{ lbs}$
 $Rfy10 = 0$
 $Rfz10 = 771 \text{ lbs} = 2 * Eej * Kej * xw$

GUIDED SUPPORT

$Rgx10 = 0$
 $Rgy10 = 21.7 \text{ lbs} = Rfz10 * H / Lsp / 12 / 2$
 $fbx10 = fby10 = 0$
 $Delx10 = Dely10 = 0$

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- 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

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- 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 (lateral)
 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

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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 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 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 LIGO - BEAM TUBE DESIGN Configuration 3, K = 8316 + 20% Maximum Differential Settlements	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY AKK	MADE BY	CHKD BY	SHT 15 OF 29
	DATE 3/11/94	DATE 4.4.94	DATE	DATE	5.20

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 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 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 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 19 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 (lateral)
 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% Maximum Differential Settlements	OFFICE: NOE-C		REVISION:		REFERENCE NO. 930212
	MADE BY RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 19 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	v.23

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

	<u>COMPRESSION</u>	<u>TENSION</u>
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 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 27 OF 28
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.27

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

	<u>COMPRESSION</u>	<u>TENSION</u>
fa(c or t) / Fa =	-0.131	0.085
fbx / Fbx =	1.115	0.723
fby / Fby =	0.000	0.000
fd / Fbxy =	<u>0.015</u>	<u>0.010</u>
SUM =	0.999 < 1.00	0.817 < 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
	DATE 3/11/94	DATE 4-4-94	DATE	DATE
				SHT 25 OF 29 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

	<u>COMPRESSION</u>	<u>TENSION</u>
fa(c or t) / Fa =	-0.109	0.071
fbx / Fbx =	1.037	0.672
fby / Fby =	0.057	0.037
fd / Fbxy =	<u>0.015</u>	<u>0.009</u>
SUM =	0.999 < 1.00	0.789 < 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	SHT. 26 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE DATE

COMBINATION 14 - DL + Insul + Seis z + Dif settle + Vac + -16 F (Case 2+5+7+8+11)

SETTLEMENT WITH COMBINATION

Delta x, x8 = $\frac{0}{1.411}$ in Maxset = 1.411 = $(x8^2 + y8^2)^{0.5}$
 Delta y, y8 = $\frac{1.411}{1.411}$ 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 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 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

$$M_o = (p / 2 / \text{landa}^2) * (A / (A + t*c + 2 * t / \text{landa}))$$

- p = 14.7 psi, internal pressure
- landa = $0.7277 = (3 * (1 - 0.3^2) / (((D_o + t) / 2)^2 * t^2))^{0.25}$
- A = 1.5 sq in = tss * wss
- t = 0.127 in = t
- c = 0.375 in = tss

$$M_o = 10.976 \text{ in lbs / in}$$

$$\text{Stress} = 4083 \text{ psi} = 6 * M / t^2 < 3 * S = 17700 \text{ psi}$$

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 28 OF 29
	DATE 3/11/94	DATE 4-4-94	DATE	DATE	6.32

- 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	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 RJW	CHKD BY WJC	MADE BY	CHKD BY	SHT 29 OF 29
	DATE 3/11/94	DATE 4.4.94	DATE	DATE	6.33