SECTION A

DERIVATION OF EQUATIONS FOR CODE REQUIRED INTERMEDIATE RAILING SPHERE PASS-THROUGH RESISTANCE

A.1—EFFECTIVE MODULUS OF ELASTICITY FOR WIRE ROPE CABLE

The modulus of elasticity for Type-316 Stainless Steel is:

$$E := 28000 \cdot \text{ksi}$$

However, the effective modulus of elasticity for wire rope is less than the nominal material modulus of elasticity because of the twist in the wire rope strands. With the rope twist, the individual wire strands are longer than the actual cable length, thus for a given stress, strain will be greater in the cable than in a solid round bar of equal area. This increase in strain for a given load appears as a lower "effective" modulus of elasticity. For ease of use, this effective modulus is calculated based on the nominal cable area, rather than actual steel area, to make calculations involving cable diameter simpler.

Symbols and Notations

ε	Strain, in/in.
σ	Stress, ksi (ksi = 1000 psi).
A	Cross-sectional area, in^2.
D	Diameter of wire rope cable, in.
E	Modulus of Elasticity, ksi.
E_{eff}	Effective Modulus of Elasticity, ksi.
G	Cable stretch factor, determined by wire rope manufacturer.
W	Load in cable, lbf.

Objective

Given the value for G, determine the effective modulus of elasticity, E_{eff}

Stress and Strain

The basic stress-strain relationship for a material, througout the linear-elastic range, is given by:

$$\varepsilon = \frac{\sigma}{E} \qquad \textbf{(1)}$$

Stress is defined as the force (load) divided by the area:

$$\sigma = \frac{W}{A} \qquad \textbf{(2)}$$

Area for a circular cross-section of diameter, D, is given by:

$$A = \frac{\pi \cdot D^2}{4} \qquad \textbf{(3)}$$

Combining Eqns (1), (2) and (3) produces this equation for strain, given a force, P:

$$\varepsilon = \frac{4 \cdot W}{\pi \cdot D^2 \cdot E} \qquad \textbf{(4)}$$

Stretch in a Wire Rope

The stretch in a wire rope under load has been quantified emperically,and follows the equation:

$$\varepsilon = \frac{W}{D^2} \cdot \frac{G}{\left(100 \cdot \frac{in^2}{lbf}\right)} \qquad \textbf{(5)}$$

The value of *G* varies according to strand geometry and cable material. For stainless steel 1x19 wire rope:

$$G := 7.79 \cdot 10^{-6}$$

Effective Modulus of Elasticity

Since the strain from each of Eqns. (4) and (5) must be the same, we can set the two equations equal to each other and solve for the effective modulus of elasticity:

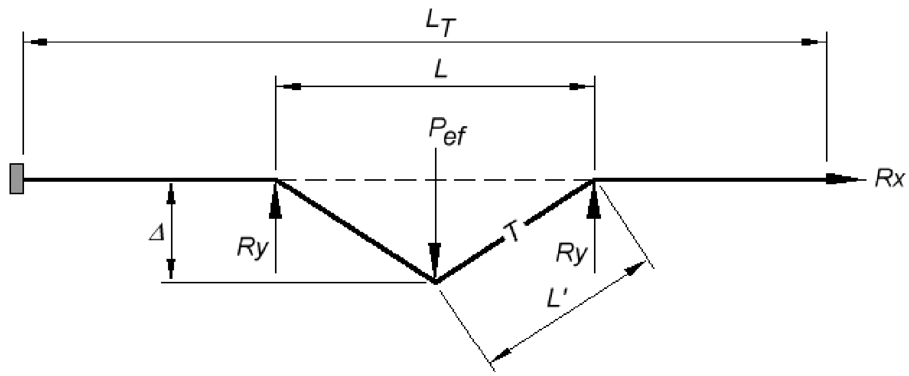
$$\frac{4 \cdot P}{\pi \cdot D^2 \cdot E_{eff}} = \frac{P}{D^2} \cdot \frac{G}{\left(100 \cdot \frac{in^2}{lbf}\right)}$$

$$E_{eff} := \frac{400 \cdot lbf}{\pi \cdot G \cdot in^2} \qquad E_{eff} = 16345\,ksi$$

Effective Modulus of Elasticity for 316 Stainless Steel 1x19 Wire Rope:

$$E_{eff} := 16300 \cdot ksi$$

A.2—LOAD-DEFLECTION RELATIONSHIP FOR AN EXTENSIBLE, FLEXIBLE CABLE



Symbols and Notations

- Δ — Deflection of cable under mid-span point load, P_{ef}.
- L — Spacing between intermediate supports, in.
- L' — Length of deflected cable from mid-span point load to support. In unloaded case, L' = L / 2, in.
- L_T — Length of cable between anchor points, ft.
- P_{ef} — Mid-span point load required to produce deflection Δ, in.
- R_x — Axial end reaction at intermediate support, due to deflection of cable, lbs.
- R_y — Out-of-plane end reaction at intermediate support, due to deflection of cable, lbs.
- T — Tension load in cable between intermediate supports, due to deflection of cable, lbs.

Objective

Given a mid-span deflection, Δ, determine the point load required to produce that deflection, including the effects of stretch over the length of the cable between anchor points.

Determination of Reactions

Out-of-plane end reactions, R_y, can be calculated by taking the sum of moments about one of the support points:

$$\sum M = 0: \quad P_{ef}\cdot\frac{L}{2} - R_y\cdot L = 0$$

$$R_y\cdot L = \frac{P_{ef}\cdot L}{2}$$

$$R_y = \frac{P_{ef}}{2} \qquad \textbf{(6)}$$

The axial end reaction, R_x, can be calculated by taking the sum of the moments about the point where the load is applied (mid-span) using forces to the right of the applied load:

$$\sum M = 0: \quad R_y\cdot\frac{L}{2} - R_x\cdot\Delta = 0$$

$$\frac{P_{ef}}{2}\cdot\frac{L}{2} = R_x\cdot\Delta$$

$$R_x = \frac{P_{ef} \cdot L}{4 \cdot \Delta} \qquad \textbf{(7)}$$

Knowing the two end reactions, the tension in the cable may be resolved using the Pythagorean Theorum:

$$T = \sqrt{R_y^2 + R_x^2}$$

$$T = \sqrt{\left(\frac{P_{ef}}{2}\right)^2 + \left(\frac{P_{ef} \cdot L}{4 \cdot \Delta}\right)^2}$$

$$T = \frac{1}{\Delta} \cdot \sqrt{\frac{P_{ef}^2}{4} \cdot \Delta^2 + \frac{P_{ef}^2}{4} \cdot \frac{L^2}{4 \cdot \Delta^2} \cdot \Delta^2}$$

$$T = \frac{P_{ef}}{2 \cdot \Delta} \cdot \sqrt{\Delta^2 + \frac{L^2}{4}} \qquad \textbf{(8)}$$

Strain Compatibility

The elongated (stretched) length of the cable under load can be found directly from the geometry, using the Pythagorean Theorum:

$$L' = \sqrt{\Delta^2 + \left(\frac{L}{2}\right)^2} = \sqrt{\Delta^2 + \frac{L^2}{4}}$$

where *L'* (the hypotenuse) represents one-half of the total elongated length.

The elongation (change in length) in the cable is given by:

$$\delta = 2 \cdot L' - L$$

$$\delta = 2 \cdot \sqrt{\Delta^2 + \frac{L^2}{4}} - L \qquad \textbf{(9)}$$

This total elongation is a result of cable stretch over two distinct regions: the region between the intermediate supports where the cable is loaded and where defelection in the cable is occuring, and the region beyond the intermediate supports where the cable is being stretched due to the tension from the axial reaction.

$$\delta = \frac{T \cdot L}{E \cdot A} + \frac{R_x \cdot (L_T - L)}{E \cdot A}$$

Substituting Eqns. (7) and (8) and simplifying yields:

$$\delta = \frac{\left(\frac{P_{ef}}{2 \cdot \Delta} \cdot \sqrt{\Delta^2 + \frac{L^2}{4}}\right) \cdot L}{E \cdot A} + \frac{\left(\frac{P_{ef} \cdot L}{4 \cdot \Delta}\right) \cdot (L_T - L)}{E \cdot A}$$

$$\delta = \frac{P_{ef} \cdot L}{2 \cdot \Delta \cdot E \cdot A} \cdot \sqrt{\Delta^2 + \frac{L^2}{4}} + \frac{P_{ef} \cdot L}{2 \cdot \Delta \cdot E \cdot A} \cdot \left(\frac{L_T - L}{2}\right)$$

$$\delta = \frac{P_{ef} \cdot L}{2 \cdot \Delta \cdot E \cdot A} \cdot \left(\sqrt{\Delta^2 + \frac{L^2}{4}} + \frac{L_T - L}{2}\right) \qquad \textbf{(10)}$$

Simultaneous Equations

Since the total elongation given by both Equations (9) and (10) must be the same, we now have two equations that can be solved for one variable in terms of the other.

Substituting Eqn. (9) for δ in Eqn. (10) and solving for P_{ef} gives us:

$$2\cdot\sqrt{\Delta^2+\frac{L^2}{4}}-L=\frac{P_{ef}\cdot L}{2\cdot\Delta\cdot E\cdot A}\cdot\left(\sqrt{\Delta^2+\frac{L^2}{4}}+\frac{L_T-L}{2}\right)$$

$$P_{ef}=\frac{2\cdot\Delta\cdot E\cdot A}{L}\cdot\frac{2\cdot\sqrt{\Delta^2+\frac{L^2}{4}}-L}{\sqrt{\Delta^2+\frac{L^2}{4}}+\frac{L_T-L}{2}}$$

$$P_{ef}=\frac{4\cdot\Delta\cdot E\cdot A}{L}\cdot\frac{\sqrt{4\cdot\Delta^2+L^2}-L}{\sqrt{4\cdot\Delta^2+L^2}+L_T-L}$$

Mathcad Function:

$$P_{ef}(\Delta,D,L,L_T):=\left|\begin{array}{l} A\leftarrow\dfrac{\pi\cdot D^2}{4}\\ \dfrac{4\cdot\Delta\cdot E_{eff}\cdot A}{L}\cdot\dfrac{\sqrt{4\cdot\Delta^2+L^2}-L}{\sqrt{4\cdot\Delta^2+L^2}+L_T-L}\end{array}\right.$$

Example 1: Given a 3/8" diameter 1x19 wire rope supported and anchored at 42", calculate the point load required to cause a mid-span deflection of 1":

$D := 0.375\cdot in$

$L := 42\cdot in$

$L_T := 42\cdot in$

$\Delta := 1\cdot in$

$P_{ef}(\Delta,D,L,L_T) = 194.1\,lbf$

Example 2: Given a 3/8" diameter 1x19 wire rope supported every 42" and with a length of 42 feet between anchors, calculate the point load required to cause a mid-span deflection of 1":

$D := 0.375\cdot in$

$L := 42\cdot in$

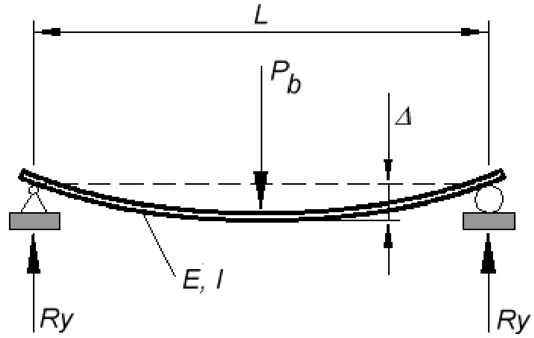
$L_T := 42\cdot ft$

$\Delta := 1\cdot in$

$P_{ef}(\Delta,D,L,L_T) = 16.2\,lbf$

A.3—LOAD-DEFLECTION RELATIONSHIP IN FLEXURAL BENDING

The overall cable load-deflection relationship includes a component due to the flexural stiffness of the wire rope. Flexural stiffness is directly related to the effective modulus of elasticity and to the cable's moment of inertia.



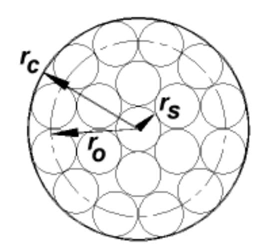
Symbols and Notations

Δ	Deflection of cable under mid-span point load, P_b, in.
A_s	Area of individual wire rope strand, in^2.
C_o	Circumference of cable outer strand centerline, in.
d	Distance of centroid of individual wire rope strand to centroid of wire rope, in.
E	Modulus of Elasticity, ksi.
E_{eff}	Effective Modulus of Elasticity for wire rope cable, ksi.
I	Moment of Inertia, in^4.
I_{1x19}	Moment of inertia of 1x19 wire rope, in^4.
I_s	Moment of inertia of individual wire rope strand, in^4.
L	Spacing between intermediate supports, in.
P_b	Mid-span point load required to produce deflection Δ, lbs.
r_c	Radius of cable, in.
r_s	Radius of individual wire rope strand, in.
R_y	Out-of-plane end reaction at intermediate support, due to deflection of cable, lbs.

Objective

Given a mid-span deflection, Δ, determine the point load required to produce that deflection due to flexural bending.

Strand Radius



Knowing strand geometry within the wire rope, we can determine the radius of individual strands, r_s, given the wire rope diameter, r_c.

In the 19-strand geometry, the outer layer contains 12 strands that fit snugly around their centerline, given by r_o. The circumference of this centerline circle, C_o, is given by the following two equations:

$$C_o = 12\cdot\left[2\cdot r_s + \left(r_s - r_s\cdot\cos\left(\frac{360\cdot deg}{12}\right)\right)\right] \qquad \textbf{(11)}$$

$$C_o = 2\cdot\pi\cdot\left(r_c - r_s\right) \qquad \textbf{(12)}$$

Setting Eqns. (11) and (12) equal to each other, and solving for r_s, we get:

$$12\cdot\left[2\cdot r_s + \left(r_s - r_s\cdot\cos(15\cdot deg)\right)\right] = 2\cdot\pi\cdot\left(r_c - r_s\right)$$

$$r_s = \frac{\pi\cdot r_c}{18 - \left(6\cdot\cos(15\cdot deg) + \pi\right)}$$

$$r_s = 0.2047\cdot r_c \qquad \textbf{(13)}$$

Moment of Inertia

For a circular cross section, Area and Moment of Inertia are given by:

$$A_s = \pi\cdot r_s^{2} \qquad\qquad I_s = \frac{\pi\cdot r_s^{4}}{4}$$

Because the 1x19 wire rope is composed of individual strands with voids between them, the moment of inertia for the wire rope will be less than the moment of inertia of a solid circular area of the same diameter.

Moment of Inertia of a composite body is given by the equation:

$$I = \sum_{j}\left(I_j + A_j\cdot d_j^{2}\right) \qquad \textbf{(14)}$$

where d is the distance of the centroid of the individual part to the centroid of the composite body.

Expanding Eqns. (13) and (14) for the 19 strands yields:

$$I_{1x19} = \left[I_s + 8\cdot\left(I_s + A_s\cdot r_s^{2}\right) + 2\cdot\left[I_s + A_s\cdot\left(2\cdot r_s\right)^{2}\right] + 4\cdot\left[I_s + A_s\cdot\left(\frac{r_c - r_s}{\sqrt{2}}\right)^{2}\right]\right] \dots$$
$$+ 4\cdot\left[I_s + A_s\cdot\left(\frac{r_s}{\tan(15\cdot deg)}\right)^{2}\right]$$

$$I_{1x19} = 19\cdot I_s + 16\cdot A_s\cdot r_s^{2} + 2\cdot A_s\cdot\left(r_c - r_s\right)^{2} + 4\cdot A_s\cdot\frac{r_s^{2}}{\tan(15\cdot deg)^{2}}$$

Mathcad Function:

$$I_{1x19}(D) := \left|\begin{array}{l} r_s \leftarrow 0.2047\cdot\frac{D}{2} \\ A_s \leftarrow \pi\cdot r_s^{2} \\ I_s \leftarrow \frac{\pi\cdot r_s^{4}}{4} \\ 19\cdot I_s + 16\cdot A_s\cdot r_s^{2} + 2\cdot A_s\cdot\left(\frac{D}{2} - r_s\right)^{2} + 4\cdot A_s\cdot\frac{r_s^{2}}{\tan(15\cdot deg)^{2}} \end{array}\right.$$

Flexural Bending

The deflection of a simply supported beam under a point load located at the mid-span is given by:

$$\Delta = \frac{P_b \cdot L^3}{48 \cdot E \cdot I}$$

The equation can also be rearranged to calculate the load necessary to cause a mid-span deflection of *Δ*:

$$P_b = \frac{48 \cdot E \cdot I \cdot \Delta}{L^3}$$

Mathcad Function:

$$P_b(\Delta, D, L) := \frac{48 \cdot E_{eff} \cdot I_{1x19}(D) \cdot \Delta}{L^3}$$

Example: Given a 3/8" diameter 1x19 wire rope supported every 42", calculate the point load required to cause a mid-span deflection of 1" due to pure bending:

$$D := 0.375 \cdot in$$

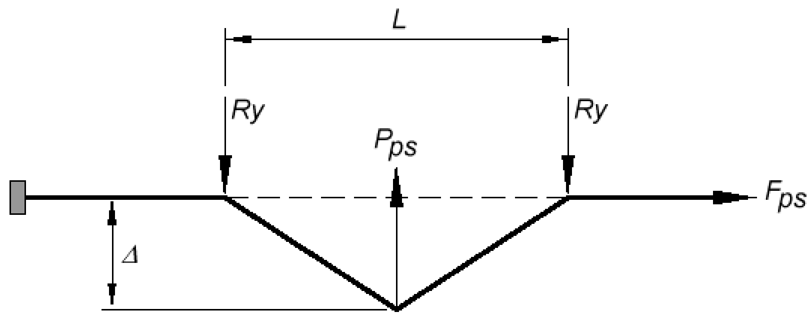
$$L := 42 \cdot in$$

$$\Delta := 1 \cdot in$$

$$P_b(\Delta, D, L) = 7.7\,lbf$$

A.4—EFFECTS OF CABLE PRESTRESSING

The effect of cable prestressing is to provide a force to balance an applied load. This balancing force is directly related to the geometry of the cable and the prestress force.



Symbols and Notations

- Δ Deflection of cable at mid-span, in.
- L Spacing between intermediate supports, in.
- F_{ps} Applied prestressing force, lbs.
- P_{ps} Mid-span balance point load due to prestressing, lbs.
- R_y Out-of-plane end reaction at intermediate support, lbs.

Objective

Given an initial prestress force, F_{ps}, and a mid-span deflection, Δ, determine the resulting balancing force, P_{ps}.

Balancing Force

The end reaction R_y is found by taking the sum of moments about the other end point:

$$\Sigma M = 0: \quad P_{ps} \cdot \frac{L}{2} - R_y \cdot L = 0$$

$$R_y \cdot L = \frac{P_{ps} \cdot L}{2}$$

$$R_y = \frac{P_{ps}}{2}$$

Taking the sum of the moments about the point where the load is applied (mid-span) using forces to the right of the applied load, we can compute the balance force, P_{ps}:

$$\Sigma M = 0: \quad R_y \cdot \frac{L}{2} + F_{ps} \cdot \Delta = 0$$

$$\frac{P_{ps}}{2} \cdot \frac{L}{2} = -F_{ps} \cdot \Delta$$

$$P_{ps} = -\frac{4 \cdot F_{ps} \cdot \Delta}{L}$$

Our applied load is equal to the magnitude of P_{ps}, but opposite in sign. Therefore, in the context of our applied load, the equation for P_{ps} becomes:

$$P_{ps} = \frac{4 \cdot F_{ps} \cdot \Delta}{L}$$

Mathcad Function: $P_{ps}(F_{ps}, \Delta, L) := \frac{4 \cdot F_{ps} \cdot \Delta}{L}$

Example: Given a wire rope supported at 42", calculate the mid-span balancing load with a 400 lbs prestress load and a mid-span deflection of 1":

$$F_{ps} := 400 \cdot \mathrm{lbf}$$

$$L := 42 \cdot \mathrm{in}$$

$$\Delta := 1 \cdot \mathrm{in}$$

$$P_{ps}(F_{ps}, \Delta, L) = 38.1\,\mathrm{lbf}$$

A.5—PUTTING IT ALL TOGETHER

Symbols and Notations

Δ Deflection of cable under mid-span point load, *P*.

ΔF_{psT} Change in prestress force due to temperature change, lbs.

D Diameter of wire rope cable, in.

F_{ps} Applied prestressing force, lbs.

L Spacing between intermediate supports, in.

L_T Length of cable between anchor points, ft.

P Mid-span point load required to produce deflection Δ, lbs.

P_b Component of mid-span point load, *P*, resisted by flexural bending, lbs.

P_{ef} Component of mid-span point load, *P*, resisted by stretching of cable, lbs.

P_{ps} Component of mid-span point load, *P*, resisted by cable prestressing, lbs.

Combined Load-Deflection Relationship

The effects of cable stretch, flexural beam action, and prestressing force combine to create a composite relationship between the applied load and the deflection of the cable. That is, for a given point load, applied at the mid-span of the cable, the cable will deflect until the load is balanced by the sum of the reactions due to cable stretch, flexure, and prestressing force.

Recall the load-deflection relationships previously derived:

Extensible, Flexible Cable:

$$P_{ef} = \frac{4 \cdot \Delta \cdot E \cdot A}{L} \cdot \frac{\sqrt{4 \cdot \Delta^2 + L^2} - L}{\sqrt{4 \cdot \Delta^2 + L^2} + L_T - L}$$

Flexural Bending: $P_b = \dfrac{48 \cdot E \cdot I \cdot \Delta}{L^3}$

Presstressing: $P_{ps} = \dfrac{4 \cdot F_{ps} \cdot \Delta}{L}$

Strain compatibility laws tell us that when a load is applied to the cable, the deflection in each of the above cases must the same. Therefore, for a given deflection, the applied load required to cause that deflection, *P*, is the sum of the three components:

$$P = P_{ef} + P_b + P_{ps}$$

Mathcad Function: $P(\Delta, D, L, L_T, F_{ps}) := P_{ef}(\Delta, D, L, L_T) + P_b(\Delta, D, L) + P_{ps}(F_{ps}, \Delta, L)$

Example: Given a 3/8" diameter 1x19 wire rope supported every 42", with an achorage distance of 24'-6", and with a prestress load of 400 lbs., calculate the point load required to cause a mid-span deflection of 1":

$D := 0.375 \cdot \text{in}$

$L := 42 \cdot \text{in}$

$L_T := 24.5 \cdot \text{ft}$

$F_{ps} := 400 \cdot \text{lbf}$

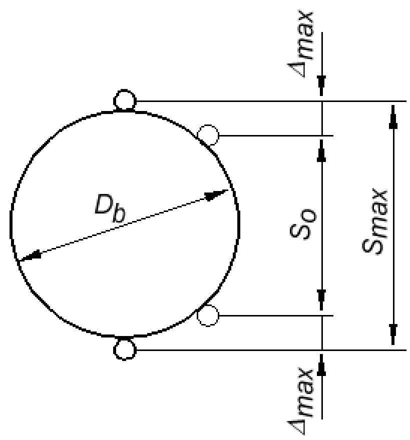
$\Delta := 1 \cdot \text{in}$

$P(\Delta, D, L, L_T, F_{ps}) = 73.5\ \text{lbf}$

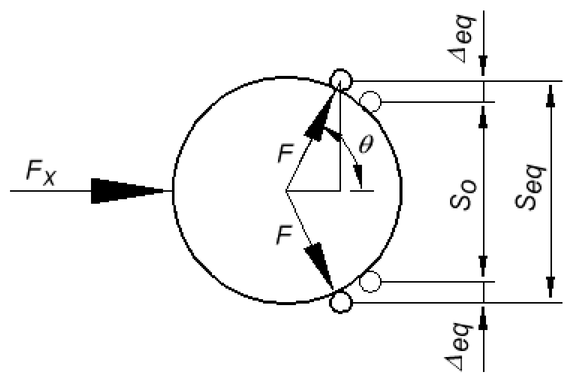
A.6—SPHERE PASS-THROUGH RESISTANCE

Building codes require that intermediate railing components for guardrail systems be spaced such that a sphere of 4" diameter shall not pass between the railings.

