ULTRA-TEC®
CABLE RAILING

Engineering Information

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Experimental Test to Determine Cable Tension Necessary to Resist Sphere Pass-through Requirement of International Building Code

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Engineering Analysis of Sphere Pass-through Requirement of International Building Code

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Summary of Loads by Part

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ULTRA-TEC®
CABLE RAILING

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Section A

Experimental Test to Determine Cable Tension Necessary to Resist Sphere Pass-Through Requirement of International Building Code

The 2015 International Building Code (IBC) and 2015 International Residential Code (IRC) require that guardrail intermediate railings be spaced so as to prevent a 4.0 in. diameter sphere from passing through them. (IBC 1015.4/IRC R312.1.3) However, the code does not state that a load is to be applied to the 4.0 in. sphere. While the absence of that load specification is not critical to solid railing members, it may be important for wire rope railing infill, since it is flexible. Therefore, in the absence of IBC/CBC guidelines, a rational load requirement has been developed based on the following:

The 2015 IRC Section R301.5 does address a requirement for railing infill by stating that railing infill must withstand a load of 50 lb applied over a 1.0 square foot area, applied horizontally and perpendicular to the railing plane. Applying that pressure over the projected area of a 4.0 in. diameter sphere, the resulting load on the sphere is calculated as follows::

$$F = 50\ \text{lb/sq ft} \times 144\ \text{sq in/sq ft} \times \frac{\pi \times (4.0\ \text{in})^2}{4} = 4.36\ \text{lb}$$

To allow for dynamic/impact loading, a conservative safety factor of 2.0 is applied:

$F_{MAX} = 4.36 \times 2.0 = 8.72$ lb

Therefore, in the absence of a load required by code, 8.7 lb is used as the standard force applied to a 4.0 in. diameter sphere, which cable railing infill must not allow to pass in order to be IBC/IRC compliant.

The railing infill case to be tested is:

.125 in. diameter, 1x19 construction, 316 stainless steel cables

48.0 in. unsupported cable span

3.125 in. cable spacing, center to center

This represents the thinnest cable in our Ultra-tec® line, hence the largest space between cables, given our standard center to center cable spacing of 3.125 in. The 48 in. cable unsupported span was chosen to be convenient for both design and installation of the railing system.

Railing Mock-Up and Test Arrangement

A steel frame was constructed to support two tensioned cables. See Fig. 1. The cables had been tensioned to 60% of their ultimate strength prior to installation, to eliminate the possibility of any constructional stretch during testing. A calibrated load cell was anchored to one end of the frame, and one of the cables is attached to its opposite end, allowing direct measurement of the tension in that cable. See Fig. 2.