When the sphere is in contact with two of the cables and loaded perpendicular to the plane of the cables, the load will cause the cables to deflect and spread apart. If the load is great enough, the cables will spread far enough apart to allow the sphere to pass through the cables; if the load is less, the system will reach equilibrium, and the sphere will be prevented from passing through the cables.



Initial and Pass-Through Conditions



Conditions at Equilibrium

Symbols and Notations

Δ	Deflection of cable under force vector, *F*, in.
Δ_{eq}	Deflection of cable at equilibrium, in.
Δ_{max}	Deflection of cable at pass-through, in.
θ	Angle between applied load, F_x, and the resulting force vector, *F*, applied to the cable.
D	Diameter of wire rope cable, in.
D_b	Diameter of sphere, in.
F	Force applied to cable, lbs; magnitude is a function of α.
F_x	Applied force on sphere, perpendicular to plane of cable railing infill, lbs.
S_{eq}	Spacing (spread) between cables at equilibrium, in.
S_{max}	Spacing (spread) between cables at pass-through, in.
S_o	Initial spacing between cables, in.

Objective

Derive the equations that govern the system, and provide a method for determining the adequacy of a cable intermediate railing system in resisting pass-through of the required sphere.

Assumptions

1. The sphere and the cables are frictionless.
2. Curvature of the cable in contact with the sphere is negligible and force, *F*, may be assumed to be a point load.

3. The sphere is located at the mid-span of the cables, between the cable supports.

Force Applied to the Sphere

The 2003 *International Building Code* (IBC) require that guardrail intermediate railings be spaced so as to prevent a 4" diameter sphere from passing between the rails (IBC 1012.3). However, the code does not state what load is to be applied to the 4" diameter sphere. While such an oversight is not critical to solid railing members, it is of utmost importance in flexible railing systems such as wire-rope cables. In the absence of Code guidelines, a rational load must be developed.

The 2003 IBC requires a load of 50 psf, applied over a one square foot area to be applied horizontally to the intermediate railings (IBC 1607.7.1.2).

$$w := 50 \cdot psf$$

The projected horizontal area of the 4" sphere is a circle of 4" diameter:

$$d := 4 \cdot in$$

$$A := \frac{\pi \cdot d^2}{4}$$

$$A = 12.566\,in^2$$

Because objects that the guardrail infill system must resist may be moving, we will also conservatively include an impact factor of 2.0. Therefore, the force on the sphere under the IBC base load, and considering impact is:

$$F_x := 2 \cdot w \cdot A$$

$$F_x = 8.7\,lbf$$

Cable Load Angle

When a force, F_x, is applied to the sphere in contact with two cables, the force is transmitted to the cables in proportion to the spread (spacing) of the cables. The transmitted force, *F*, is applied at an angle, θ, which can be determined from the trigonometric relationship between the center of the sphere and the center of the cable:

$$\text{Hypotenuse} = \frac{D_b + D}{2}$$

$$\text{Opposite} = \frac{S_o}{2} + \Delta$$

$$\theta = \text{asin}\left(\frac{\text{Opposite}}{\text{Hypotenuse}}\right) = \text{asin}\left(\frac{\frac{S_o}{2} + \Delta}{\frac{D_b + D}{2}}\right)$$

$$\theta = \text{asin}\left(\frac{S_o + 2 \cdot \Delta}{D_b + D}\right)$$

Mathcad Function: $\theta(\Delta, D, D_b, S_o) := \text{asin}\left(\frac{S_o + 2 \cdot \Delta}{D_b + D}\right)$

Example: Given two 3/8" diameter wire rope cables with an initial spacing of 3" supporting a 4" diameter sphere. Calculate the angle at which the load is applied to each of the two cables when the sphere first contacts the cables (i.e., $\Delta = 0$).

$$D_b := 4 \cdot in$$

$$D := 0.375 \cdot in$$

$$S_o := 3 \cdot in$$

$$\Delta := 0 \cdot in$$

$$\theta(\Delta, D, D_b, S_o) = 43.292\,deg$$

Force Applied to Cable

Knowing the angle θ, the force applied to the cable can be easily calculated:

$$F = \frac{\frac{F_x}{2}}{\cos(\theta)}$$

$$F = \frac{F_x}{2 \cdot \cos(\theta)}$$

Note that as the cables spread farther apart, angle θ increases. As θ increases, cos(θ) decreases. Since the cosine term is in the denominator, as cos(θ) decreases, the force, *F*, applied to the cable increases. As θ approaches 90°, *F* approaches infinity.

Mathcad Function:

$$F(F_x, \Delta, D, D_b, S_o) := \frac{F_x}{2 \cdot \cos(\theta(\Delta, D, D_b, S_o))}$$

Example: Given two 3/8" diameter wire rope cables with an initial spacing of 3" supporting a 4" diameter sphere with a 10 lb load. Calculate the load applied to each of the two cables if the final cable spacing is 3.75".

$$F_x := 10 \cdot lbf$$

$$D_b := 4 \cdot in$$

$$D := 0.375 \cdot in$$

$$S_o := 3 \cdot in$$

$$S_{final} := 3.75 \cdot in$$

$$\Delta := \frac{S_{final} - S_o}{2} \qquad \Delta = 0.375\,in$$

$$F(F_x, \Delta, D, D_b, S_o) = 9.707\,lbf$$

Maximum Cable Deflection

The cable spread at pass-through is equal to the sum of the sphere diameter and the cable diameter:

$$S_{max} = D_b + D$$

The maximum cable deflection occurs at pass-through, and is equal to one-half of the difference between the maximum cable spread and the initial cable spacing:

$$\Delta_{max} = \frac{S_{max} - S_o}{2}$$

$$\Delta_{max} = \frac{D_b + D - S_o}{2}$$

Mathcad Function:

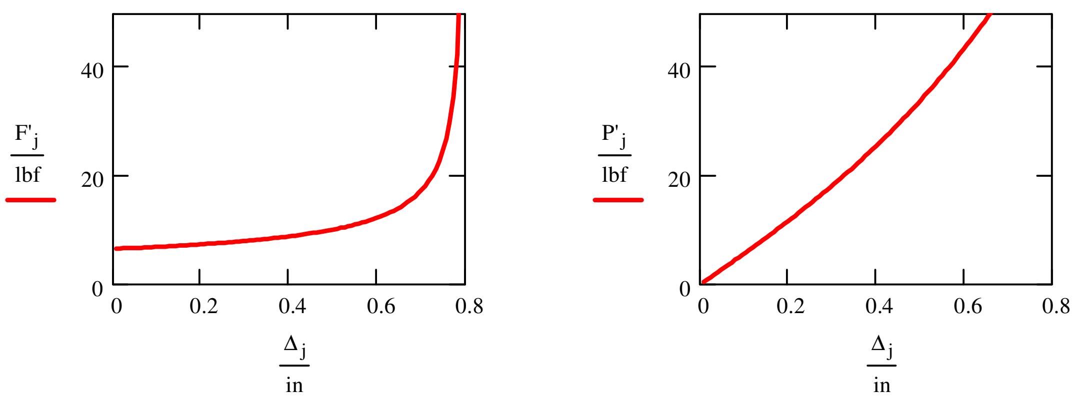
$$\Delta_{max}(D, D_b, S_o) := \frac{D_b + D - S_o}{2}$$

Equilibrium Deflection

If the load on the sphere is not sufficient to cause a deflection in the cables at least equal to Δ_{max}, the system will reach equilibrium and the sphere will not pass between the cables. When this condition exists, the force, *F*, transmitted to each of the cables is equal to the resisting force of the cables, *P*.

Recall that the magnitude of the resisting force, *P*, is directly related to the cable deflection, Δ. Likewise, the magnitude of the force applied to the cable by the loaded sphere is also related to the cable deflection, Δ (because Δ controls the angle θ).

To determine whether equilibrium occurs, we must find the deflection that results in the same magnitude of applied force, *F*, as the magnitude of the resisting force, *P*. The deflection at which this occurs is known as the *equilibrium deflection*, Δ_{eq}. If the equilibrium deflection is less than the maximum deflection, Δ_{max}, the cables successfully resist the sphere, which does not pass through the cables.



(A) Transmitted Force, *F*, vs. Deflection, Δ.

(B) Cable Resisting Force, *P*, vs. Deflection, Δ.

The Figures above show typical force versus deflection relationships for the force transmitted by the sphere and the cable resisting force. Determining the equilibrium deflection is an iterative procedure to find the point at which the two curves cross.

Mathcad Function:

The Mathcad **root()** function can be used to automate the iterative process of determining a value for Δ where the transmitted force F is equal to the cable resistance force, P:

$$\Delta_{eq}(F_x, D_b, D, S_o, L, L_T, F_{ps}) := \left| \begin{array}{l} \Delta \leftarrow 0 \cdot in \\ root\left(\begin{array}{l} F(F_x, \Delta, D, D_b, S_o) \ldots \\ + -P(\Delta, D, L, L_T, F_{ps}) \end{array}, \Delta\right) \end{array} \right.$$

(The first line assigns an initial value to the solver.)

This routine, however, is ill behaved—if the system does not reach equilibrium, i.e., the sphere passes through the cables, there is no root to the equation and the Mathcad **root()** fuction returns an error instead of a value. To make this routine better behaved, an error-trapping function can be included:

$$\Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}, L, L_T, F_{ps}) := \left| \begin{array}{l} \Delta \leftarrow 0 \cdot in \\ \Delta_{max} \text{ on error } root\left(\begin{array}{l} F(F_x, \Delta, D, D_b, S_o) \ldots \\ + -P(\Delta, D, L, L_T, F_{ps}) \end{array}, \Delta \right) \end{array} \right.$$

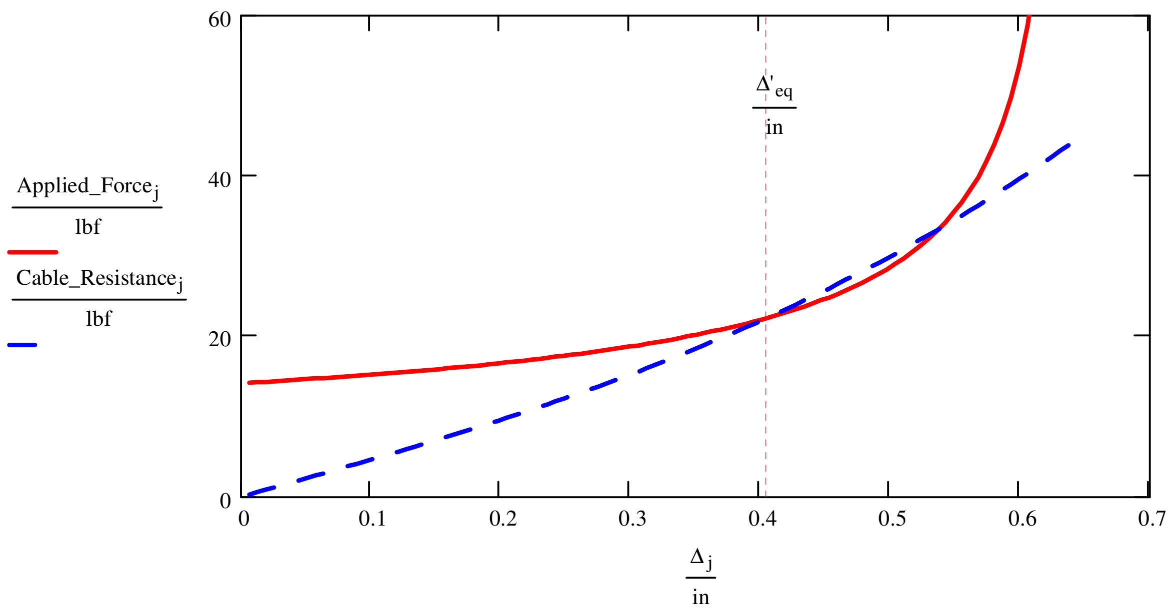
If equilibrium cannot be reached, this routine returns *Δmax*, indicating that the sphere passed-through the cables.

Example: Given the following parameters,

Diameter of Cable:	$D := 0.375 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 12 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$		
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 20 \cdot lbf$

Determine the equilibrium deflection, and plot the load vs. deflection curves.

Equilibrium Deflection: $\Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}) = 0.404\,in$



— END OF SECTION A —

SECTION B

WIRE-ROPE CABLE INTERMEDIATE RAILING PASS-THROUGH RESISTANCE TO 4" SPHERE

B.1—INTRODUCTION

These calculations check the resistance of wire-rope cable intermediate railings to pass-through of a 4" diameter sphere as required by 2006 IBC 1012.3.

The sphere is loaded perpendicular to the plane and at the mid-span of the infill cables. Contact between the sphere and the cables is assumed to be frictionless.

The sphere is successfully resisted if the cable deflection and spread reaches an equilibrium with the applied force before the cables are spread far enough apart to allow the sphere to pass through.

The equations used in these calculations are derived in Section A.

B.2—CHECKS FOR 1/8" WIRE ROPE CABLE @ 3.1" SPACING

Diameter of Cable:	$D := 0.125 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$		
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.125\,in$

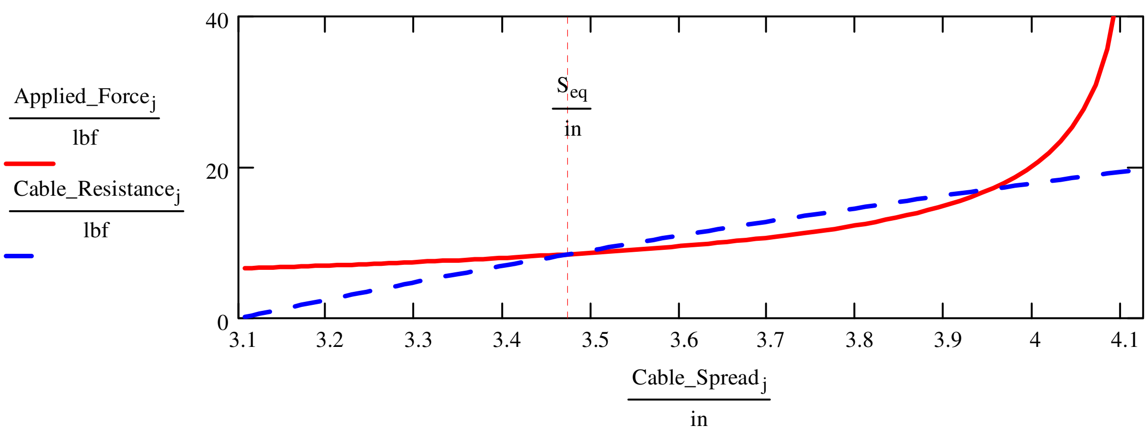
Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.513\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}\right)$ $\quad \Delta'_{eq} = 0.222\,in$

Cable Anchor Reaction: $R_x := \dfrac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 401.8\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.474\,in$

$\dfrac{S_{eq}}{S_{max}} = 0.842$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.3—CHECKS FOR 3/16" WIRE ROPE CABLE @ 3.1" SPACING

Diameter of Cable:	$D := 0.1875 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$		
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.188\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.544\,in$

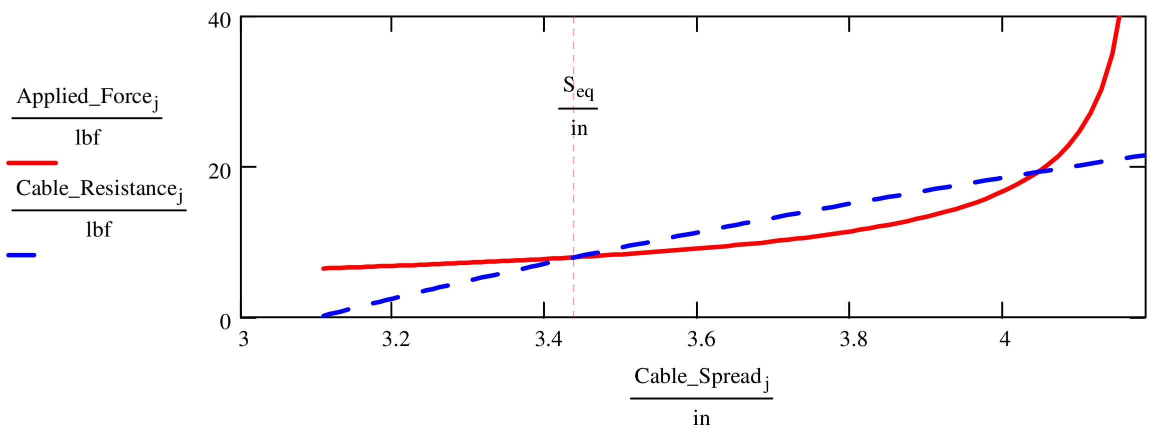
Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}\right)$ $\quad \Delta'_{eq} = 0.206\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 406.6\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.439\,in$

$$\frac{S_{eq}}{S_{max}} = 0.821$$

If < 1.0, System reaches equilibrium and is GOOD



SUCCESSFULLY RESISTS SPHERE

B.4—CHECKS FOR 3/16" WIRE ROPE CABLE @ 3.25" SPACING

Diameter of Cable: $D := 0.1875 \cdot in$ Cable Spacing: $S_o := 3.25 \cdot in$

Support Spacing: $L := 42 \cdot in$ Anchor Spacing: $L_T := 50 \cdot ft$

Prestress Force: $F_{ps} := 400 \cdot lbf$

Sphere Diameter: $D_b := 4 \cdot in$ Load on Sphere $F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $S_{max} = 4.188\,in$

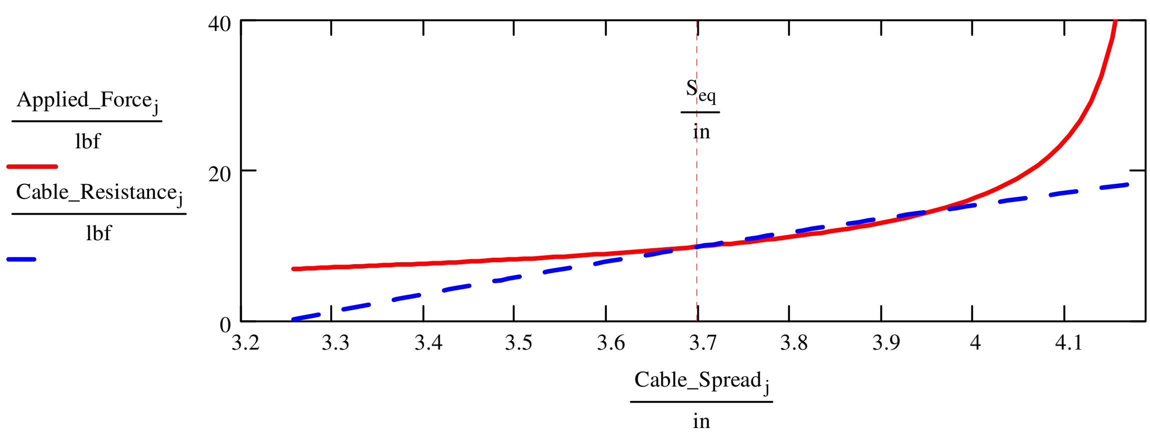
Deflection at Pass-Thru: $\Delta'_{max} := \frac{S_{max} - S_o}{2}$ $\Delta'_{max} = 0.469\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps})$ $\Delta'_{eq} = 0.254\,in$

Cable Anchor Reaction: $R_x := \frac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $R_x = 407.4\,lbf$

Spread at Equilibrium: $S_{eq} := \frac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $S_{eq} = 3.699\,in$

$\frac{S_{eq}}{S_{max}} = 0.883$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.5—CHECKS FOR 1/4" WIRE ROPE CABLE @ 3.1" SPACING

Diameter of Cable: $D := 0.25 \cdot in$ Cable Spacing: $S_o := 3.1 \cdot in$

Support Spacing: $L := 42 \cdot in$ Anchor Spacing: $L_T := 50 \cdot ft$

Prestress Force: $F_{ps} := 400 \cdot lbf$

Sphere Diameter: $D_b := 4 \cdot in$ Load on Sphere $F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $S_{max} = 4.25\,in$

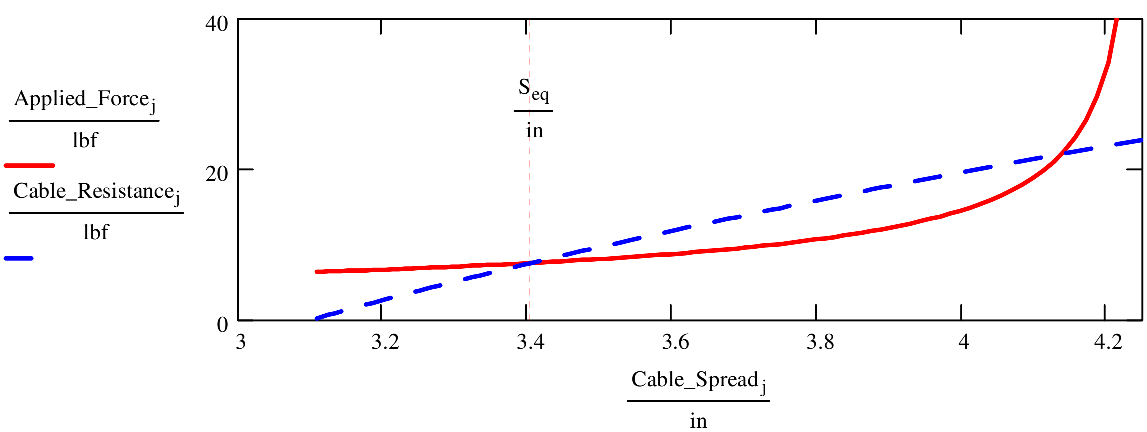
Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\Delta'_{max} = 0.575\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps})$ $\Delta'_{eq} = 0.19\,in$

Cable Anchor Reaction: $R_x := \dfrac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $R_x = 418.2\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $S_{eq} = 3.405\,in$

$\dfrac{S_{eq}}{S_{max}} = 0.801$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.6—CHECKS FOR 1/4" WIRE ROPE CABLE @ 3.25" SPACING

Diameter of Cable: $D := 0.25 \cdot in$ Cable Spacing: $S_o := 3.25 \cdot in$

Support Spacing: $L := 42 \cdot in$ Anchor Spacing: $L_T := 50 \cdot ft$

Prestress Force: $F_{ps} := 400 \cdot lbf$

Sphere Diameter: $D_b := 4 \cdot in$ Load on Sphere $F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $S_{max} = 4.25\, in$

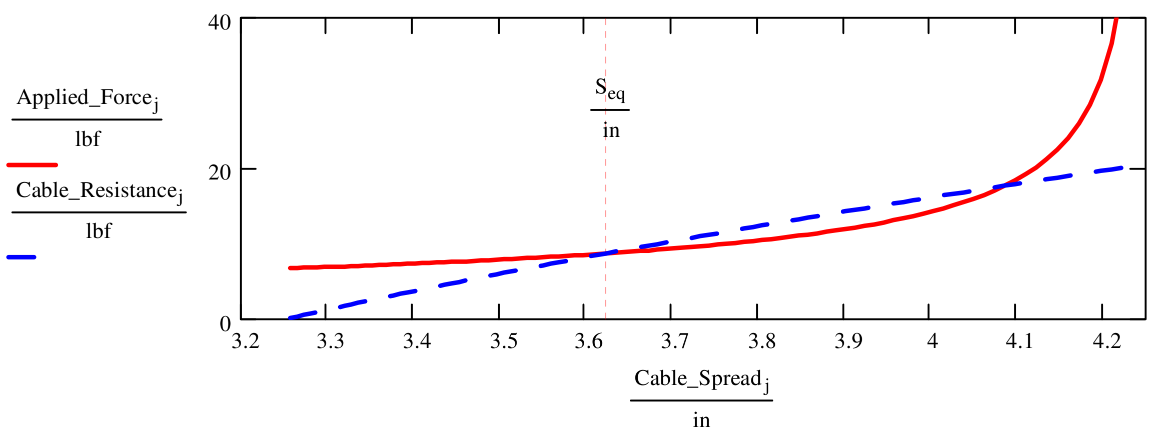
Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\Delta'_{max} = 0.5\, in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}\right)$ $\Delta'_{eq} = 0.22\, in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $R_x = 419\, lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $S_{eq} = 3.624\, in$

$\dfrac{S_{eq}}{S_{max}} = 0.853$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.7—CHECKS FOR 1/4" WIRE ROPE CABLE @ 3.36" SPACING

Diameter of Cable:	$D := 0.25 \cdot in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$		
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.25\,in$

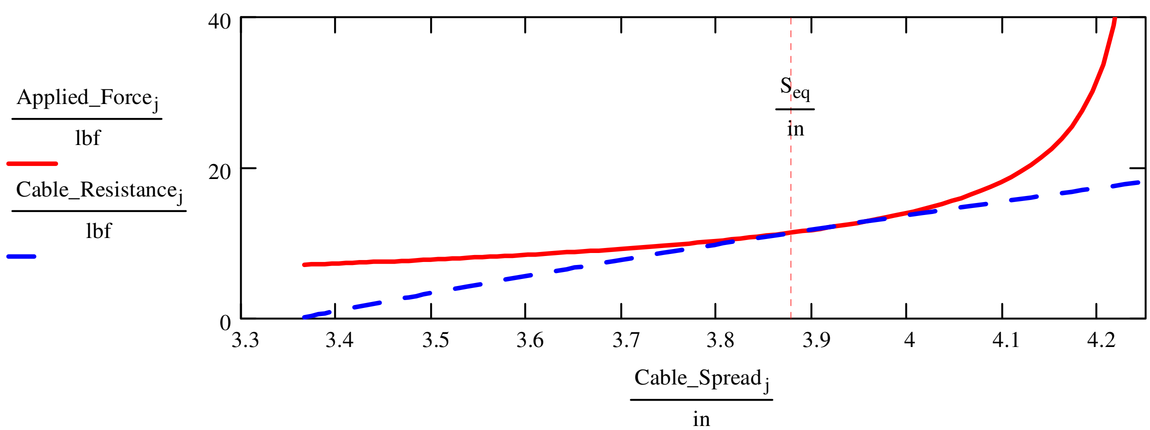
Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.445\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps})$ $\quad \Delta'_{eq} = 0.285\,in$

Cable Anchor Reaction: $R_x := \dfrac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 421.1\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.88\,in$

$\dfrac{S_{eq}}{S_{max}} = 0.913$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.8—CHECKS FOR 5/16" WIRE ROPE CABLE @ 3.1" SPACING

Diameter of Cable: $D := 0.3125 \cdot in$ Cable Spacing: $S_o := 3.1 \cdot in$

Support Spacing: $L := 42 \cdot in$ Anchor Spacing: $L_T := 50 \cdot ft$

Prestress Force: $F_{ps} := 400 \cdot lbf$

Sphere Diameter: $D_b := 4 \cdot in$ Load on Sphere $F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $S_{max} = 4.313\, in$

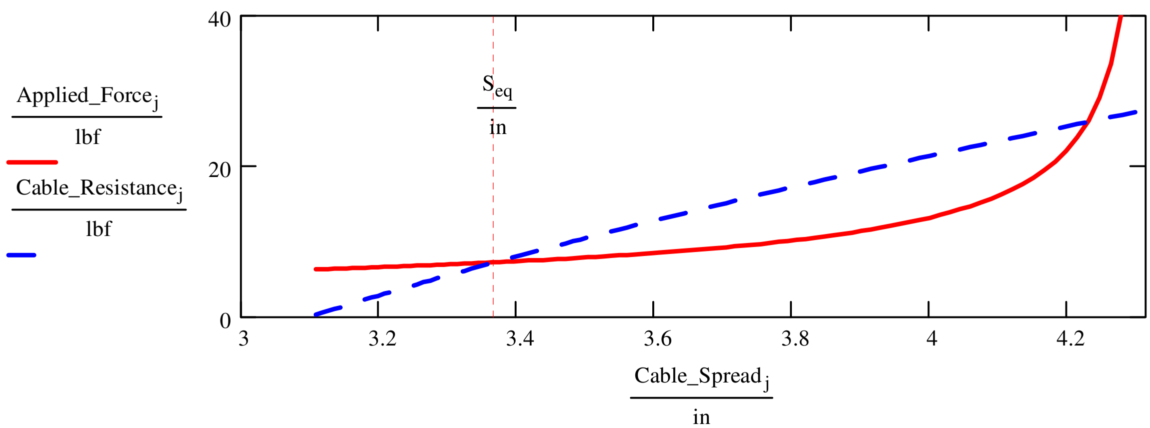
Deflection at Pass-Thru: $\Delta'_{max} := \frac{S_{max} - S_o}{2}$ $\Delta'_{max} = 0.606\, in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}\right)$ $\Delta'_{eq} = 0.172\, in$

Cable Anchor Reaction: $R_x := \frac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $R_x = 441.8\, lbf$

Spread at Equilibrium: $S_{eq} := \frac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $S_{eq} = 3.368\, in$

$\frac{S_{eq}}{S_{max}} = 0.781$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.9—CHECKS FOR 5/16" WIRE ROPE CABLE @ 3.25" SPACING

Diameter of Cable: $D := 0.3125 \cdot in$ Cable Spacing: $S_o := 3.25 \cdot in$

Support Spacing: $L := 42 \cdot in$ Anchor Spacing: $L_T := 50 \cdot ft$

Prestress Force: $F_{ps} := 400 \cdot lbf$

Sphere Diameter: $D_b := 4 \cdot in$ Load on Sphere $F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $S_{max} = 4.313\,in$

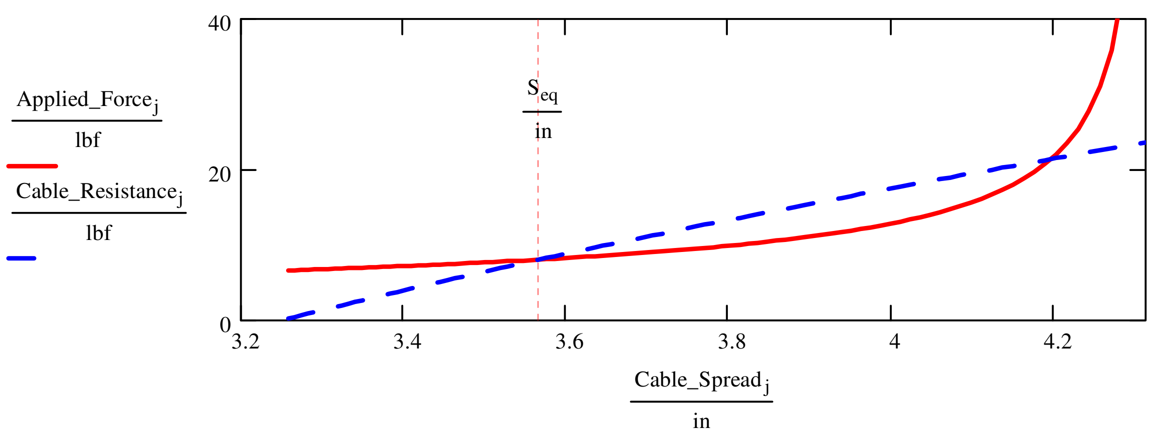
Deflection at Pass-Thru: $\Delta'_{max} := \frac{S_{max} - S_o}{2}$ $\Delta'_{max} = 0.531\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps})$ $\Delta'_{eq} = 0.192\,in$

Cable Anchor Reaction: $R_x := \frac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $R_x = 442.5\,lbf$

Spread at Equilibrium: $S_{eq} := \frac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $S_{eq} = 3.567\,in$

$\frac{S_{eq}}{S_{max}} = 0.827$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.10—CHECKS FOR 5/16" WIRE ROPE CABLE @ 3.36" SPACING

Diameter of Cable:	$D := 0.3125 \cdot in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$		
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

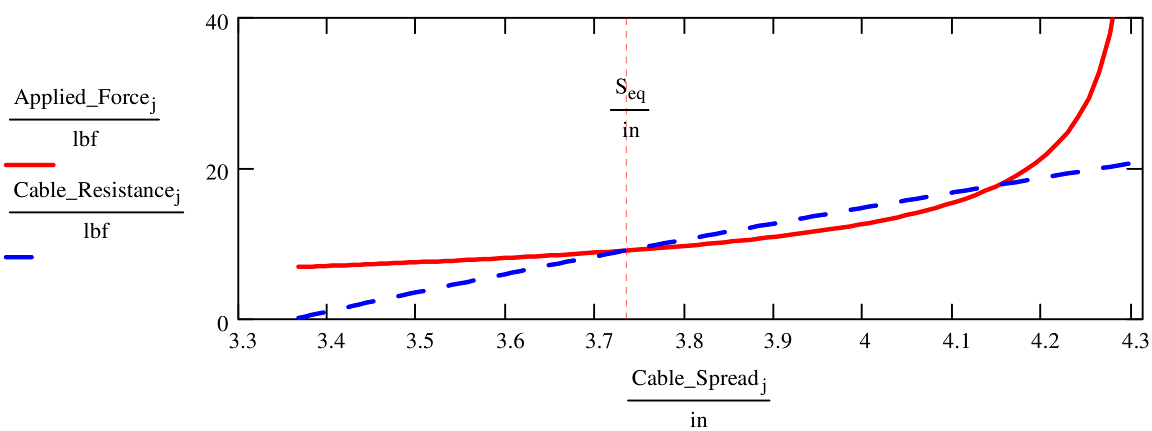
Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.476\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}\right)$ $\quad \Delta'_{eq} = 0.216\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 443.5\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.735\,in$

$\dfrac{S_{eq}}{S_{max}} = 0.866$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.11—CHECKS FOR 3/8" WIRE ROPE CABLE @ 3.1" SPACING

Diameter of Cable:	$D := 0.375 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$		
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,in$

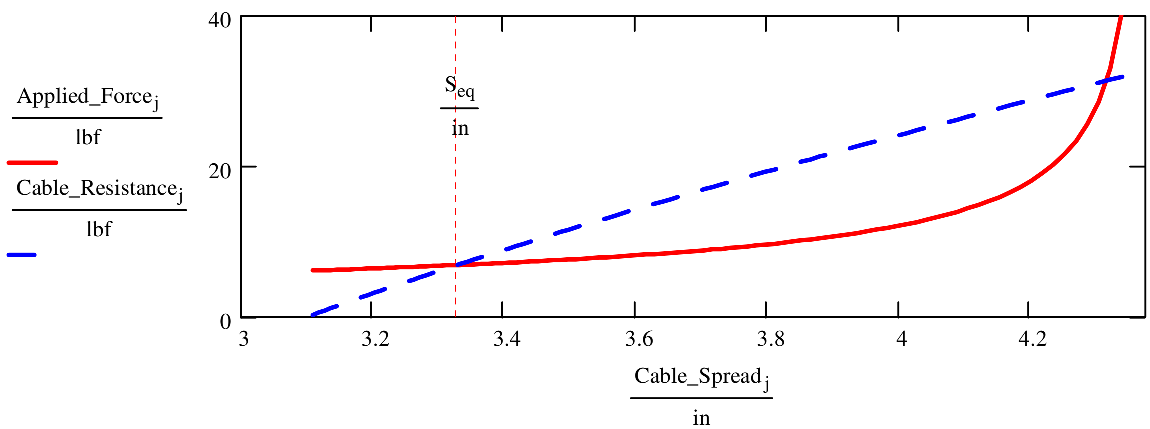
Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.638\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}\right)$ $\quad \Delta'_{eq} = 0.15\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 483.8\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.328\,in$

$\dfrac{S_{eq}}{S_{max}} = 0.761$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.12—CHECKS FOR 3/8" WIRE ROPE CABLE @ 3.25" SPACING

Diameter of Cable:	$D := 0.375 \cdot in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$		
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,in$

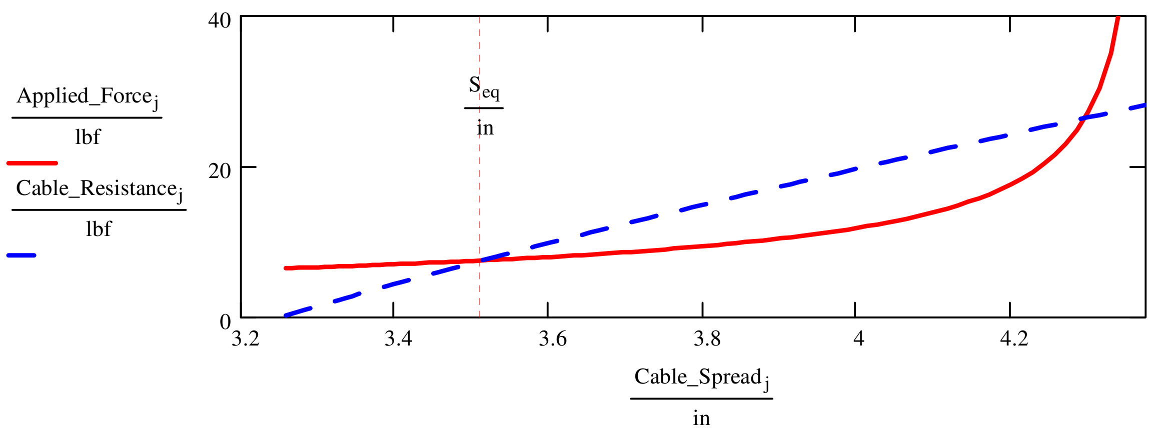
Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.563\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}\right)$ $\quad \Delta'_{eq} = 0.164\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 484.5\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.513\,in$

$\dfrac{S_{eq}}{S_{max}} = 0.803$ ***If < 1.0, System reaches equilibrium and is GOOD***



SUCCESSFULLY RESISTS SPHERE

B.13—CHECKS FOR 3/8" WIRE ROPE CABLE @ 3.36" SPACING

Diameter of Cable:	$D := 0.375 \cdot in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$		
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\, in$

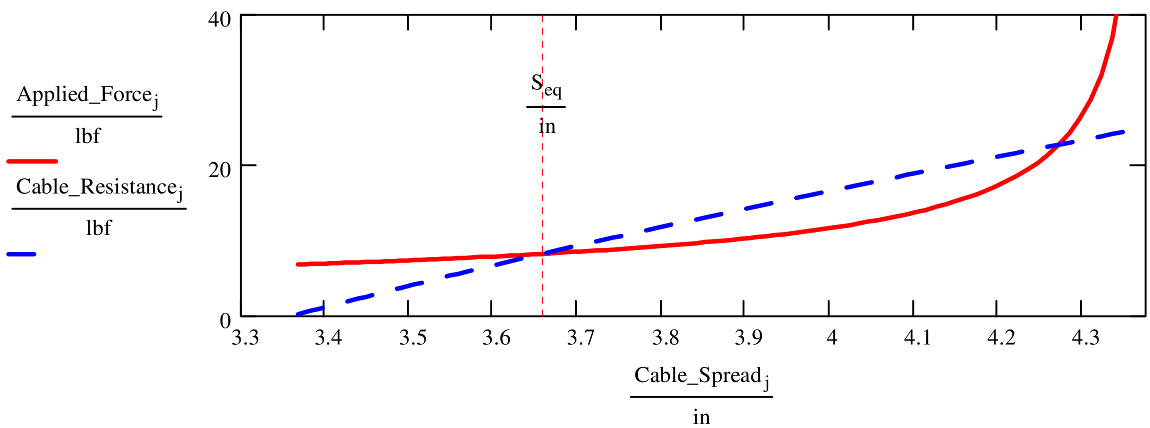
Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.508\, in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}\right)$ $\quad \Delta'_{eq} = 0.178\, in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 485.2\, lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.659\, in$

$\dfrac{S_{eq}}{S_{max}} = 0.836$ ***If < 1.0, System reaches equilibrium and is GOOD***



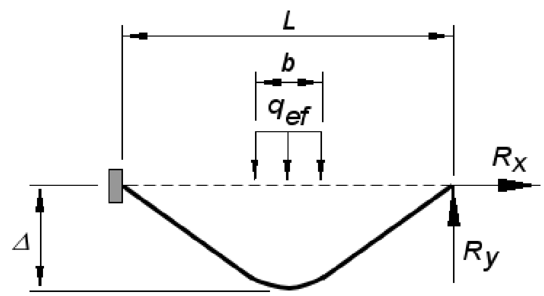
SUCCESSFULLY RESISTS SPHERE

— END OF SECTION B —

SECTION C

DERIVATION OF EQUATIONS FOR CODE REQUIRED LOADING ON INTERMEDIATE RAILING COMPONENTS

C.1—LOAD-DEFLECTION RELATIONSHIP FOR AN EXTENSIBLE, FLEXIBLE CABLE UNDER A PARTIAL UNIFORM LOAD



Symbols and Notations

Δ	Deflection of cable under uniform load, q_{ef}.
b	Length of partial uniform load, in.
L	Spacing between intermediate supports, in.
q_{ef}	Partial uniform load required to produce deflection Δ, plf.
R_x	In-plane end reaction, due to deflection of cable, lbs.
R_y	Out-of-plane end reaction, due to deflection of cable, lbs.
s	Length of the curved segment of cable under the partial uniform load, in.
s_1	Length of the straight segment of cable between the partial uniform load and the support, in.
T_o	Tension load in cable at point of maximum deflection, lbs.
T_1	Tension load in straight segment of cable, lbs.
T_{avg}	Average tension load in curved segment of cable, lbs.

Objective

Given a mid-span deflection, Δ, determine the partial uniform load required to produce that deflection.

Determination of Reactions

Out-of-plane end reactions, R_{y}, can be calculated by taking the sum of moments about one of the support points:

$$\Sigma M = 0: \quad q_{ef} \cdot b \cdot \frac{L}{2} - R_y \cdot L = 0$$

$$R_y \cdot L = \frac{q_{ef} \cdot b \cdot L}{2}$$

$$R_y = \frac{q_{ef} \cdot b}{2} \qquad \textbf{(1)}$$

The in-plane end reaction, R_x, can be calculated by taking the sum of the moments about the mid-point of the cable, using forces to the right of the applied load:

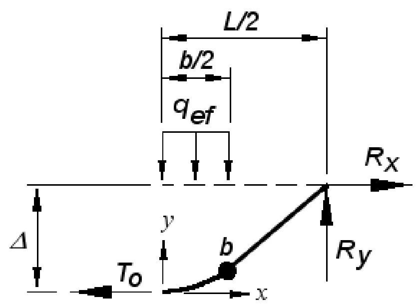
$$\Sigma M = 0: \qquad q_{ef} \cdot \frac{b}{2} \cdot \frac{L}{4} + R_x \cdot \Delta - R_y \cdot \frac{L}{2} = 0$$

$$R_x \cdot \Delta = \frac{R_y \cdot L}{2} - \frac{q_{ef} \cdot b \cdot L}{8}$$

$$R_x = \frac{\frac{q_{ef} \cdot b}{2} \cdot \frac{L}{2} - \frac{q_{ef} \cdot b \cdot L}{8}}{\Delta} = \frac{2 \cdot q_{ef} \cdot b \cdot L}{8 \cdot \Delta} - \frac{q_{ef} \cdot b \cdot L}{8 \cdot \Delta}$$

$$R_x = \frac{q_{ef} \cdot b \cdot L}{8 \cdot \Delta} \qquad \textbf{(2)}$$

Strain Compatibility



The deflected shape of the cable under the uniform load is a parabola of the form:

$$y = \frac{q \cdot x^2}{2T_o}$$

where the origin (x=0 and y=0) is the point of maximum deflection.

The mid-span tension in the cable, T_o, can be calculated by taking the sum of the moments about the right-hand end point of the cable, using forces to the right of the applied load:

$$\Sigma M = 0: \qquad q_{ef} \cdot \frac{b}{2} \cdot \frac{L}{4} - T_o \cdot \Delta = 0$$

$$T_o = \frac{q_{ef} \cdot b \cdot L}{8 \cdot \Delta} \qquad \textbf{(3)}$$

which is equal to R_x, obtained in Eqn. (2).

Substituting Eqn. (3) into the parabola equation gives us:

$$y = \frac{q_{ef} \cdot x^2}{2 \cdot \left(\frac{q_{ef} \cdot b \cdot L}{8 \cdot \Delta} \right)}$$

$$y = \frac{4\cdot\Delta\cdot x^2}{b\cdot L} \qquad \textbf{(4)}$$

The length of the parabola from midpoint to the end of the partial uniform load is given by:

$$s = \int_0^{\frac{b}{2}} \sqrt{1 + \left(\frac{dy}{dx}\right)^2}\, dx \qquad \textbf{(5)}$$

where *dy/dx* represents the incremental change in *y*, given an incremental change in *x*, which is the derivative of Eqn (4):

$$\frac{dy}{dx} = \frac{d}{dx}\cdot\left(\frac{4\cdot\Delta\cdot x^2}{b\cdot L}\right)$$

$$\frac{dy}{dx} = \frac{8\cdot\Delta\cdot x}{b\cdot L} \qquad \textbf{(6)}$$

Substituting Eqn. (6) back into Eqn. (5) yields:

$$s = \int_0^{\frac{b}{2}} \sqrt{1 + \left(\frac{8\cdot\Delta\cdot x}{b\cdot L}\right)^2}\, dx$$

The cable deflection at the point where the partial uniform load ends can be calculated using Eqn. (4):

$$\Delta_b = \Delta - y_b$$

$$\Delta_b = \Delta - \frac{4\cdot\Delta\cdot b^2}{b\cdot L}$$

$$\Delta_b = \Delta - \frac{4\cdot\Delta\cdot b}{L}$$

The length of the straight segment of cable between the uniform load and the support can be calculated using the Pythagorean theorum:

$$s_1 = \sqrt{\Delta_b{}^2 + \left(\frac{L-b}{2}\right)^2}$$

$$s_1 = \sqrt{\left(\Delta - \frac{4\cdot\Delta\cdot b}{L}\right)^2 + \left(\frac{L-b}{2}\right)^2}$$

The cable extension, δ, over the original length, *L*, is:

$$\delta = 2\cdot\left(s + s_1\right) - L$$

$$\delta = 2\cdot\left[\int_0^{\frac{b}{2}}\sqrt{1+\left(\frac{8\cdot\Delta\cdot x}{b\cdot L}\right)^2}\,dx + \sqrt{\left(\Delta - \frac{4\cdot\Delta\cdot b}{L}\right)^2 + \left(\frac{L-b}{2}\right)^2}\right] - L \qquad \textbf{(7)}$$

The tension in the straight segment of cable, between the end of the uniform load and the support, T_1, can also be computed using the Pythagorean theorum:

$$T_1 = \sqrt{R_x^{\,2} + R_y^{\,2}}$$

Substituting R_y and R_x from Eqns (1) and (2) yields:

$$T_1 = \sqrt{\left(\frac{q_{ef}\cdot b\cdot L}{8\cdot\Delta}\right)^2 + \left(\frac{q_{ef}\cdot b}{2}\right)^2}$$

$$T_1 = \frac{q_{ef}\cdot b}{2}\cdot\sqrt{\left(\frac{L}{4\cdot\Delta}\right)^2 + 1} \qquad \textbf{(8)}$$

To determine an equation for tension in the cable at any point along the loaded parabola, we turn once again to the Pythagorean theorum:

$$T = \sqrt{R_x^{\,2} + R_y^{\,2}}$$

Recall that T_o is equal to R_x, therefore this equation becomes:

$$T = \sqrt{T_o^{\,2} + \left(\frac{q_{ef}\cdot b}{2}\right)^2}$$

Substituting x for b/2, gives us an equation for tension in the cable at any point along the loaded parabola:

$$T(x) = \sqrt{T_o^{\,2} + (q_{ef}\cdot x)^2} \qquad \textbf{(9)}$$

The average tension in the cable along the parabola can be obtained by integrating Eqn. (9) and then dividing by the original length of the segment, b/2:

$$T_{avg} = \frac{\displaystyle\int_0^{\frac{b}{2}}\sqrt{T_o^{\,2} + (q_{ef}\cdot x)^2}\,dx}{\frac{b}{2}}$$

Substituting Eqn. (3) into the above equation and rearranging yields:

$$T_{avg} = \frac{2}{b}\cdot\int_0^{\frac{b}{2}}\sqrt{\left(\frac{q_{ef}\cdot b\cdot L}{8\cdot\Delta}\right)^2 + (q_{ef}\cdot x)^2}\,dx$$

$$T_{avg} = \frac{2 \cdot q_{ef}}{b} \cdot \int_0^{\frac{b}{2}} \sqrt{\left(\frac{b \cdot L}{8 \cdot \Delta}\right)^2 + x^2}\, dx$$

The total elongation is a result of the cable stretch due to the tension in the cable over two distinct regions, the parabolic segment under the load and the straight segments between the load and the supports. The total elongation is:

$$\delta = \frac{T_{avg} \cdot b}{E \cdot A} + \frac{T_1 \cdot (L - b)}{E \cdot A}$$

$$\delta = \frac{b}{E \cdot A} \cdot \frac{2 \cdot q_{ef}}{b} \cdot \int_0^{\frac{b}{2}} \sqrt{\left(\frac{b \cdot L}{8 \cdot \Delta}\right)^2 + x^2}\, dx + \frac{L - b}{E \cdot A} \cdot \left[\frac{q_{ef} \cdot b}{2} \cdot \sqrt{\left(\frac{L}{4 \cdot \Delta}\right)^2 + 1}\right]$$

$$\delta = \frac{q_{ef}}{E \cdot A} \cdot \left[2 \cdot \int_0^{\frac{b}{2}} \sqrt{\left(\frac{b \cdot L}{8 \cdot \Delta}\right)^2 + x^2}\, dx + \frac{(L - b) \cdot b}{2} \cdot \sqrt{\left(\frac{L}{4 \cdot \Delta}\right)^2 + 1}\right] \qquad \textbf{(10)}$$

Simultaneous Equations

Since the total elongation given by Eqns. (7) and (10) must be the same, we now have two equations which can be used to solve for one variable in terms of the other.

Substituting Eqn. (7) for δ in Eqn. (10) and rearranging to solve for q_{ef} gives us:

$$2 \cdot \left[\int_0^{\frac{b}{2}} \sqrt{1 + \left(\frac{8 \cdot \Delta \cdot x}{b \cdot L}\right)^2}\, dx \ldots + \sqrt{\left(\Delta - \frac{4 \cdot \Delta \cdot b}{L}\right)^2 + \left(\frac{L - b}{2}\right)^2}\right] - L = \frac{q_{ef}}{E \cdot A} \cdot \left[2 \cdot \int_0^{\frac{b}{2}} \sqrt{\left(\frac{b \cdot L}{8 \cdot \Delta}\right)^2 + x^2}\, dx \ldots + \frac{(L - b) \cdot b}{2} \cdot \sqrt{\left(\frac{L}{4 \cdot \Delta}\right)^2 + 1}\right]$$

$$q_{ef} = E \cdot A \cdot \frac{2 \cdot \left[\int_0^{\frac{b}{2}} \sqrt{1 + \left(\frac{8 \cdot \Delta \cdot x}{b \cdot L}\right)^2}\, dx + \sqrt{\left(\Delta - \frac{4 \cdot \Delta \cdot b}{L}\right)^2 + \left(\frac{L - b}{2}\right)^2}\right] - L}{2 \cdot \int_0^{\frac{b}{2}} \sqrt{\left(\frac{b \cdot L}{8 \cdot \Delta}\right)^2 + x^2}\, dx + \frac{(L - b) \cdot b}{2} \cdot \sqrt{\left(\frac{L}{4 \cdot \Delta}\right)^2 + 1}}$$

Mathcad Function:

$$q_{ef}(\Delta, D, L, b) := \left| \begin{array}{l} A \leftarrow \dfrac{\pi \cdot D^2}{4} \\ E_{eff} \cdot A \cdot \dfrac{2 \cdot \left[\displaystyle\int_{0 \cdot ft}^{\frac{b}{2}} \sqrt{1 + \left(\dfrac{8 \cdot \Delta \cdot x}{b \cdot L}\right)^2} \, dx + \sqrt{\left(\Delta - \dfrac{4 \cdot \Delta \cdot b}{L}\right)^2 + \left(\dfrac{L - b}{2}\right)^2} \right] - L}{2 \cdot \displaystyle\int_{0 \cdot ft}^{\frac{b}{2}} \sqrt{\left(\dfrac{b \cdot L}{8 \cdot \Delta}\right)^2 + x^2} \, dx + \dfrac{(L - b) \cdot b}{2} \cdot \sqrt{\left(\dfrac{L}{4 \cdot \Delta}\right)^2 + 1}} \end{array} \right.$$

Example 1: Given a 3/8" diameter 1x19 wire rope supported at 42", calculate the 1 foot length uniform load required to cause a maximum deflection of 1":

$$D := 0.375 \cdot in$$

$$L := 42 \cdot in$$

$$b := 1 \cdot ft$$

$$\Delta := 1 \cdot in$$

$$q_{ef}(\Delta, D, L, b) = 158.4\,plf$$

Example 2: Given a 3/8" diameter 1x19 wire rope supported at 42", calculate the 1 foot length uniform load required to cause a maximum deflection of 0.5":

$$D := 0.375 \cdot in$$

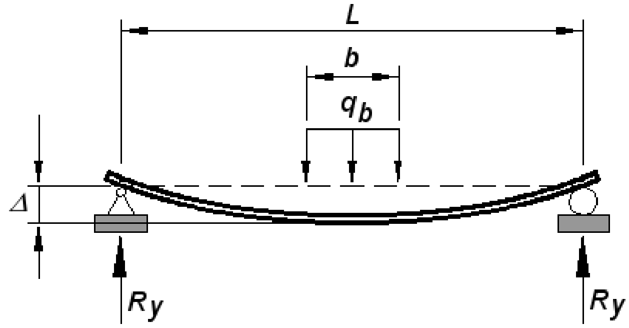
$$L := 42 \cdot in$$

$$b := 1 \cdot ft$$

$$\Delta := 0.5 \cdot in$$

$$q_{ef}(\Delta, D, L, b) = 19.9\,plf$$

C.2—LOAD-DEFLECTION RELATIONSHIP IN FLEXURAL BENDING



Symbols and Notations

Δ	Deflection of cable under uniform load, q_b, in.
b	Length of partial applied load, in.
D	Diameter of wire rope cable, in.
E_{eff}	Effective Modulus of Elasticity for wire rope cable, ksi.
I	Moment of Inertia, in^4.
I_{1x19}	Moment of inertia of 1x19 wire rope, in^4.
L	Spacing between intermediate supports, in.
q_b	Partial uniform load required to produce deflection Δ, lbs.

Objective

Given a deflection, Δ, determine the partial uniform load required to produce that deflection due to flexural bending.

Flexural Bending

The deflection of a simply-supported beam 3.5 feet long under a partial uniform load of length 1 foot was empirically computed to be:

$$\Delta = \frac{q_b \cdot b \cdot L^3}{50 \cdot E \cdot I}$$

This equation can be rearranged to calculate the load necessary to cause a deflection of Δ:

$$q_b = \frac{50 \cdot E \cdot I \cdot \Delta}{b \cdot L^3}$$

Mathcad Function: $$q_b(\Delta, D, L, b) := \frac{50 \cdot E_{eff} \cdot I_{1x19}(D) \cdot \Delta}{b \cdot L^3}$$

Example: Given a 3/8" diameter 1x19 wire rope supported at 42", calculate the uniform load required to cause a deflection of 1" due to pure bending:

$$D := 0.375 \cdot in$$

$$L := 42 \cdot in$$

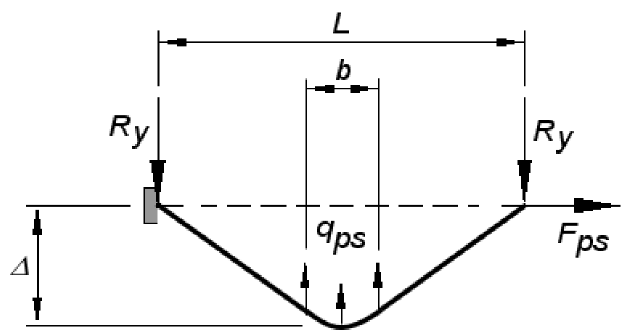
$$b := 1 \cdot ft$$

$$\Delta := 1 \cdot in$$

$$q_b(\Delta, D, L, b) = 7.998\, plf$$

C.3—EFFECTS OF CABLE PRESTRESSING

The effect of cable prestressing is to provide a force to balance an applied load. This balancing force is directly related to the geometry of the cable and the prestressing force.



Symbols and Notations

Δ	Deflection of cable at mid-span, in.
b	Length of partial applied load, in.
L	Spacing between intermediate supports, in.
F_{ps}	Applied prestressing force, lbs.
q_{ps}	Partial uniform balance load due to prestressing, lbs.
R_y	Out-of-plane end reaction, lbs.

Objective

Given an initial prestress force, F_{ps}, and a mid-span deflection, Δ, determine the resulting balancing force, q_{ps}.

Balancing Force

The end reaction, R_y, can be found by taking the sum of the moments about the other end point:

$$\Sigma M = 0: \quad q_{ps} \cdot b \cdot \frac{L}{2} - R_y \cdot L = 0$$

$$R_y \cdot L = \frac{q_{ps} \cdot b \cdot L}{2}$$

$$R_y = \frac{q_{ps} \cdot b \cdot L}{2}$$

Taking the sum of the moments at mid-span and considering forces to the right, we can compute the balance force q_{ps}:

Σ M = 0:

$$q_{ps} \cdot \frac{b}{2} \cdot \frac{L}{4} - R_y \cdot \frac{L}{2} - F_{ps} \cdot \Delta = 0$$

$$\frac{q_{ps} \cdot b \cdot L}{4} - \frac{q_{ps} \cdot b \cdot L}{8} = -F_{ps} \cdot \Delta$$

$$q_{ps} = -\frac{8 \cdot F_{ps} \cdot \Delta}{b \cdot L}$$

Our applied load is equal to the magnitude of q_{ps}, but opposite in sign. Therefore, in the context of our applied load, the equation for q_{ps} becomes:

$$q_{ps} = \frac{8 \cdot F_{ps} \cdot \Delta}{b \cdot L}$$

Mathcad Function:

$$q_{ps}(\Delta, L, b, F_{ps}) := \frac{8 \cdot F_{ps} \cdot \Delta}{b \cdot L}$$

Example: Given a 3/8" diameter 1x19 wire rope supported at 42", calculate the 1 foot long balancing load with a 400 lb prestress force and a deflection of 1":

$$D := 0.375 \cdot in$$

$$L := 42 \cdot in$$

$$b := 1 \cdot ft$$

$$F_{ps} := 400 \cdot lbf$$

$$\Delta := 1 \cdot in$$

$$q_{ps}(\Delta, L, b, F_{ps}) = 76.2\ plf$$

C.4—PUTTING IT ALL TOGETHER

Symbols and Notations

Δ	Deflection of cable under uniform load, *q*.
b	Length of applied partial uniform load, in.
D	Diameter of wire rope cable, in.
F_{ps}	Applied prestressing force, lbs.
L	Spacing between supports, in.
q	Partial uniform load required to produce deflection *Δ*, plf.
q_b	Component of uniform load, q, resisted by flexural bending, plf.
q_{ef}	Component of uniform load, q, resisted by stretching of cable, plf.
q_{ps}	Component of uniform load, q, resisted by cable prestressing, plf.

Combined Load-Deflection Relationship

The effects of cable stretch, flexural bending, and prestressing force combine to create a composite relationship between the applied load and the deflection of the cable. That is, for a given uniform load, the cable will deflect until the load is balanced by the sum of the reactions due to cable stretch, flexure, and prestressing force.

Recall the load-deflection relationships previously derived:

Extensible, Flexible Cable:

$$q_{ef} = E\cdot A\cdot\frac{2\cdot\left[\int_0^{\frac{b}{2}}\sqrt{1+\left(\frac{8\cdot\Delta\cdot x}{b\cdot L}\right)^2}\,dx+\sqrt{\left(\Delta-\frac{4\cdot\Delta\cdot b}{L}\right)^2+\left(\frac{L-b}{2}\right)^2}\right]-L}{2\cdot\int_0^{\frac{b}{2}}\sqrt{\left(\frac{b\cdot L}{8\cdot\Delta}\right)^2+x^2}\,dx+\frac{(L-b)\cdot b}{2}\cdot\sqrt{\left(\frac{L}{4\cdot\Delta}\right)^2+1}}$$

Flexural Bending:

$$q_b = \frac{50\cdot E\cdot I\cdot\Delta}{b\cdot L^3}$$

Presstressing:

$$q_{ps} = \frac{8\cdot F_{ps}\cdot\Delta}{b\cdot L}$$

Strain compatibility laws tell us that when a load is applied to the cable, the deflection in each of the above cases must the same. Therefore, for a given deflection, the applied load required to cause that deflection is the sum of the three components:

$$q = q_{ef} + q_b + q_{ps}$$

Mathcad Function: $q(\Delta,D,L,b,F_{ps}) := q_{ef}(\Delta,D,L,b) + q_b(\Delta,D,L,b) + q_{ps}(\Delta,L,b,F_{ps})$

Example: Given a 3/8" diameter 1x19 wire rope supported at 42" and with a prestress load of 400 lbs., calculate the 1 foot long uniform load required to cause a mid-span deflection of 1":

$$D := 0.375\cdot in$$

$$L := 42\cdot in$$

$$b := 1\cdot ft$$

$$F_{ps} := 400\cdot lbf$$

$$\Delta := 1\cdot in$$

$$q(\Delta, D, L, b, F_{ps}) = 242.6\,plf$$

C.5—BUILDING CODE LOAD REQUIREMENTS

The 2003 *International Building Code* requires intermediate rails "to withstand a horizontally applied normal load of 50 pounds on an area equal to 1 square foot, including openings and space between rails" (IBC 1607.7.1.2).

To meet this requirement, the end reactions, R_x and R_y, caused by the 50 lbs over 1 square ft load must be determined, so that they may be included in the railing system frame calculations.

Symbols and Notations

Δ	Deflection of cable under uniform load, q_{app}.
b	Length of applied load q_{app}, in.
D	Diameter of wire rope cable, in.
F_{ps}	Applied prestressing force, lbs.
L	Spacing between supports, in.
q_{app}	Applied uniform load, plf.
R_x	In-plane support reaction, lbs.
R_y	Out-of-plane support reaction, lbs.

End Reactions

Recall, from Section C.1, that R_x and R_y can be found using the sum of the moments about one of the supports and about the middle of the cable, respectively. Substituting the applied partial load, q_{app}, for the partial load, q_{ef}, and noting that the deflection Δ represents the combined effects of the extensible-flexible cable, bending in the cable and prestressing, Eqns. (1) and (2) may be rewritten:

$$R_y = \frac{q_{app}\cdot b}{2} \qquad \textbf{(11)}$$

$$R_x = \frac{q_{app}\cdot b\cdot L}{8\cdot\Delta} \qquad \textbf{(12)}$$

Determining the out-of-plane reaction, R_y, is straightforward; however, calculating the in-plane reaction, R_x, requires knowing the deflection in the cable, Δ. Given the applied uniform load, q_{app}, we can calculate the deflection using the Mathcad **root()** function introduced earlier:

$$\Delta = \mathrm{root}\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$$

Knowing the value for Δ, the reactions can be determined, as shown in the Mathcad functions below.

Mathcad Functions:

$$R_y\left(q_{app}, b\right) := \frac{q_{app} \cdot b}{2}$$

$$R_x\left(D, L, F_{ps}, q_{app}, b\right) := \left| \begin{array}{l} \Delta \leftarrow 0 \cdot in \\ \Delta \leftarrow \mathrm{root}\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right) \\ \dfrac{q_{app} \cdot b \cdot L}{8 \cdot \Delta} \end{array} \right.$$

Example. Given 3/8" wire rope cables spaced at 3.11", supported at 42", and with a 400 lb prestress force in each cable, determine the reactions for a single cable when subjected to the code-required 50 psf loading.

$D := 0.375 \cdot in$

$s := 3.11 \cdot in$

$L := 42 \cdot in$

$b := 1 \cdot ft$

$F_{ps} := 400 \cdot lbf$

$q_{app} := (50 \cdot psf) \cdot s \qquad q_{app} = 12.958\, plf$

$R_y\left(q_{app}, b\right) = 6.5\, lbf$

$R_x\left(D, L, F_{ps}, q_{app}, b\right) = 460.3\, lbf$

— END OF SECTION C —

SECTION D

CABLE END REACTIONS UNDER CODE REQUIRED LOADING FOR INTERMEDIATE RAILING COMPONENTS

D.1—INTRODUCTION

The 2006 *International Building Code* requires intermediate rails "to withstand a horizontally applied normal load of 50 pounds on an area equal to 1 square foot, including openings and space between rails" (IBC 1607.7.1.2).

To meet this requirement, the end reactions, R_x and R_v, caused by the 50 lbs over 1 square ft load must be determined, so that they may be included in the railing frame calculations.

The equations used in these calculations are derived in Section C.

There are no pass/fail criteria for this loading; however, cable hardware shall be used whose allowable load capacities exceed the values for R'_x listed herein.

D.2—1/8" WIRE ROPE CABLE

3.1" Spacing

Diameter of Cable:	$D := 0.125 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$ $\quad b := 1 \cdot ft$		
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 12.917\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.168\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 403.1\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 6.5\,lbf$	

3.25" Spacing

Diameter of Cable:	$D := 0.125 \cdot in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$ $\quad b := 1 \cdot ft$		
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 13.542\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.176\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 403.4\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 6.8\,lbf$	

3.36" Spacing

Diameter of Cable:	$D := 0.125 \cdot in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$ $\quad b := 1 \cdot ft$		
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 14\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.182\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 403.6\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 7\,lbf$	

D.3—3/16" WIRE ROPE CABLE

3.1" Spacing

Diameter of Cable:	$D := 0.1875 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$	$b := 1 \cdot ft$	
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 12.917\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.166\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 408.4\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 6.5\,lbf$	

3.25" Spacing

Diameter of Cable:	$D := 0.1875 \cdot in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$	$b := 1 \cdot ft$	
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 13.542\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.174\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 408.9\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 6.8\,lbf$	

3.36" Spacing

Diameter of Cable:	$D := 0.1875 \cdot in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$	$b := 1 \cdot ft$	
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 14\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.18\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 409.4\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 7\,lbf$	

D.4—1/4" WIRE ROPE CABLE

3.1" Spacing

Diameter of Cable:	$D := 0.25 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$	$b := 1 \cdot ft$	
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 12.917\, plf$	
Cable Deflection:	$\Delta := root(q(\Delta, D, L, b, F_{ps}) - q_{app}, \Delta)$	$\Delta = 0.162\, in$	
Axial (in-plane) Reaction:	$R'_x := R_x(D, L, F_{ps}, q_{app}, b)$	$R'_x = 418.1\, lbf$	
Out-of-Plane Reaction:	$R'_y := R_y(q_{app}, b)$	$R'_y = 6.5\, lbf$	

3.25" Spacing

Diameter of Cable:	$D := 0.25 \cdot in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$	$b := 1 \cdot ft$	
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 13.542\, plf$	
Cable Deflection:	$\Delta := root(q(\Delta, D, L, b, F_{ps}) - q_{app}, \Delta)$	$\Delta = 0.17\, in$	
Axial (in-plane) Reaction:	$R'_x := R_x(D, L, F_{ps}, q_{app}, b)$	$R'_x = 419\, lbf$	
Out-of-Plane Reaction:	$R'_y := R_y(q_{app}, b)$	$R'_y = 6.8\, lbf$	

3.36" Spacing

Diameter of Cable:	$D := 0.25 \cdot in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$	$b := 1 \cdot ft$	
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 14\, plf$	
Cable Deflection:	$\Delta := root(q(\Delta, D, L, b, F_{ps}) - q_{app}, \Delta)$	$\Delta = 0.175\, in$	
Axial (in-plane) Reaction:	$R'_x := R_x(D, L, F_{ps}, q_{app}, b)$	$R'_x = 419.7\, lbf$	
Out-of-Plane Reaction:	$R'_y := R_y(q_{app}, b)$	$R'_y = 7\, lbf$	

D.5—5/16" WIRE ROPE CABLE

3.1" Spacing

Diameter of Cable:	$D := 0.3125 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$	$b := 1 \cdot ft$	
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 12.917\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.156\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 434.4\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 6.5\,lbf$	

3.25" Spacing

Diameter of Cable:	$D := 0.3125 \cdot in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$	$b := 1 \cdot ft$	
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 13.542\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.163\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 435.7\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 6.8\,lbf$	

3.36" Spacing

Diameter of Cable:	$D := 0.3125 \cdot in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$	$b := 1 \cdot ft$	
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 14\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.168\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 436.7\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 7\,lbf$	

D.2—3/8" WIRE ROPE CABLE

3.1" Spacing

Diameter of Cable:	$D := 0.375 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$ $\quad b := 1 \cdot ft$		
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 12.917\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.147\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 460.1\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 6.5\,lbf$	

3.25" Spacing

Diameter of Cable:	$D := 0.375 \cdot in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$ $\quad b := 1 \cdot ft$		
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 13.542\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.154\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 461.8\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 6.8\,lbf$	

3.36" Spacing

Diameter of Cable:	$D := 0.375 \cdot in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Prestress Force:	$F_{ps} := 400 \cdot lbf$
Code-Required Load:	$w := 50 \cdot psf$ $\quad b := 1 \cdot ft$		
Uniform Load on Cable:	$q_{app} := w \cdot S_o$	$q_{app} = 14\,plf$	
Cable Deflection:	$\Delta := root\left(q\left(\Delta, D, L, b, F_{ps}\right) - q_{app}, \Delta\right)$	$\Delta = 0.159\,in$	
Axial (in-plane) Reaction:	$R'_x := R_x\left(D, L, F_{ps}, q_{app}, b\right)$	$R'_x = 463\,lbf$	
Out-of-Plane Reaction:	$R'_y := R_y\left(q_{app}, b\right)$	$R'_y = 7\,lbf$	

— END OF SECTION D —

SECTION E

DERIVATION OF EQUATIONS FOR THERMAL EFFECTS ON WIRE ROPE CABLE INTERMEDIATE RAILINGS

E.1—THERMAL EXPANSION AND CONTRACTION

Symbols and Notations

α Thermal expansion coefficient for wire rope cable, in/in/°F.

α_c Thermal expansion coefficient for concrete, in/in/°F.

α_{eff} Effective thermal expansion coefficient considering effects of cables, frame and support, in/in/°F.

α_{frame} Average thermal expansion coefficient of the frame and supporting base, in/in/°F.

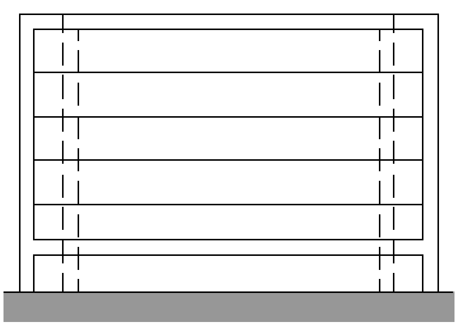
α_{stl} Thermal expansion coefficient for carbon steel, in/in/°F.

Background

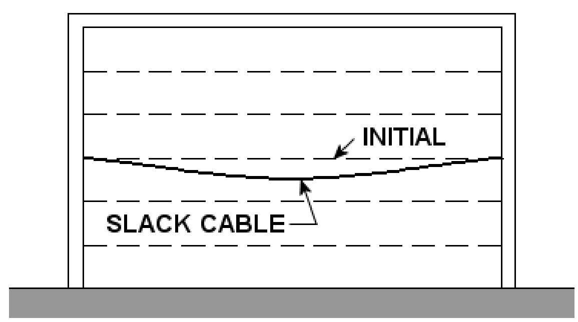
When an object changes temperature, it expands or contracts an amount proportional to the temperature change. Every material responds to a temperature change at a unique rate, known as the material's *thermal expansion coefficient*. The thermal expansion coefficient, α, for 316 stainless steel wire rope is:

$$\alpha := 9.6 \cdot 10^{-6} \cdot \frac{\text{in}}{\text{in} \cdot {}^\circ\text{F}}$$

As temperature increases, the handrail and infill cables expand. This thermal expansion has opposite effects in the frame and the cables—as the top rail (and bottom rail of the frame, if so equipped) expands, it tends to make the cables more taut *(below, left)*, but as the cables themselves expand, they tend to go slack *(below, right)*.



FRAME EXPANSION



CABLE EXPANSION

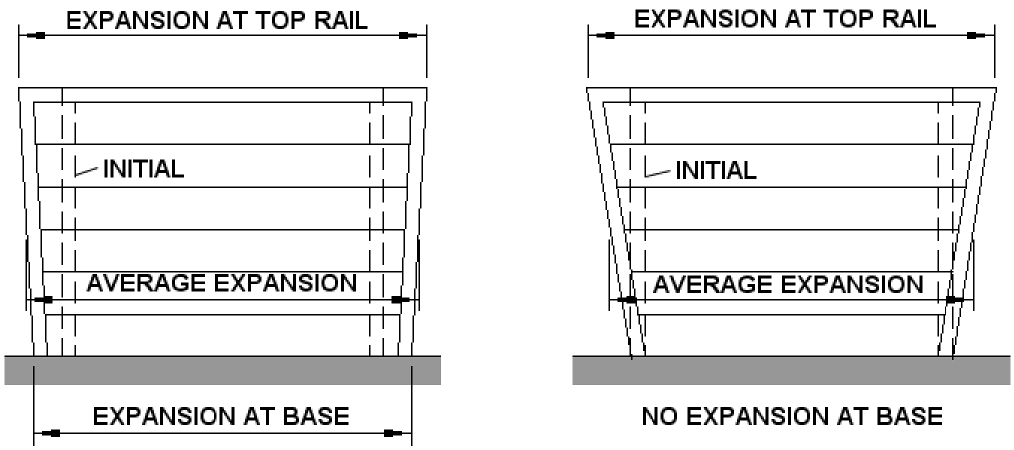
If the frame and the cables are of the same material, with the same thermal expansion coefficient, α, and the same modulus of elasticity, *E*, the thermal strains in the the frame and in the cables would be equal, but of opposite signs, and no net change in cable tension would occur. This condition would be met, for example, if the frame, as well as the intermediate cable railings, were stainless steel. Often, however, the frame is carbon steel, which has a slightly different thermal expansion coefficient:

$$\alpha_{stl} := 6.5 \cdot 10^{-6} \cdot \frac{\text{in}}{\text{in} \cdot {}^\circ\text{F}}$$

If the frame has no bottom rail, the bottom of the frame is then the concrete slab, which has yet a different thermal expansion coefficient:

$$\alpha_c := 5.0 \cdot 10^{-6} \cdot \frac{in}{in \cdot °F}$$

The intermediate cables would thus see a tensioning effect from the frame that varied between the thermal strain in the concrete and the thermal strain in the carbon steel top rail *(see below)*.



(A) BASE FREE TO EXPAND **(B) RESTRAINED BASE**

On the average, the frame would react as if the thermal expansion coefficient were the average of the coefficients for carbon steel and concrete. If the concrete were restrained from movement, as in a balcony enclosed on three sides, the average thermal expansion coefficient would simply be one-half of the coefficient value for carbon steel. This is the (conservative) case we will use in these equations:

$$\alpha_{frame} := 3.25 \cdot 10^{-6} \cdot \frac{in}{in \cdot °F}$$

Since the thermal expansion coefficient for the stainless steel wire rope infill cables is greater than the frame's value, the cables will tend to expand more than the frame, and the effective expansion will be the numerical difference between the two:

$$\alpha_{eff} := \alpha - \alpha_{frame}$$

$$\alpha_{eff} = 6.35 \times 10^{-6} \frac{in}{in \cdot °F}$$

For a stainless steel frame, the average thermal expansion coefficient would simply be one-half of the coefficient value for stainless steel:

$$\alpha_{SSframe} := 4.8 \cdot 10^{-6} \cdot \frac{in}{in \cdot °F}$$

Similarly, the effective thermal expansion coefficient would be:

$$\alpha_{SSeff} := \alpha - \alpha_{SSframe}$$

$$\alpha_{SSeff} = 4.8 \times 10^{-6} \frac{in}{in \cdot °F}$$

Because the effective thermal expansion coefficient for stainless steel frames is less than for carbon steel frames, the thermal effects on systems with stainless steel frames are less. Therefore, using α_{eff} for both materials provides conservative results, and will be used exclusively for the remainder of this discussion.

E.2—EFFECT ON PRESTRESSING FORCE

Symbols and Notations

α_{eff}	Effective thermal expansion coefficient considering effects of cables, frame and support, in/in/°F.
ΔF_{psT}	Change in prestress force due to temperature change, lbs.
ΔT	Change in temperature, °F
ε	Strain, in/in.
σ	Stress, ksi.
A	Cross-sectional area, in^2.
D	Diameter of wire rope cable, in.
E	Modulus of Elasticity, ksi.
E_{eff}	Effective Modulus of Elasticity, ksi.

Strain Change to Prestress Force Change

Thermal expansion or contraction can be quantified, since the resulting strain change is directly proportional to the temperature change:

$$\Delta\varepsilon = \alpha_{eff}\cdot\Delta T$$

Because our railing infill cables are prestressed (pretensioned) and thus restrained from changing length, the strain change in the cable manifests itself as an increase or decrease in the stress in the cable. This change in stress is given by:

$$\Delta\sigma = \Delta\varepsilon\cdot E$$

The change in prestress force is the product of the stress change and the area of the cable.

$$\Delta F_{psT} = -\Delta\sigma\cdot A$$

$$\Delta F_{psT} = -\alpha_{eff}\cdot\Delta T\cdot E\cdot A$$

Mathcad Function:

$$\Delta F_{psT}(\Delta T, D) := \left| \begin{array}{l} A \leftarrow \dfrac{\pi\cdot D^2}{4} \\ -\alpha_{eff}\cdot\Delta T\cdot E_{eff}\cdot A \end{array} \right.$$

Example: Given a ten degree temperature change, compute the change in prestress force for a 3/8" wire rope:

$$\Delta T := 10\cdot{}^\circ F$$

$$D := 0.375\cdot in$$

$$\Delta F_{psT}(\Delta T, D) = -114.3\,lbf$$

E.3—EFFECTS OF TEMPERATURE INCREASE ON SPHERE PASS-THROUGH RESISTANCE

Symbols and Notations

Δ	Deflection of cable under mid-span point load, *P.*
ΔF_{psT}	Change in prestress force due to temperature change, lbs.
ΔT	Change in temperature, °F.
D	Diameter of wire rope cable, in.
F_{ps}	Applied prestressing force, lbs.
L	Spacing between intermediate supports, in.
L_T	Length of cable between anchor points, ft.
P	Mid-span point load required to produce deflection Δ, lbs.
P_b	Component of mid-span point load, *P*, resisted by flexural bending, lbs.
P_{ef}	Component of mid-span point load, *P*, resisted by stretching of cable, lbs.
P_{ps}	Component of mid-span point load, *P*, resisted by cable prestressing, lbs.

Temperature Effects

As derived previously, changes in temperature and the resulting expansion and contraction in the wire-rope cable, can be incorporated as a change in the effective prestress force:

$$\Delta F_{psT} = -\alpha_{eff} \cdot \Delta T \cdot E \cdot A$$

Therefore, the effective prestress force, F'_{ps} becomes:

$$F'_{ps} = F_{ps} + \Delta F_{psT}$$

Mathcad Functions, including Temperature Effects

Incorporating temperature effects,

$$F'_{ps} := F_{ps} + \Delta F_{psT}(\Delta T, D)$$

the Mathcad function for the load-deflection relationship that was derived in Section A can be rewritten:

$$P(\Delta, D, L, L_T, F_{ps}, \Delta T) := \left| \begin{array}{l} F'_{ps} \leftarrow F_{ps} + \Delta F_{psT}(\Delta T, D) \\ P_{ef}(\Delta, D, L, L_T) + P_b(\Delta, D, L) + P_{ps}(F'_{ps}, \Delta, L) \end{array} \right.$$

Similarly, the equation for equilibrium deflection, Δeq, derived in Section A, can also be rewritten to include temperature effects:

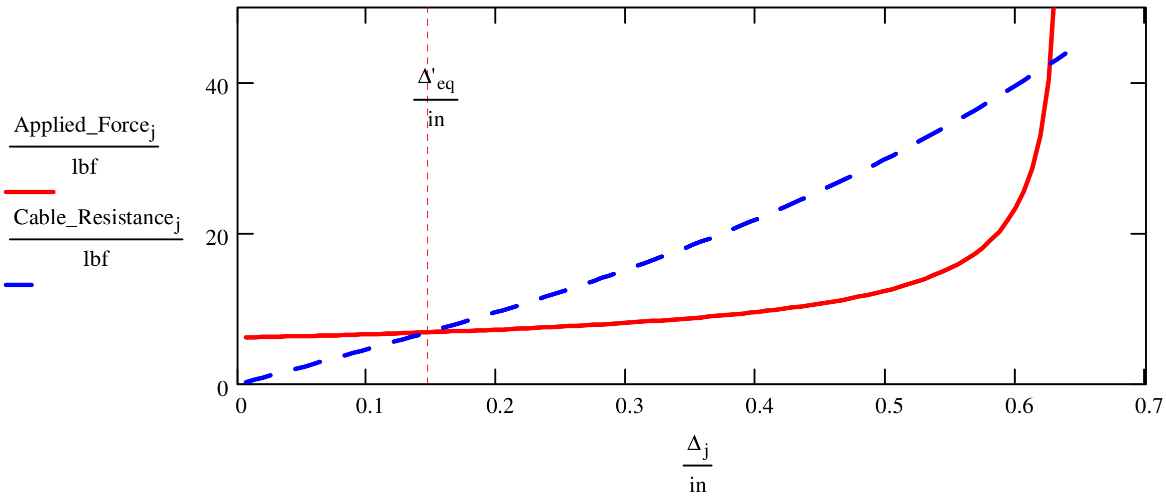
$$\Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}, L, L_T, F_{ps}, \Delta T) := \left| \begin{array}{l} \Delta \leftarrow 0 \cdot in \\ \Delta_{max} \text{ on error } \mathrm{root}\left(\begin{array}{l} F(F_x, \Delta, D, D_b, S_o) \ldots \\ + -P(\Delta, D, L, L_T, F_{ps}, \Delta T) \end{array}, \Delta \right) \end{array} \right.$$

Example 1: Given the following parameters,

Diameter of Cable:	$D := 0.375 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 12 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 0 \cdot {}^\circ F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Determine the equilibrium deflection, and plot the load vs. deflection curves.

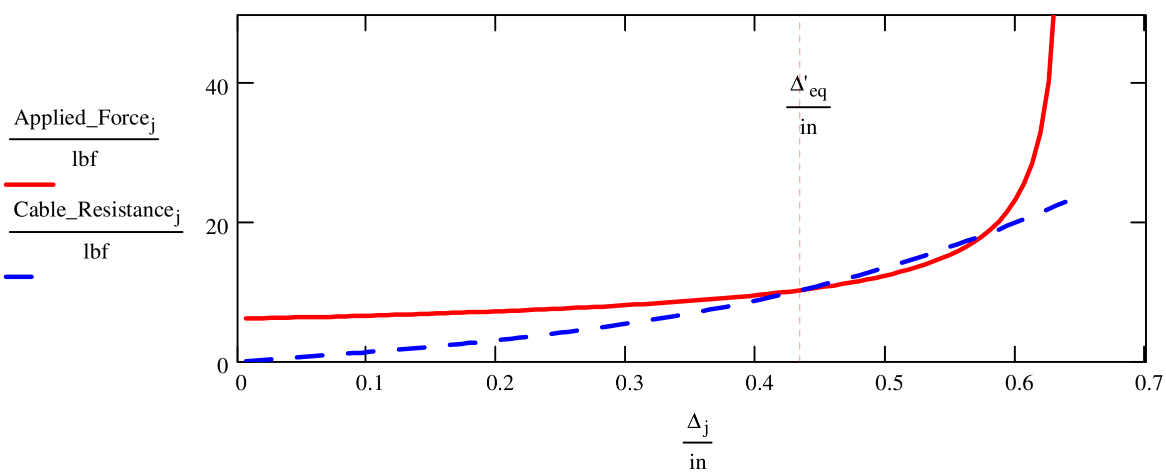
Equilibrium Deflection: $\Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}\left(D, D_b, S_o\right), L, L_T, F_{ps}, \Delta T\right) = 0.147\,in$



Example 2: Given the same parameters, but with a 30°F increase in temperature, determine the equilibrium deflection, and plot the load vs. deflection curves.

Temperature Change: $\Delta T := 30 \cdot {}^\circ F$

Equilibrium Deflection: $\Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}\left(D, D_b, S_o\right), L, L_T, F_{ps}, \Delta T\right) = 0.434\,in$



— **END OF SECTION E** —

SECTION F

THERMAL BEHAVIOR OF WIRE-ROPE CABLE INTERMEDIATE RAILINGS

F.1—TEMPERATURE INCREASE VS. PRESTRESS LOAD (SUFFICIENT TO CAUSE LOSS OF 400 lbs. PRESTRESS LOAD)

F.1.1—1/8" WIRE ROPE CABLE

Prestress Force: $F_{ps} := 400 \cdot lbf$

Diameter of Wire Rope: $D := 0.125 \cdot in$ Area of Wire Rope: $A := \frac{\pi \cdot D^2}{4}$ $A = 0.012\,in^2$

Thermal Expansion Coefficient for Wire Rope Cable: $\alpha = 9.6 \times 10^{-6} \frac{in}{in \cdot °F}$

Temperature Change to Cause Loss of Prestress: $\Delta T := \frac{F_{ps}}{\alpha \cdot E_{eff} \cdot A}$ $\Delta T = 208.3\,°F$

Effective Thermal Expansion Coefficient *(See Section A)*: $\alpha_{eff} = 6.35 \times 10^{-6} \frac{in}{in \cdot °F}$

Temperature Change to Cause Loss of Prestress: $\Delta T := \frac{F_{ps}}{\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = 314.9\,°F$

F.1.2—3/16" WIRE ROPE CABLE

Prestress Force: $F_{ps} := 400 \cdot lbf$

Diameter of Wire Rope: $D := 0.1875 \cdot in$ Area of Wire Rope: $A := \frac{\pi \cdot D^2}{4}$ $A = 0.028\,in^2$

Thermal Expansion Coefficient for Wire Rope Cable: $\alpha = 9.6 \times 10^{-6} \frac{in}{in \cdot °F}$

Temperature Change to Cause Loss of Prestress: $\Delta T := \frac{F_{ps}}{\alpha \cdot E_{eff} \cdot A}$ $\Delta T = 92.6\,°F$

Effective Thermal Expansion Coefficient *(See Section A)*: $\alpha_{eff} = 6.35 \times 10^{-6} \frac{in}{in \cdot °F}$

Temperature Change to Cause Loss of Prestress: $\Delta T := \frac{F_{ps}}{\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = 140\,°F$

F.1.3—1/4" WIRE ROPE CABLE

Prestress Force:	$F_{ps} := 400 \cdot lbf$			
Diameter of Wire Rope:	$D := 0.25 \cdot in$	Area of Wire Rope:	$A := \frac{\pi \cdot D^2}{4}$	$A = 0.049\, in^2$
Thermal Expansion Coefficient for Wire Rope Cable:	$\alpha = 9.6 \times 10^{-6} \frac{in}{in \cdot °F}$			
Temperature Change to Cause Loss of Prestress:	$\Delta T := \frac{F_{ps}}{\alpha \cdot E_{eff} \cdot A}$	$\Delta T = 52.1\ °F$		
Effective Thermal Expansion Coefficient *(See Section A)*:	$\alpha_{eff} = 6.35 \times 10^{-6} \frac{in}{in \cdot °F}$			
Temperature Change to Cause Loss of Prestress:	$\Delta T := \frac{F_{ps}}{\alpha_{eff} \cdot E_{eff} \cdot A}$	$\Delta T = 78.7\ °F$		

F.1.4—5/16" WIRE ROPE CABLE

Prestress Force:	$F_{ps} := 400 \cdot lbf$			
Diameter of Wire Rope:	$D := 0.3125 \cdot in$	Area of Wire Rope:	$A := \frac{\pi \cdot D^2}{4}$	$A = 0.077\, in^2$
Thermal Expansion Coefficient for Wire Rope Cable:	$\alpha = 9.6 \times 10^{-6} \frac{in}{in \cdot °F}$			
Temperature Change to Cause Loss of Prestress:	$\Delta T := \frac{F_{ps}}{\alpha \cdot E_{eff} \cdot A}$	$\Delta T = 33.3\ °F$		
Effective Thermal Expansion Coefficient *(See Section A)*:	$\alpha_{eff} = 6.35 \times 10^{-6} \frac{in}{in \cdot °F}$			
Temperature Change to Cause Loss of Prestress:	$\Delta T := \frac{F_{ps}}{\alpha_{eff} \cdot E_{eff} \cdot A}$	$\Delta T = 50.4\ °F$		

F.1.5—3/8" WIRE ROPE CABLE

Prestress Force:	$F_{ps} := 400 \cdot lbf$		
Diameter of Wire Rope:	$D := 0.375 \cdot in$	Area of Wire Rope:	$A := \frac{\pi \cdot D^2}{4}$ $A = 0.11\,in^2$
Thermal Expansion Coefficient for Wire Rope Cable:	$\alpha = 9.6 \times 10^{-6} \frac{in}{in \cdot °F}$		
Temperature Change to Cause Loss of Prestress:	$\Delta T := \frac{F_{ps}}{\alpha \cdot E_{eff} \cdot A}$	$\Delta T = 23.1\,°F$	
Effective Thermal Expansion Coefficient *(See Section A)*:	$\alpha_{eff} = 6.35 \times 10^{-6} \frac{in}{in \cdot °F}$		
Temperature Change to Cause Loss of Prestress:	$\Delta T := \frac{F_{ps}}{\alpha_{eff} \cdot E_{eff} \cdot A}$	$\Delta T = 35\,°F$	

TABLE F-1.

TEMPERATURE INCREASE vs. PRESTRESS LOAD
(TO CAUSE LOSS OF 400 lbs. PRESTRESS)

Wire Rope Cable Dia. (in.)	Cable in Frame Restrained From Expanding	Cable in Frame Free to Expand
1/8	+208 °F	+315 °F
3/16	+93 °F	+140 °F
1/4	+52 °F	+79 °F
5/16	+33 °F	+50 °F
3/8	+23 °F	+35 °F

Notes:
1. Increase in temperature above temperature at cable installation or retightening.
2. Based on initial prestress load of 400 lbs.

F.2—TEMPERATURE INCREASE THAT REDUCES PRESTRESS FORCE SUFFICIENT TO ALLOW 4" SPHERE TO PASS-THROUGH

F.2.1—1/8" WIRE ROPE CABLE

3.1" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D := 0.125 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 10.5 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 59 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.125\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.513\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.352\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 335.5\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.739\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.906$

3.1" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D := 0.125 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 25 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 55 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.125\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.513\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.349\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 335.4\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.732\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.905$

3.1" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D := 0.125 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 53 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\qquad S_{max} = 4.125\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\qquad \Delta'_{max} = 0.513\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\qquad \Delta'_{eq} = 0.341\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\qquad R_x = 335.5\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\qquad S_{eq} = 3.713\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.9$

F.2.2—3/16" WIRE ROPE CABLE

3.1" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D := 0.1875 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 10.5 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 42 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\qquad S_{max} = 4.188\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\qquad \Delta'_{max} = 0.544\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\qquad \Delta'_{eq} = 0.385\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\qquad R_x = 310.6\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\qquad S_{eq} = 3.798\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.907$

3.1" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D := 0.1875 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 25 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 36 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.188\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.544\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.348\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 310.8\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.719\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.888$

3.1" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D := 0.1875 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 35 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.188\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.544\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.361\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 309.7\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.746\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.894$

3.25" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D := 0.1875\cdot in$	Cable Spacing:	$S_o := 3.25\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 10.5\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 12\cdot °F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.188\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.469\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.304\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 386.4\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.802\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.908$

3.25" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D := 0.1875\cdot in$	Cable Spacing:	$S_o := 3.25\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 25\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 9\cdot °F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.188\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.469\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.307\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 386\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.808\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.909$

3.25" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D := 0.1875 \cdot in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 8 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.188\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.469\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.312\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 385.6\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.818\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.912$

F.2.3—1/4" WIRE ROPE CABLE

3.1" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D := 0.25 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 10.5 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 35 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.25\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.575\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.405\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 287.8\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.831\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.901$

3.1" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D = 0.25\,in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 25 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 29 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.25\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.575\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.382\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 287.1\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.78\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.889$

3.1" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D = 0.25\,in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 27 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.25\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.575\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.374\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 287.6\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.763\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.885$

3.25" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D = 0.25\,in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 10.5 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 19 \cdot {}^\circ F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\qquad S_{max} = 4.25\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\qquad \Delta'_{max} = 0.5\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\qquad \Delta'_{eq} = 0.333\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\qquad R_x = 353\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\qquad S_{eq} = 3.854\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.907$

3.25" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D = 0.25\,in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 25 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 15 \cdot {}^\circ F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\qquad S_{max} = 4.25\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\qquad \Delta'_{max} = 0.5\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\qquad \Delta'_{eq} = 0.328\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\qquad R_x = 353.4\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\qquad S_{eq} = 3.843\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.904$

3.25" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D = 0.25\,in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 13 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.25\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \frac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.5\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.312\,in$

Cable Anchor Reaction: $R_x := \frac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 356\,lbf$

Spread at Equilibrium: $S_{eq} := \frac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.809\,in$

Equilibrium Check: $\frac{S_{eq}}{S_{max}} = 0.896$

3.36" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D = 0.25\,in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 10.5 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 5 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.25\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \frac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.445\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.313\,in$

Cable Anchor Reaction: $R_x := \frac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 420.5\,lbf$

Spread at Equilibrium: $S_{eq} := \frac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.939\,in$

Equilibrium Check: $\frac{S_{eq}}{S_{max}} = 0.927$

3.36" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D = 0.25\,in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 25 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 1 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.25\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.445\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.284\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 421.1\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.879\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.913$

3.36" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D = 0.25\,in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 0 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.25\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.445\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.285\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 421.1\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.88\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.913$

F.2.4—5/16" WIRE ROPE CABLE

3.1" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D := 0.3125 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 10.5 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 33 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.606\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T)$ $\quad \Delta'_{eq} = 0.501\,in$

Cable Anchor Reaction: $R_x := \dfrac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 295.6\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 4.039\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.937$

3.1" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D = 0.313\,in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 25 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 26 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.606\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T)$ $\quad \Delta'_{eq} = 0.42\,in$

Cable Anchor Reaction: $R_x := \dfrac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 267.5\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.85\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.893$

3.1" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D = 0.313\,in$	Cable Spacing:	$S_o := 3.1\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 50\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 23\cdot °F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.606\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.375\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 270.3\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.753\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.87$

3.25" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D = 0.313\,in$	Cable Spacing:	$S_o := 3.25\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 10.5\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 22\cdot °F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.531\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.358\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 324.9\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.898\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.904$

3.25" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D = 0.313\,in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 25 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 17 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.531\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T)$ $\quad \Delta'_{eq} = 0.338\,in$

Cable Anchor Reaction: $R_x := \dfrac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 326.6\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.854\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.894$

3.25" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D = 0.313\,in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 16 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.531\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T)$ $\quad \Delta'_{eq} = 0.363\,in$

Cable Anchor Reaction: $R_x := \dfrac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 324.9\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.907\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.906$

3.36" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D = 0.313\,in$	Cable Spacing:	$S_o := 3.36\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 10.5\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 13\cdot °F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.476\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.314\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 382.2\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.933\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.912$

3.36" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D = 0.313\,in$	Cable Spacing:	$S_o := 3.36\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 25\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 9\cdot °F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.476\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.298\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 385\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.898\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.904$

3.36" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D = 0.313\,in$	Cable Spacing:	$S_o := 3.36 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 50 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 8 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.313\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.476\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T)$ $\quad \Delta'_{eq} = 0.301\,in$

Cable Anchor Reaction: $R_x := \dfrac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 384.3\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.904\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.905$

F.2.5—3/8" WIRE ROPE CABLE

3.1" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D := 0.375 \cdot in$	Cable Spacing:	$S_o := 3.1 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 10.5 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 34 \cdot °F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.638\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T)$ $\quad \Delta'_{eq} = 0.499\,in$

Cable Anchor Reaction: $R_x := \dfrac{F(F_x, \Delta'_{eq}, D, D_b, S_o) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 261.5\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 4.017\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.918$

3.1" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D = 0.375\,in$	Cable Spacing:	$S_o := 3.1\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 25\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 25\cdot {}^\circ F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.638\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.439\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 250\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.879\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.887$

3.1" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D = 0.375\,in$	Cable Spacing:	$S_o := 3.1\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 50\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 22\cdot {}^\circ F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.638\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.4\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 252\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.794\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.867$

3.25" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D = 0.375\,in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 10.5 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 26 \cdot {}^\circ F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.563\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.455\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 324.3\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 4.104\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.938$

3.25" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D = 0.375\,in$	Cable Spacing:	$S_o := 3.25 \cdot in$
Support Spacing:	$L := 42 \cdot in$	Anchor Spacing:	$L_T := 25 \cdot ft$
Prestress Force:	$F_{ps} := 400 \cdot lbf$	Temperature Change:	$\Delta T := 19 \cdot {}^\circ F$
Sphere Diameter:	$D_b := 4 \cdot in$	Load on Sphere	$F_x := 8.7 \cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.563\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.365\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right) \cdot L}{4 \cdot \Delta'_{eq}}$ $\quad R_x = 301.4\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o \cdot S_{max}}{S_{max} - 2 \cdot \Delta'_{eq}}$ $\quad S_{eq} = 3.9\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.891$

3.25" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D = 0.375\,in$	Cable Spacing:	$S_o := 3.25\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 50\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 17\cdot °F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.563\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.349\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 303.7\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.867\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.884$

3.36" Cable Spacing—Anchor Spacing 10.5 feet

Diameter of Cable:	$D = 0.375\,in$	Cable Spacing:	$S_o := 3.36\cdot in$
Support Spacing:	$L := 42\cdot in$	Anchor Spacing:	$L_T := 10.5\cdot ft$
Prestress Force:	$F_{ps} := 400\cdot lbf$	Temperature Change:	$\Delta T := 19\cdot °F$
Sphere Diameter:	$D_b := 4\cdot in$	Load on Sphere	$F_x := 8.7\cdot lbf$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,in$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.508\,in$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.36\,in$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 351.4\,lbf$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 4.021\,in$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.919$

3.36" Cable Spacing—Anchor Spacing 25 feet

Diameter of Cable:	$D = 0.375\,\text{in}$	Cable Spacing:	$S_o := 3.36\cdot\text{in}$
Support Spacing:	$L := 42\cdot\text{in}$	Anchor Spacing:	$L_T := 25\cdot\text{ft}$
Prestress Force:	$F_{ps} := 400\cdot\text{lbf}$	Temperature Change:	$\Delta T := 14\cdot{}^\circ\text{F}$
Sphere Diameter:	$D_b := 4\cdot\text{in}$	Load on Sphere	$F_x := 8.7\cdot\text{lbf}$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,\text{in}$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.508\,\text{in}$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.327\,\text{in}$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 351.1\,\text{lbf}$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 3.951\,\text{in}$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.903$

3.36" Cable Spacing—Anchor Spacing 50 feet

Diameter of Cable:	$D = 0.375\,\text{in}$	Cable Spacing:	$S_o := 3.36\cdot\text{in}$
Support Spacing:	$L := 42\cdot\text{in}$	Anchor Spacing:	$L_T := 50\cdot\text{ft}$
Prestress Force:	$F_{ps} := 400\cdot\text{lbf}$	Temperature Change:	$\Delta T := 13\cdot{}^\circ\text{F}$
Sphere Diameter:	$D_b := 4\cdot\text{in}$	Load on Sphere	$F_x := 8.7\cdot\text{lbf}$

Spread at Pass-Thru: $S_{max} := D_b + D$ $\quad S_{max} = 4.375\,\text{in}$

Deflection at Pass-Thru: $\Delta'_{max} := \dfrac{S_{max} - S_o}{2}$ $\quad \Delta'_{max} = 0.508\,\text{in}$

Deflection at Equilibrium: $\Delta'_{eq} := \Delta_{eq}\left(F_x, D_b, D, S_o, \Delta_{max}(D, D_b, S_o), L, L_T, F_{ps}, \Delta T\right)$ $\quad \Delta'_{eq} = 0.353\,\text{in}$

Cable Anchor Reaction: $R_x := \dfrac{F\left(F_x, \Delta'_{eq}, D, D_b, S_o\right)\cdot L}{4\cdot\Delta'_{eq}}$ $\quad R_x = 350.5\,\text{lbf}$

Spread at Equilibrium: $S_{eq} := \dfrac{S_o\cdot S_{max}}{S_{max} - 2\cdot\Delta'_{eq}}$ $\quad S_{eq} = 4.007\,\text{in}$

Equilibrium Check: $\dfrac{S_{eq}}{S_{max}} = 0.916$

TABLE F-2.

TEMPERATURE INCREASE TO ALLOW 4" SPHERE TO PASS-THROUGH

Wire Rope Cable Dia. (in.)	Cable Spacing (in.)	Cable Anchorage Spacing		
		10.5 ft	25 ft	50 ft
1/8	3.1	+59 °F	+55 °F	+53 °F
3/16	3.1	+42 °F	+36 °F	+35 °F
	3.25	+12 °F	+9 °F	+8 °F
1/4	3.1	+35 °F	+29 °F	+27 °F
	3.25	+19 °F	+15 °F	+13 °F
	3.36	+5 °F	*Note 3*	*Note 3*
5/16	3.1	+33 °F	+26 °F	+23 °F
	3.25	+22 °F	+17 °F	+16 °F
	3.36	+13 °F	+9 °F	+8 °F
3/8	3.1	+34 °F	+25 °F	+22 °F
	3.25	+26 °F	+19 °F	+17 °F
	3.36	+19 °F	+14 °F	+13 °F

Notes:
1. Increase in temperature above temperature at cable installation or retightening.
2. Based on initial prestress load of 400 lbs.
3. Cable requires full prestressing load to prevent 4" sphere from passing-through, any temperature rise will allow sphere to pass through.

F.3—TEMPERATURE DECREASE VS. PRESTRESS LOAD

F.3.1—1/8" WIRE ROPE CABLE

Initial Prestress Force: $F_{ps} := 400 \cdot lbf$

One-Third Increase: $F_{ps1} := 1.33 \cdot F_{ps}$ $F_{ps1} = 532\,lbf$

One-Half Increase: $F_{ps2} := 1.5 \cdot F_{ps}$ $F_{ps2} = 600\,lbf$

Diameter of Wire Rope: $D := 0.125 \cdot in$

Area of Wire Rope: $A := \frac{\pi \cdot D^2}{4}$ $A = 0.012\,in^2$

Thermal Expansion Coefficient for Wire Rope Cable: $\alpha = 9.6 \times 10^{-6}\,\frac{in}{in \cdot °F}$

Effective Thermal Expansion Coefficient *(See Section A)*: $\alpha_{eff} = 6.35 \times 10^{-6}\,\frac{in}{in \cdot °F}$

Temperature Change to Cause One-Third Increase in Prestress: $\Delta T := \frac{F_{ps1}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -277\,°F$ $\Delta T := \frac{F_{ps1}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -418.8\,°F$

Temperature Change to Cause One-Half Increase in Prestress: $\Delta T := \frac{F_{ps2}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -312.5\,°F$ $\Delta T := \frac{F_{ps2}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -472.4\,°F$

F.3.2—3/16" WIRE ROPE CABLE

Initial Prestress Force: $F_{ps} := 400 \cdot lbf$

One-Third Increase: $F_{ps1} := 1.33 \cdot F_{ps}$ $F_{ps1} = 532\,lbf$

One-Half Increase: $F_{ps2} := 1.5 \cdot F_{ps}$ $F_{ps2} = 600\,lbf$

Diameter of Wire Rope: $D := 0.1875 \cdot in$

Area of Wire Rope: $A := \frac{\pi \cdot D^2}{4}$ $A = 0.028\,in^2$

Thermal Expansion Coefficient for Wire Rope Cable: $\alpha = 9.6 \times 10^{-6}\,\frac{in}{in \cdot °F}$

Effective Thermal Expansion Coefficient *(See Section A)*: $\alpha_{eff} = 6.35 \times 10^{-6}\,\frac{in}{in \cdot °F}$

Temperature Change to Cause One-Third Increase in Prestress: $\Delta T := \frac{F_{ps1}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -123.1\,°F$ $\Delta T := \frac{F_{ps1}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -186.1\,°F$

Temperature Change to Cause One-Half Increase in Prestress: $\Delta T := \frac{F_{ps2}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -138.9\,°F$ $\Delta T := \frac{F_{ps2}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -209.9\,°F$

F.3.3—1/4" WIRE ROPE CABLE

Initial Prestress Force: $F_{ps} := 400 \cdot lbf$

One-Third Increase: $F_{ps1} := 1.33 \cdot F_{ps}$ $F_{ps1} = 532\,lbf$

One-Half Increase: $F_{ps2} := 1.5 \cdot F_{ps}$ $F_{ps2} = 600\,lbf$

Diameter of Wire Rope: $D := 0.25 \cdot in$

Area of Wire Rope: $A := \frac{\pi \cdot D^2}{4}$ $A = 0.049\,in^2$

Thermal Expansion Coefficient for Wire Rope Cable: $\alpha = 9.6 \times 10^{-6} \frac{in}{in \cdot {}^\circ F}$

Effective Thermal Expansion Coefficient *(See Section A)*: $\alpha_{eff} = 6.35 \times 10^{-6} \frac{in}{in \cdot {}^\circ F}$

Temperature Change to Cause One-Third Increase in Prestress: $\Delta T := \frac{F_{ps1}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -69.3\,{}^\circ F$ $\Delta T := \frac{F_{ps1}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -104.7\,{}^\circ F$

Temperature Change to Cause One-Half Increase in Prestress: $\Delta T := \frac{F_{ps2}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -78.1\,{}^\circ F$ $\Delta T := \frac{F_{ps2}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -118.1\,{}^\circ F$

F.3.4—5/16" WIRE ROPE CABLE

Initial Prestress Force: $F_{ps} := 400 \cdot lbf$

One-Third Increase: $F_{ps1} := 1.33 \cdot F_{ps}$ $F_{ps1} = 532\,lbf$

One-Half Increase: $F_{ps2} := 1.5 \cdot F_{ps}$ $F_{ps2} = 600\,lbf$

Diameter of Wire Rope: $D := 0.3125 \cdot in$

Area of Wire Rope: $A := \frac{\pi \cdot D^2}{4}$ $A = 0.077\,in^2$

Thermal Expansion Coefficient for Wire Rope Cable: $\alpha = 9.6 \times 10^{-6} \frac{in}{in \cdot {}^\circ F}$

Effective Thermal Expansion Coefficient *(See Section A)*: $\alpha_{eff} = 6.35 \times 10^{-6} \frac{in}{in \cdot {}^\circ F}$

Temperature Change to Cause One-Third Increase in Prestress: $\Delta T := \frac{F_{ps1}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -44.3\,{}^\circ F$ $\Delta T := \frac{F_{ps1}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -67\,{}^\circ F$

Temperature Change to Cause One-Half Increase in Prestress: $\Delta T := \frac{F_{ps2}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -50\,{}^\circ F$ $\Delta T := \frac{F_{ps2}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -75.6\,{}^\circ F$

F.3.5—3/8" WIRE ROPE CABLE

Initial Prestress Force: $F_{ps} := 400 \cdot lbf$

One-Third Increase: $F_{ps1} := 1.33 \cdot F_{ps}$ $F_{ps1} = 532\,lbf$

One-Half Increase: $F_{ps2} := 1.5 \cdot F_{ps}$ $F_{ps2} = 600\,lbf$

Diameter of Wire Rope: $D := 0.375 \cdot in$

Area of Wire Rope: $A := \frac{\pi \cdot D^2}{4}$ $A = 0.11\,in^2$

Thermal Expansion Coefficient for Wire Rope Cable: $\alpha = 9.6 \times 10^{-6} \frac{in}{in \cdot °F}$

Effective Thermal Expansion Coefficient *(See Section A)*: $\alpha_{eff} = 6.35 \times 10^{-6} \frac{in}{in \cdot °F}$

Temperature Change to Cause One-Third Increase in Prestress: $\Delta T := \frac{F_{ps1}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -30.8\,°F$ $\Delta T := \frac{F_{ps1}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -46.5\,°F$

Temperature Change to Cause One-Half Increase in Prestress: $\Delta T := \frac{F_{ps2}}{-\alpha \cdot E_{eff} \cdot A}$ $\Delta T = -34.7\,°F$ $\Delta T := \frac{F_{ps2}}{-\alpha_{eff} \cdot E_{eff} \cdot A}$ $\Delta T = -52.5\,°F$

TABLE F-3.

TEMPERATURE DECREASE vs. PRESTRESS LOAD
(TO CAUSE 1.33 AND 1.5 TIMES INCREASE IN PRESTRESS)

Wire Rope Cable Dia. (in.)	Cable in Frame Restrained From Expanding		Cable in Frame Free to Expand	
	One-Third Increase in Prestress Load (532 lbs.)	One-Half Increase in Prestress Load (600 lbs.)	One-Third Increase in Prestress Load (532 lbs.)	One-Half Increase in Prestress Load (600 lbs.)
1/8	–277 °F	–313 °F	–419 °F	–472 °F
3/16	–123 °F	–139 °F	–186 °F	–210 °F
1/4	–69 °F	–78 °F	–105 °F	–118 °F
5/16	–44 °F	–50 °F	–67 °F	–77 °F
3/8	–31 °F	–35 °F	–47 °F	–53 °F

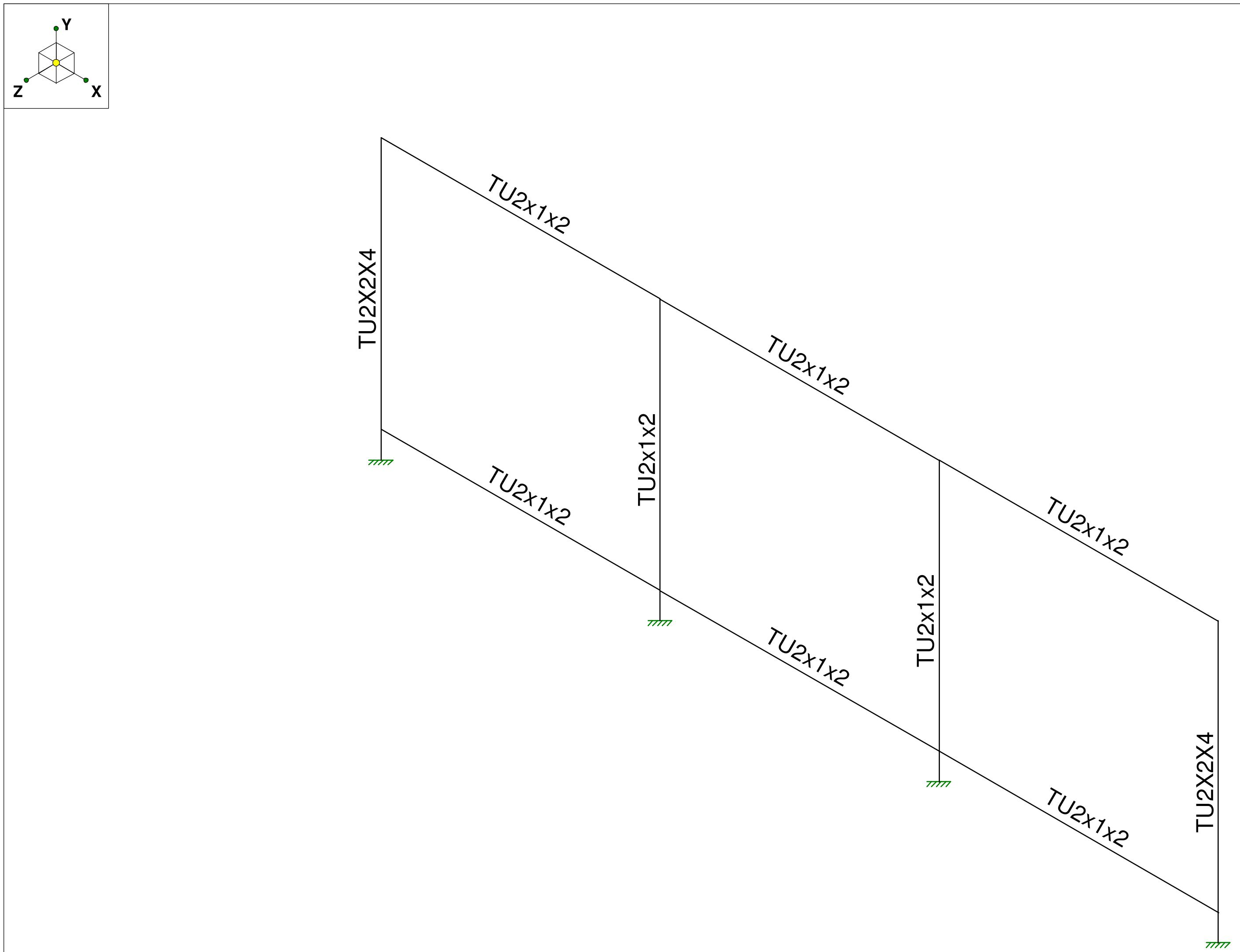
Notes:
1. Decrease in temperature below temperature at cable installation or retightening/loosening.
2. Based on initial prestress load of 400 lbs.

SECTION G

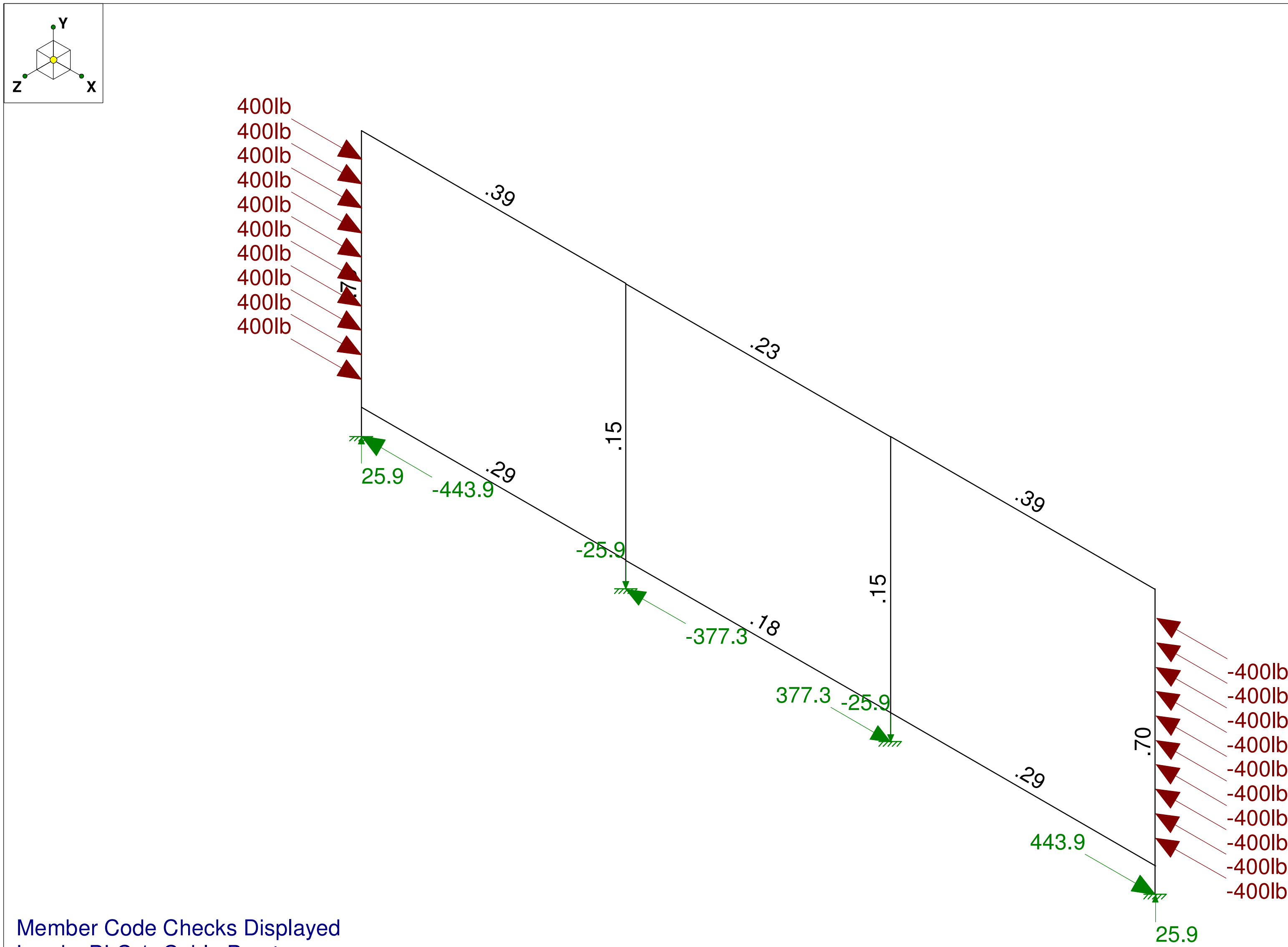
STRUCTURAL CALCULATIONS
FOR METAL FRAMED RAILINGS

G.5—2" SQ TUBE x 42-1/2" HIGH RAIL WITH 2" x 1" RECT TOP RAIL WITH BOTTOM RAIL

Height:	**36.5"**
Anchor Post:	**2" x 2" x 0.25" Tube**
Intermediate Posts:	**2" x 1" x 0.120" Tube**
Top Rail Adjacent to Anchor Post:	**2" x 1" x 0.120" Tube**
Top Rail Elsewhere:	**2" x 1" x 0.120" Tube**
Bottom Rail:	**2" x 1" x 0.120" Tube**
Number of Cables:	**10**
Cable Spacing:	**3.36"**

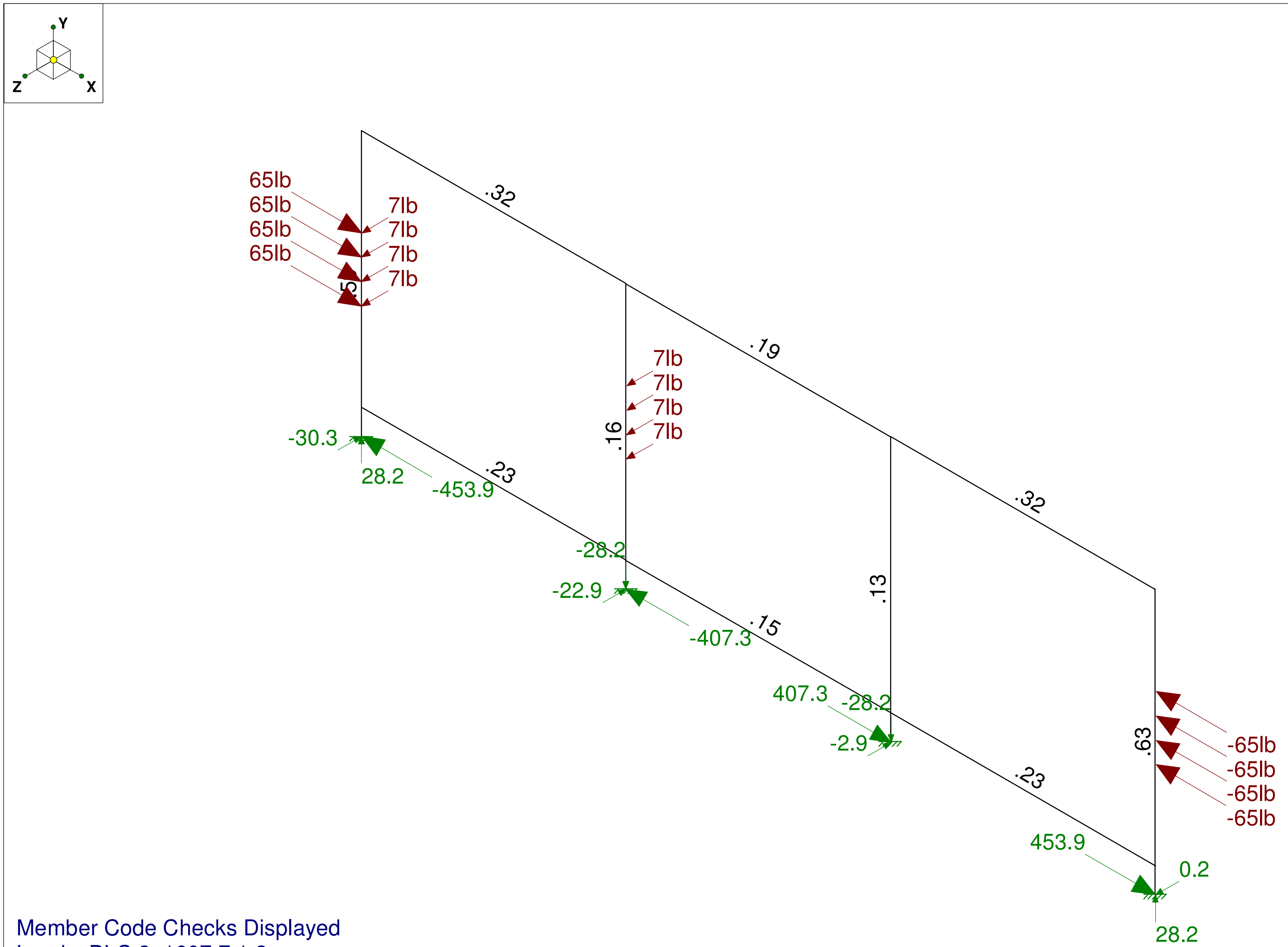


	2" SQ TUBE x 42.5" HIGH RAIL W/ 2x1 RECT TOP RAIL W/ BTM RAIL	
		G5.R3D
The Cable Connection		



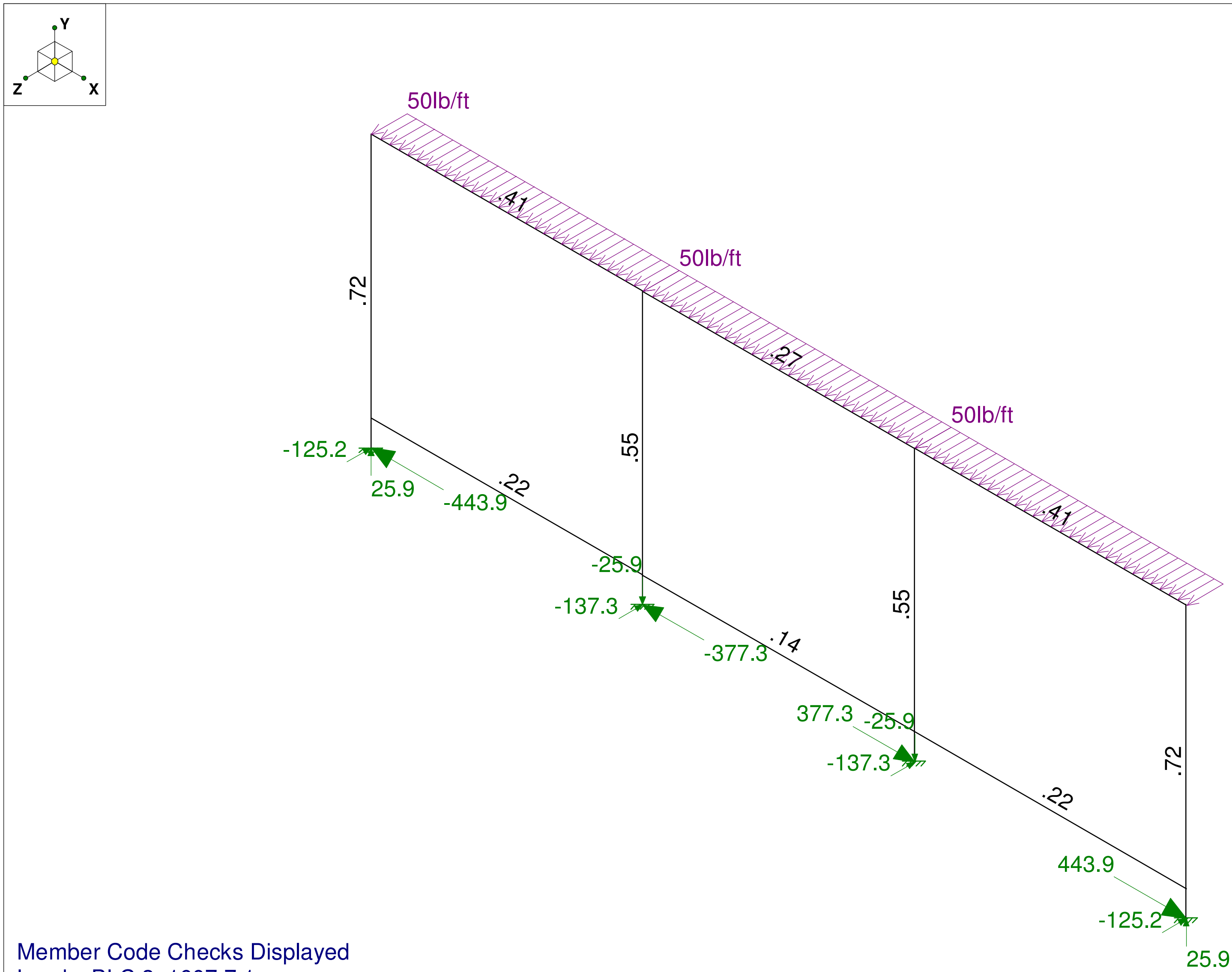
Member Code Checks Displayed
Loads: BLC 1, Cable Prestress
Results for LC 1, Cable Prestress
Reaction units are lb and k-ft

	2" SQ TUBE x 42.5" HIGH RAIL W/ 2x1 RECT TOP RAIL W/ BTM RAIL	
		G5.R3D
The Cable Connection		



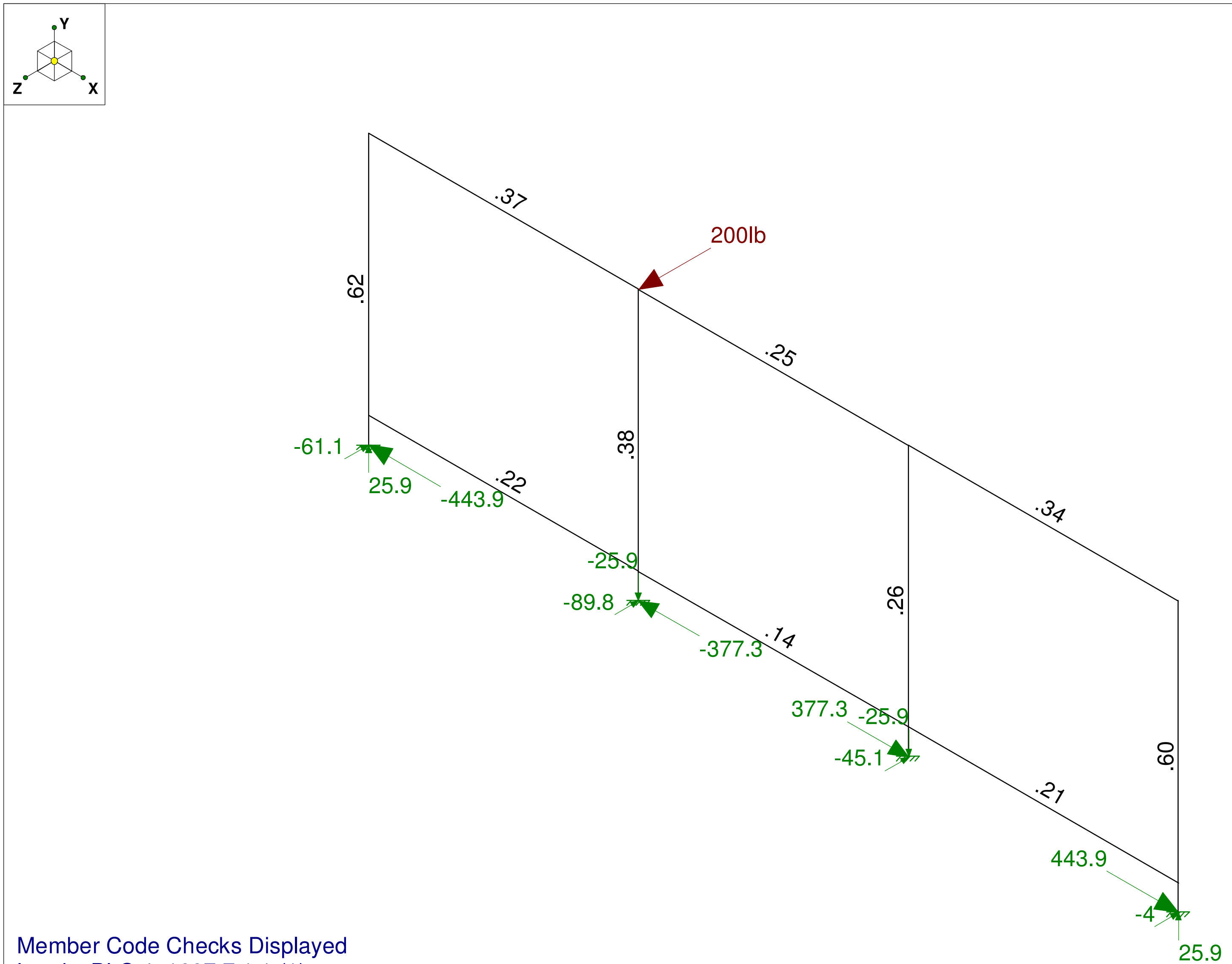
Member Code Checks Displayed
Loads: BLC 2, 1607.7.1.2
Results for LC 2, 1607.7.1.2
Reaction units are lb and k-ft

	2" SQ TUBE x 42.5" HIGH RAIL W/ 2x1 RECT TOP RAIL W/ BTM RAIL	
		G5.R3D
The Cable Connection		



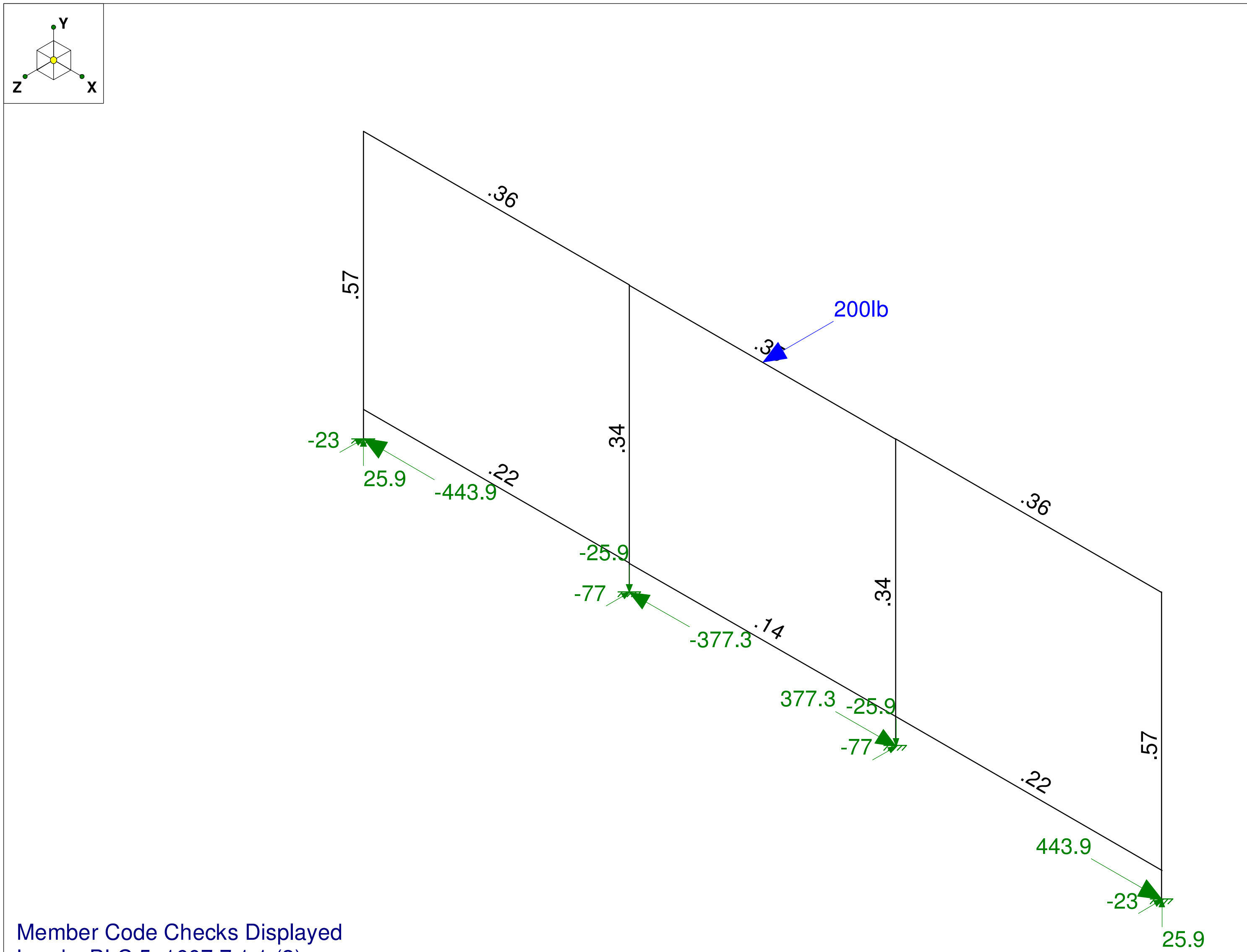
Member Code Checks Displayed
Loads: BLC 3, 1607.7.1
Results for LC 3, 1607.7.1
Reaction units are lb and k-ft

	2" SQ TUBE x 42.5" HIGH RAIL W/ 2x1 RECT TOP RAIL W/ BTM RAIL	
		G5.R3D
The Cable Connection		



Member Code Checks Displayed
Loads: BLC 4, 1607.7.1.1 (1)
Results for LC 4, 1607.7.1.1 (1)
Reaction units are lb and k-ft

	2" SQ TUBE x 42.5" HIGH RAIL W/ 2x1 RECT TOP RAIL W/ BTM RAIL	
		G5.R3D
The Cable Connection		



Member Code Checks Displayed
Loads: BLC 5, 1607.7.1.1 (2)
Results for LC 5, 1607.7.1.1 (2)
Reaction units are lb and k-ft

	2" SQ TUBE x 42.5" HIGH RAIL W/ 2x1 RECT TOP RAIL W/ BTM RAIL	
		G5.R3D
The Cable Connection		

General Material Properties

	Label	E [ksi]	G [ksi]	Nu	Therm (\1E5 F)	Density[k/ft^3]
1	GEN_TS	29000	11154	.3	.65	.49
2	GEN_RIGID	1e+6		.3	.65	0

Hot Rolled Steel Properties

	Label	E [ksi]	G [ksi]	Nu	Therm (\1E5 F)	Density[k/ft^3]	Yield[ksi]
1	HR_TS	29000	11154	.3	.65	.49	46
2	HR_RIGID	1e+6		.3	.65	0	0

General Section Sets

	Label	Shape	Type	Material	A [in2]	Iyy [in4]	Izz [in4]	J [in4]
1	LINK	ARB_LINK_1	Beam	GEN_RIGID	1e+6	1e+6	1e+6	1

Hot Rolled Steel Section Sets

	Label	Shape	Design List	Type	Material	Design Rules	A [in2]	Iyy [in4]	Izz [in4]	J [in4]
1	RAIL	TU2x1x2	Tube	Beam	HR_TS	Typical	.662	.102	.321	.238
2	POST	TU2X2X4	Tube	Beam	HR_TS	Typical	1.59	.766	.766	1.36
3	IPOST	TU2x1x2	Tube	Beam	HR_TS	Typical	.662	.102	.321	.238

Member Primary Data

	Label	I Joint	J Joint	K Joint	Rotate(deg)	Section/Shape	Design List	Type	Material	Design Rules
1	M1	N1	N2		90	POST	Tube	Beam	HR_TS	Typical
2	M2	N3	N4		90	IPOST	Tube	Beam	HR_TS	Typical
3	M3	N2	N4		90	RAIL	Tube	Beam	HR_TS	Typical
4	M4	N4	N8		90	RAIL	Tube	Beam	HR_TS	Typical
5	M5	N5	N6		90	POST	Tube	Beam	HR_TS	Typical
6	M6	N7	N8		90	IPOST	Tube	Beam	HR_TS	Typical
7	M7	N8	N6		90	RAIL	Tube	Beam	HR_TS	Typical
8	M8	N11	N12		90	RAIL	Tube	Beam	HR_TS	Typical
9	M9	N12	N14		90	RAIL	Tube	Beam	HR_TS	Typical
10	M10	N14	N13		90	RAIL	Tube	Beam	HR_TS	Typical

Joint Coordinates and Temperatures

	Label	X [in]	Y [in]	Z [in]	Temp [F]	Detach From Diap...
1	N1	0	0	0	0	
2	N2	0	42.0005	0	0	
3	N3	42	0	0	0	
4	N4	42	42.0005	0	0	
5	N5	126	0	0	0	
6	N6	126	42.0005	0	0	
7	N7	84	0	0	0	
8	N8	84	42.0005	0	0	
9	N9	0	7.86	0	0	
10	N10	126	7.86	0	0	
11	N11	0	4.0005	0	0	
12	N12	42	4.0005	0	0	
13	N13	126	4.0005	0	0	
14	N14	84	4.0005	0	0	
15	N15	0	11.22	0	0	
16	N16	126	11.22	0	0	

Joint Coordinates and Temperatures (Continued)

	Label	X [in]	Y [in]	Z [in]	Temp [F]	Detach From Diap...
17	N17	0	14.58	0	0	
18	N18	126	14.58	0	0	
19	N19	0	17.94	0	0	
20	N20	126	17.94	0	0	
21	N21	0	21.3	0	0	
22	N22	126	21.3	0	0	
23	N23	0	24.66	0	0	
24	N24	126	24.66	0	0	
25	N25	0	28.02	0	0	
26	N26	126	28.02	0	0	
27	N27	0	31.38	0	0	
28	N28	126	31.38	0	0	
29	N29	0	34.74	0	0	
30	N30	126	34.74	0	0	
31	N31	0	38.1	0	0	
32	N32	126	38.1	0	0	
33	N33	42	17.94	0	0	
34	N34	42	21.3	0	0	
35	N35	42	24.66	0	0	
36	N36	42	28.02	0	0	

Joint Boundary Conditions

	Joint Label	X [k/in]	Y [k/in]	Z [k/in]	X Rot.[k-ft/rad]	Y Rot.[k-ft/rad]	Z Rot.[k-ft/rad]	Footing
1	N1	Reaction	Reaction	Reaction	Reaction	Reaction	Reaction	
2	N3	Reaction	Reaction	Reaction	Reaction	Reaction	Reaction	
3	N5	Reaction	Reaction	Reaction	Reaction	Reaction	Reaction	
4	N2							
5	N6							
6	N4							
7	N7	Reaction	Reaction	Reaction	Reaction	Reaction	Reaction	
8	N8							
9	N9							
10	N10							
11	N11							
12	N12							
13	N13							
14	N14							
15	N15							
16	N16							
17	N17							
18	N18							
19	N19							
20	N20							
21	N21							
22	N22							
23	N23							
24	N24							
25	N25							
26	N26							
27	N27							
28	N28							
29	N29							
30	N30							
31	N31							
32	N32							
33	N33							

Joint Boundary Conditions (Continued)

	Joint Label	X [k/in]	Y [k/in]	Z [k/in]	X Rot.[k-ft/rad]	Y Rot.[k-ft/rad]	Z Rot.[k-ft/rad]	Footing
34	N34							
35	N35							
36	N36							

Joint Loads and Enforced Displacements (BLC 1 : Cable Prestress)

	Joint Label	L,D,M	Direction	Magnitude[lb,k-ft in,rad lb*s^2/in]
1	N9	L	X	400
2	N10	L	X	-400
3	N15	L	X	400
4	N16	L	X	-400
5	N17	L	X	400
6	N18	L	X	-400
7	N19	L	X	400
8	N20	L	X	-400
9	N21	L	X	400
10	N22	L	X	-400
11	N23	L	X	400
12	N24	L	X	-400
13	N25	L	X	400
14	N26	L	X	-400
15	N27	L	X	400
16	N28	L	X	-400
17	N29	L	X	400
18	N30	L	X	-400
19	N31	L	X	400
20	N32	L	X	-400

Joint Loads and Enforced Displacements (BLC 2 : 1607.7.1.2)

	Joint Label	L,D,M	Direction	Magnitude[lb,k-ft in,rad lb*s^2/in]
1	N19	L	X	65
2	N21	L	X	65
3	N23	L	X	65
4	N25	L	X	65
5	N20	L	X	-65
6	N22	L	X	-65
7	N24	L	X	-65
8	N26	L	X	-65
9	N19	L	Z	7
10	N21	L	Z	7
11	N25	L	Z	7
12	N23	L	Z	7
13	N36	L	Z	7
14	N35	L	Z	7
15	N34	L	Z	7
16	N33	L	Z	7

Joint Loads and Enforced Displacements (BLC 4 : 1607.7.1.1 (1))

	Joint Label	L,D,M	Direction	Magnitude[lb,k-ft in,rad lb*s^2/in]
1	N4	L	Z	200

Member Point Loads (BLC 5 : 1607.7.1.1 (2))

	Member Label	Direction	Magnitude[lb,k-ft]	Location[in,%]
1	M4	Z	200	%50

Member Distributed Loads (BLC 3 : 1607.7.1)

	Member Label	Direction	Start Magnitude[lb/ft,...	End Magnitude[lb/ft,d...	Start Location[in,%]	End Location[in,%]
1	M3	Z	50	50	0	0
2	M4	Z	50	50	0	0
3	M7	Z	50	50	0	0

Basic Load Cases

	BLC Description	Category	X Gravity	Y Gravity	Z Gravity	Joint	Point	Distributed	Area (Me...	Surface (...
1	Cable Prestress	None				20				
2	1607.7.1.2	None				16				
3	1607.7.1	None						3		
4	1607.7.1.1 (1)	None				1				
5	1607.7.1.1 (2)	None					1			

Load Combinations

	Description	Sol...	PD...	SR...	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor	BLC	Factor
1	Cable Prestress	Yes			1	1														
2	1607.7.1.2	Yes			1	1	2	1												
3	1607.7.1	Yes			1	1	3	1												
4	1607.7.1.1 (1)	Yes			1	1	4	1												
5	1607.7.1.1 (2)	Yes			1	1	5	1												

Envelope Joint Reactions

	Joint		X [lb]	lc	Y [lb]	lc	Z [lb]	lc	MX [k-ft]	lc	MY [k-ft]	lc	MZ [k-ft]	lc
1	N1	max	-443.868	1	28.154	2	0	1	0	1	.091	3	1.466	2
2		min	-453.944	2	25.882	1	-125.164	3	-.493	3	0	1	1.359	1
3	N3	max	-377.272	1	-25.882	1	0	1	0	1	.005	5	.076	2
4		min	-407.339	2	-28.154	2	-137.336	3	-.426	3	0	2	.07	1
5	N5	max	453.944	2	28.154	2	.151	2	0	1	0	1	-1.359	1
6		min	443.868	1	25.882	1	-125.164	3	-.493	3	-.091	3	-1.466	2
7	N7	max	407.339	2	-25.882	1	0	1	0	1	0	1	-.07	1
8		min	377.272	1	-28.154	2	-137.336	3	-.426	3	-.005	4	-.076	2
9	Totals:	max	0	1	0	2	0	1						
10		min	0	2	0	1	-525	3						

Envelope Member Section Forces

	Member	Sec		Axial[lb]	lc	y Shear[lb]	lc	z Shear[lb]	lc	Torque[k-ft]	lc	y-y Momen...	lc	z-z Momen...	lc
1	M1	1	max	28.154	2	0	1	-443.868	1	.091	3	1.466	2	0	1
2			min	25.882	1	-125.164	3	-453.944	2	0	1	1.359	1	-.493	3
3		2	max	59.442	2	0	1	-1960.38	1	.108	3	.108	2	0	1
4			min	54.828	1	-132.524	3	-2120.928	2	0	1	.087	1	-.374	3
5		3	max	59.442	2	0	1	-760.38	1	.108	3	-.986	1	0	1
6			min	54.828	1	-132.524	3	-855.928	2	0	1	-1.089	2	-.258	3
7		4	max	59.442	2	0	1	939.072	2	.108	3	-.964	1	0	1
8			min	54.828	1	-132.524	3	839.62	1	0	1	-1.039	2	-.142	3
9		5	max	59.442	2	0	1	1739.072	2	.108	3	.155	2	0	2
10			min	54.828	1	-132.524	3	1639.62	1	0	1	.143	1	-.026	3
11	M2	1	max	-25.882	1	0	1	-377.272	1	.005	5	.076	2	0	1
12			min	-28.154	2	-137.336	3	-407.339	2	0	2	.07	1	-.426	3
13		2	max	-54.828	1	0	1	18.129	2	.016	5	-.01	1	0	1
14			min	-59.442	2	-129.976	3	16.725	1	0	2	-.011	2	-.315	3
15		3	max	-54.828	1	0	1	18.129	2	.016	5	.005	2	.002	2

Envelope Member Section Forces (Continued)

	Member	Sec		Axial[lb]	lc	y Shear[lb]	lc	z Shear[lb]	lc	Torque[k-ft]	lc	y-y Momen...	lc	z-z Momen...	lc
16			min	-59.442	2	-129.976	3	16.725	1	0	2	.005	1	-.201	3
17		4	max	-54.828	1	4.919	2	18.129	2	.016	5	.021	2	.004	2
18			min	-59.442	2	-129.976	3	16.725	1	0	2	.019	1	-.087	3
19		5	max	-54.828	1	4.919	2	18.129	2	.016	5	.037	2	.031	4
20			min	-59.442	2	-129.976	3	16.725	1	0	2	.034	1	0	1
21	M3	1	max	1739.072	2	0	1	-54.828	1	0	2	.155	2	0	1
22			min	1639.62	1	-132.524	3	-59.442	2	-.026	3	.143	1	-.108	3
23		2	max	1739.072	2	0	1	-54.828	1	0	2	.103	2	0	2
24			min	1639.62	1	-88.774	3	-59.442	2	-.026	3	.095	1	-.039	5
25		3	max	1739.072	2	0	1	-54.828	1	0	2	.051	2	.047	3
26			min	1639.62	1	-65.177	4	-59.442	2	-.026	3	.047	1	-.014	5
27		4	max	1739.072	2	0	1	-54.828	1	0	2	0	1	.094	4
28			min	1639.62	1	-65.177	4	-59.442	2	-.026	3	0	2	0	1
29		5	max	1739.072	2	42.476	3	-54.828	1	0	2	-.049	1	.151	4
30			min	1639.62	1	-65.177	4	-59.442	2	-.026	3	-.053	2	0	1
31	M4	1	max	1757.201	2	50.201	4	0	1	.013	4	-.015	1	.148	4
32			min	1656.346	1	-100	5	0	1	0	1	-.016	2	0	1
33		2	max	1757.201	2	50.201	4	0	1	.013	4	-.015	1	.107	5
34			min	1656.346	1	-100	5	0	1	0	1	-.016	2	0	1
35		3	max	1757.201	2	100	5	0	1	.013	4	-.015	1	.194	5
36			min	1656.346	1	0	1	0	1	0	1	-.016	2	0	1
37		4	max	1757.201	2	100	5	0	1	.013	4	-.015	1	.107	5
38			min	1656.346	1	0	1	0	1	0	1	-.016	2	0	2
39		5	max	1757.201	2	100	5	0	1	.013	4	-.015	1	.036	3
40			min	1656.346	1	0	1	0	1	0	1	-.016	2	-.028	4
41	M5	1	max	28.154	2	.151	2	453.944	2	0	1	-1.359	1	0	1
42			min	25.882	1	-125.164	3	443.868	1	-.091	3	-1.466	2	-.493	3
43		2	max	59.442	2	0	1	2120.928	2	0	1	-.087	1	0	1
44			min	54.828	1	-132.524	3	1960.38	1	-.108	3	-.108	2	-.374	3
45		3	max	59.442	2	0	1	855.928	2	0	1	1.089	2	0	1
46			min	54.828	1	-132.524	3	760.38	1	-.108	3	.986	1	-.258	3
47		4	max	59.442	2	0	1	-839.62	1	0	1	1.039	2	0	1
48			min	54.828	1	-132.524	3	-939.072	2	-.108	3	.964	1	-.142	3
49		5	max	59.442	2	0	1	-1639.62	1	0	1	-.143	1	0	1
50			min	54.828	1	-132.524	3	-1739.072	2	-.108	3	-.155	2	-.026	3
51	M6	1	max	-25.882	1	0	1	407.339	2	0	1	-.07	1	0	1
52			min	-28.154	2	-137.336	3	377.272	1	-.005	4	-.076	2	-.426	3
53		2	max	-54.828	1	0	1	-16.725	1	0	1	.011	2	0	1
54			min	-59.442	2	-129.976	3	-18.129	2	-.016	5	.01	1	-.315	3
55		3	max	-54.828	1	0	1	-16.725	1	0	1	-.005	1	0	1
56			min	-59.442	2	-129.976	3	-18.129	2	-.016	5	-.005	2	-.201	3
57		4	max	-54.828	1	0	1	-16.725	1	0	1	-.019	1	0	1
58			min	-59.442	2	-129.976	3	-18.129	2	-.016	5	-.021	2	-.087	3
59		5	max	-54.828	1	0	1	-16.725	1	0	1	-.034	1	.026	3
60			min	-59.442	2	-129.976	3	-18.129	2	-.016	5	-.037	2	0	1
61	M7	1	max	1739.072	2	28.407	5	59.442	2	.026	3	-.049	1	.05	3
62			min	1639.62	1	-42.476	3	54.828	1	0	1	-.053	2	-.012	4
63		2	max	1739.072	2	28.407	5	59.442	2	.026	3	0	1	.068	3
64			min	1639.62	1	0	1	54.828	1	0	1	0	2	-.019	4
65		3	max	1739.072	2	45.024	3	59.442	2	.026	3	.051	2	.047	3
66			min	1639.62	1	0	1	54.828	1	0	1	.047	1	-.026	4
67		4	max	1739.072	2	88.774	3	59.442	2	.026	3	.103	2	0	1
68			min	1639.62	1	0	1	54.828	1	0	1	.095	1	-.039	5
69		5	max	1739.072	2	132.524	3	59.442	2	.026	3	.155	2	0	1
70			min	1639.62	1	0	1	54.828	1	0	1	.143	1	-.108	3
71	M8	1	max	2066.984	2	7.359	3	31.288	2	0	1	-.066	1	.017	3
72			min	1916.511	1	-.13	2	28.946	1	-.006	3	-.072	2	0	2

Envelope Member Section Forces (Continued)

	Member	Sec		Axial[lb]	lc	y Shear[lb]	lc	z Shear[lb]	lc	Torque[k-ft]	lc	y-y Momen...	lc	z-z Momen...	lc
73		2	max	2066.984	2	7.359	3	31.288	2	0	1	-.041	1	.011	3
74			min	1916.511	1	-.13	2	28.946	1	-.006	3	-.044	2	0	1
75		3	max	2066.984	2	7.359	3	31.288	2	0	1	-.016	1	.004	3
76			min	1916.511	1	-.13	2	28.946	1	-.006	3	-.017	2	0	1
77		4	max	2066.984	2	7.359	3	31.288	2	0	1	.01	2	0	2
78			min	1916.511	1	-.13	2	28.946	1	-.006	3	.01	1	-.003	5
79		5	max	2066.984	2	7.359	3	31.288	2	0	1	.038	2	0	2
80			min	1916.511	1	-.13	2	28.946	1	-.006	3	.035	1	-.009	3
81	M9	1	max	1641.517	2	.014	2	0	1	.003	4	-.001	1	.003	5
82			min	1522.514	1	-1.086	4	0	1	0	1	-.002	2	0	4
83		2	max	1641.517	2	.014	2	0	1	.003	4	-.001	1	.003	5
84			min	1522.514	1	-1.086	4	0	1	0	1	-.002	2	0	1
85		3	max	1641.517	2	.014	2	0	1	.003	4	-.001	1	.003	5
86			min	1522.514	1	-1.086	4	0	1	0	1	-.002	2	0	1
87		4	max	1641.517	2	.014	2	0	1	.003	4	-.001	1	.003	5
88			min	1522.514	1	-1.086	4	0	1	0	1	-.002	2	0	1
89		5	max	1641.517	2	.014	2	0	1	.003	4	-.001	1	.004	4
90			min	1522.514	1	-1.086	4	0	1	0	1	-.002	2	0	1
91	M10	1	max	2066.984	2	0	1	-28.946	1	.006	3	.038	2	0	1
92			min	1916.511	1	-7.359	3	-31.288	2	0	1	.035	1	-.009	3
93		2	max	2066.984	2	0	1	-28.946	1	.006	3	.01	2	0	1
94			min	1916.511	1	-7.359	3	-31.288	2	0	1	.01	1	-.003	4
95		3	max	2066.984	2	0	1	-28.946	1	.006	3	-.016	1	.004	3
96			min	1916.511	1	-7.359	3	-31.288	2	0	1	-.017	2	0	2
97		4	max	2066.984	2	0	1	-28.946	1	.006	3	-.041	1	.011	3
98			min	1916.511	1	-7.359	3	-31.288	2	0	1	-.044	2	0	1
99		5	max	2066.984	2	0	1	-28.946	1	.006	3	-.066	1	.017	3
100			min	1916.511	1	-7.359	3	-31.288	2	0	1	-.072	2	0	1

Envelope Member Section Deflections

	Member	Sec		x [in]	lc	y [in]	lc	z [in]	lc	x Rotate [r...	lc	(n) L/y Ratio	lc	(n) L/z Ratio	lc
1	M1	1	max	0	1	0	1	0	1	0	1	NC	1	NC	1
2			min	0	1	0	1	0	1	0	1	NC	1	NC	1
3		2	max	0	1	.014	3	.038	2	0	1	3072.538	3	1143.117	2
4			min	0	2	0	1	.035	1	-8.429e-4	3	NC	1	1239.806	1
5		3	max	0	1	.05	3	.086	2	0	1	845.978	3	503.018	2
6			min	0	2	0	1	.079	1	-1.74e-3	3	NC	1	548.805	1
7		4	max	0	1	.101	3	.075	2	0	1	415.835	3	596.691	2
8			min	0	2	0	1	.069	1	-2.638e-3	3	NC	1	648.848	1
9		5	max	0	1	.161	3	.006	2	0	1	261.148	3	NC	2
10			min	0	2	0	1	.005	1	-3.535e-3	3	NC	1	NC	1
11	M2	1	max	0	1	0	1	0	1	0	1	NC	1	NC	1
12			min	0	1	0	1	0	1	0	1	NC	1	NC	1
13		2	max	0	2	.028	3	.001	2	1.881e-5	2	1509.573	3	NC	2
14			min	0	1	0	1	.001	1	-5.665e-4	5	NC	1	NC	1
15		3	max	0	2	.1	3	-.003	1	4.272e-5	2	418.783	3	NC	1
16			min	0	1	0	1	-.003	2	-1.338e-3	5	NC	1	9992.944	2
17		4	max	0	2	.201	3	-.005	1	6.664e-5	2	208.626	3	6740.263	1
18			min	0	1	0	1	-.005	2	-2.109e-3	5	NC	1	6210.47	2
19		5	max	0	2	.315	3	.002	2	9.055e-5	2	133.436	3	NC	2
20			min	0	1	0	1	.002	1	-2.88e-3	5	NC	1	NC	1
21	M3	1	max	.006	2	.161	3	0	2	5.868e-3	3	NC	3	NC	2
22			min	.005	1	0	1	0	1	0	1	NC	1	NC	1
23		2	max	.005	2	.203	3	-.042	1	7.115e-3	3	NC	3	993.527	1
24			min	.004	1	0	1	-.046	2	0	1	NC	1	916.449	2
25		3	max	.004	2	.248	3	-.042	1	8.362e-3	3	4281.756	3	997.632	1

Envelope Member Section Deflections (Continued)

	Member	Sec		x [in]	lc	y [in]	lc	z [in]	lc	x Rotate [r...	lc	(n) L/y Ratio	lc	(n) L/z Ratio	lc
26			min	.004	1	0	1	-.046	2	0	1	NC	1	920.245	2
27		4	max	.003	2	.286	3	-.021	1	9.61e-3	3	4433.348	3	2011.885	1
28			min	.003	1	0	1	-.023	2	0	1	NC	1	1855.865	2
29		5	max	.002	2	.315	3	0	1	1.086e-2	3	NC	3	NC	1
30			min	.002	1	0	1	0	2	0	1	NC	1	NC	2
31	M4	1	max	.002	2	.315	3	0	1	1.086e-2	3	NC	3	NC	1
32			min	.002	1	0	1	0	2	0	1	NC	1	NC	2
33		2	max	0	2	.335	3	.011	2	1.086e-2	3	2039.02	3	3900.549	2
34			min	0	1	0	1	.01	1	0	1	NC	1	4228.149	1
35		3	max	0	1	.343	3	.014	2	1.086e-2	3	1480.446	3	2925.412	2
36			min	0	1	0	1	.013	1	0	1	NC	1	3171.112	1
37		4	max	0	1	.335	3	.011	2	1.086e-2	3	2039.02	3	3900.549	2
38			min	0	2	0	1	.01	1	0	1	NC	1	4228.149	1
39		5	max	-.002	1	.315	3	0	1	1.086e-2	3	NC	3	NC	1
40			min	-.002	2	0	1	0	2	0	1	NC	1	NC	2
41	M5	1	max	0	1	0	1	0	1	0	1	NC	1	NC	1
42			min	0	1	0	1	0	1	0	1	NC	1	NC	1
43		2	max	0	1	.014	3	-.035	1	8.429e-4	3	3072.538	3	1239.806	1
44			min	0	2	0	1	-.038	2	0	1	NC	1	1143.117	2
45		3	max	0	1	.05	3	-.079	1	1.74e-3	3	845.978	3	548.805	1
46			min	0	2	0	1	-.086	2	0	1	NC	1	503.018	2
47		4	max	0	1	.101	3	-.069	1	2.638e-3	3	415.835	3	648.848	1
48			min	0	2	0	1	-.075	2	0	1	NC	1	596.691	2
49		5	max	0	1	.161	3	-.005	1	3.535e-3	3	261.148	3	NC	1
50			min	0	2	0	1	-.006	2	0	1	NC	1	NC	2
51	M6	1	max	0	1	0	1	0	1	0	1	NC	1	NC	1
52			min	0	1	0	1	0	1	0	1	NC	1	NC	1
53		2	max	0	2	.028	3	-.001	1	5.665e-4	5	1509.195	3	NC	1
54			min	0	1	0	1	-.001	2	0	1	NC	1	NC	2
55		3	max	0	2	.1	3	.003	2	1.338e-3	5	418.778	3	9993.122	2
56			min	0	1	0	1	.003	1	0	1	NC	1	NC	1
57		4	max	0	2	.201	3	.005	2	2.109e-3	5	208.624	3	6211.912	2
58			min	0	1	0	1	.005	1	0	1	NC	1	6741.83	1
59		5	max	0	2	.315	3	-.002	1	2.88e-3	5	133.436	3	NC	1
60			min	0	1	0	1	-.002	2	0	1	NC	1	NC	2
61	M7	1	max	-.002	1	.315	3	0	1	1.086e-2	3	NC	3	NC	1
62			min	-.002	2	0	1	0	2	0	1	NC	1	NC	2
63		2	max	-.003	1	.286	3	-.021	1	9.61e-3	3	4433.348	3	2011.885	1
64			min	-.003	2	0	1	-.023	2	0	1	NC	1	1855.865	2
65		3	max	-.004	1	.248	3	-.042	1	8.362e-3	3	4281.756	3	997.632	1
66			min	-.004	2	0	1	-.046	2	0	1	NC	1	920.245	2
67		4	max	-.004	1	.203	3	-.042	1	7.115e-3	3	NC	3	993.527	1
68			min	-.005	2	0	1	-.046	2	0	1	NC	1	916.449	2
69		5	max	-.005	1	.161	3	0	2	5.868e-3	3	NC	3	NC	2
70			min	-.006	2	0	1	0	1	0	1	NC	1	NC	1
71	M8	1	max	.006	2	.002	3	0	2	1.021e-3	3	NC	3	NC	2
72			min	.006	1	0	1	0	1	0	1	NC	1	NC	1
73		2	max	.005	2	.004	3	.017	2	1.284e-3	3	NC	3	2410.017	2
74			min	.005	1	0	1	.016	1	0	1	NC	1	2606.667	1
75		3	max	.004	2	.004	3	.015	2	1.547e-3	3	NC	3	2782.209	2
76			min	.004	1	0	1	.014	1	0	1	NC	1	3010.272	1
77		4	max	.003	2	.004	3	.005	2	1.811e-3	3	NC	3	8051.207	2
78			min	.003	1	0	1	.005	1	0	1	NC	1	8721.265	1
79		5	max	.002	2	.004	3	0	1	2.074e-3	3	NC	3	NC	1
80			min	.002	1	0	1	0	2	0	1	NC	1	NC	2
81	M9	1	max	.002	2	.004	3	0	1	2.074e-3	3	NC	3	NC	1
82			min	.002	1	0	1	0	2	0	1	NC	1	NC	2

Envelope Member Section Deflections (Continued)

	Member	Sec		x [in]	lc	y [in]	lc	z [in]	lc	x Rotate [r...	lc	(n) L/y Ratio	lc	(n) L/z Ratio	lc
83		2	max	0	2	.005	3	.001	2	2.074e-3	3	NC	3	NC	2
84			min	0	1	0	1	0	1	0	1	NC	1	NC	1
85		3	max	0	1	.005	3	.001	2	2.074e-3	3	NC	3	NC	2
86			min	0	1	0	1	.001	1	0	1	NC	1	NC	1
87		4	max	0	1	.005	3	.001	2	2.074e-3	3	NC	3	NC	2
88			min	0	2	0	1	0	1	0	1	NC	1	NC	1
89		5	max	-.002	1	.004	3	0	1	2.074e-3	3	NC	3	NC	1
90			min	-.002	2	0	1	0	2	0	1	NC	1	NC	2
91	M10	1	max	-.002	1	.004	3	0	1	2.074e-3	3	NC	3	NC	1
92			min	-.002	2	0	1	0	2	0	1	NC	1	NC	2
93		2	max	-.003	1	.004	3	.005	2	1.811e-3	3	NC	3	8051.207	2
94			min	-.003	2	0	1	.005	1	0	1	NC	1	8721.265	1
95		3	max	-.004	1	.004	3	.015	2	1.547e-3	3	NC	3	2782.209	2
96			min	-.004	2	0	1	.014	1	0	1	NC	1	3010.272	1
97		4	max	-.005	1	.004	3	.017	2	1.284e-3	3	NC	3	2410.017	2
98			min	-.005	2	0	1	.016	1	0	1	NC	1	2606.667	1
99		5	max	-.006	1	.002	3	0	2	1.021e-3	3	NC	3	NC	2
100			min	-.006	2	0	1	0	1	0	1	NC	1	NC	1

Envelope AISC ASD Steel Code Checks

	Member	Shape	Code C...	Loc[in]	lc	Shear C...	Loc[in]	Dir	lc	Fa [ksi]	Ft [ksi]	Fb y-y [...	Fb z-z [...	Cb	Cmy	Cmz	ASD Eqn
1	M1	TU2X2X4	.718	0	3	.131	4.375	z	3	28.267	36.791	40.47	40.47	1....	.642	.621	H1-2
2	M2	TU2x1x2	.545	0	3	.085	0	z	1	17.313	36.791	36.791	36.791	1....	.793	.575	H2-1
3	M3	TU2x1x2	.405	0	3	.044	0	y	3	17.314	36.791	36.791	36.791	2....	.464	.85	H1-2
4	M4	TU2x1x2	.347	21	5	.021	0	y	4	17.314	36.791	36.791	36.791	1	1	.85	H1-1
5	M5	TU2X2X4	.718	0	3	.131	4.375	z	3	28.267	36.791	40.47	40.47	1....	.642	.621	H1-2
6	M6	TU2x1x2	.545	0	3	.085	0	z	1	17.313	36.791	36.791	36.791	1....	.793	.575	H2-1
7	M7	TU2x1x2	.405	42	3	.044	42	y	3	17.314	36.791	36.791	36.791	2....	.464	.85	H1-2
8	M8	TU2x1x2	.293	0	1	.012	0	z	3	12.988	27.6	27.6	27.6	1....	.389	.6	H1-1
9	M9	TU2x1x2	.181	0	1	.004	0	y	4	12.988	27.6	27.6	27.6	1....	1	.6	H1-1
10	M10	TU2x1x2	.293	42	1	.012	0	z	3	12.988	27.6	27.6	27.6	1....	.389	.6	H1-1