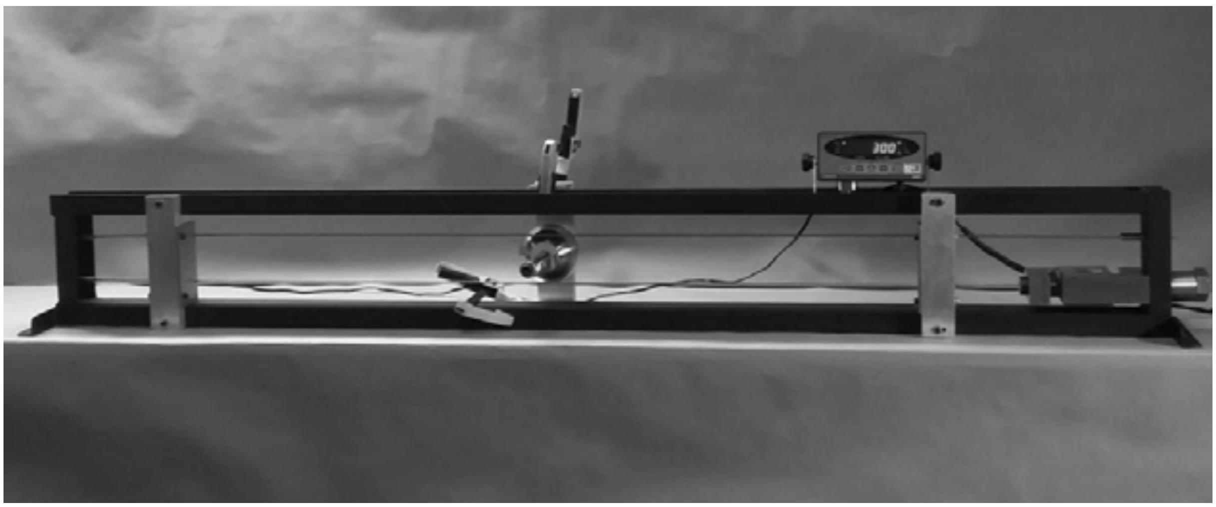

Fig. 1

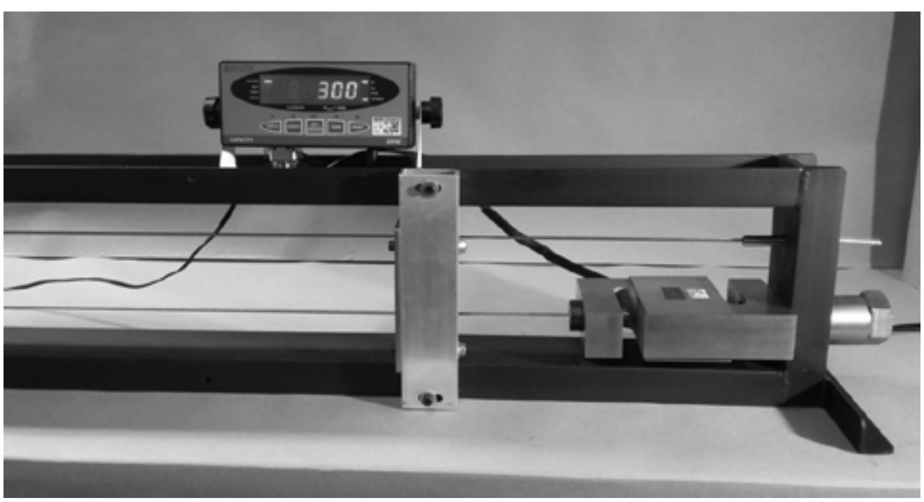

Fig. 2

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Since there was only one available load cell, a calibrated electronic tension meter was used to duplicate the tension in the second cable. See Fig. 3. Variation between the two instruments was ruled out by using the tension meter to first measure the tension in the cable attached to the load cell, and then to tension the second cable, reproducing the same reading on the tension meter as for the first cable.

Fig. 3

A fixture to support and precisely guide a 4.0 in. diameter steel sphere was built and clamped to the center of the frame. See Fig.4. The guide rod for the steel sphere was centered between the two cables and checked for perpendicularity to the plane containing the cable centerlines. The steel sphere was machined to within +/-.001 in. of its 4.0 in. diameter. Its central bore was machined to be .005 in. larger than the precision ground .750 in. diameter guide rod. As such, the sphere had no detectable play in the vertical direction, and ran smoothly on the guide rod.

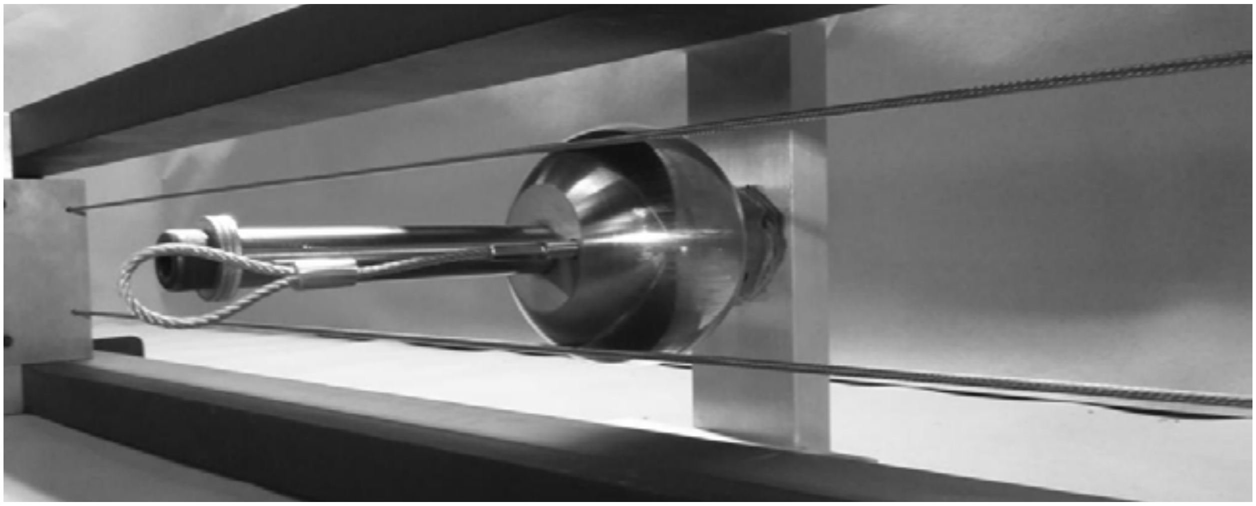

Fig. 4

A short cable with a swaged eye was threaded into the sphere. The sphere was then pulled through the two cables using a cablibrated electroic handheld pull-force meter, as shown in Fig. 5.

The frame was built to be adjustable for both cable-to-cable spacing and cable-unsuppported span. The guide rod fixture was clamped to the frame rather than being permanently attached, to allow for different cable-unsupported spans to be tested.

Fig. 5

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Test Procedure

Several different combinations were tested before settling on the 3.125 in. cable to cable spacing and 48.0 in. unsupported span case.

The sphere pull-through test was performed with cable tension set at 175, 200, 225, 250, 275, and 300 lb.

For each individual trial, the force required to overcome the friction between the sphere and the guide rod was recorded as the sphere was pulled to contact the cables. The total force required to pull the sphere through the cables was then recorded, and the friction force deducted from the result.

Care was taken to move the sphere slowly, so as not to impart a dynamic load to the cables.

Care was also taken to pull the sphere with the pulling cable parallel to the guide rod. It was not considered necessary to constrain the motion of the handheld pull-force meter, since it was found to be easy to keep the pulling cable very close to parallel by eye. The cable was always held to closer than 5 degrees of parallel, which may easily be discerned by the naked eye. The error introduced by a 5 degree variance would only be .38%, which may be considered negligible.

Twenty trials were performed at each tension level, recording both the friction force on the sphere and the total pull-through force for each trial. The friction force was deducted from each total pull-through force, and the average net force of the twenty trials calculated.

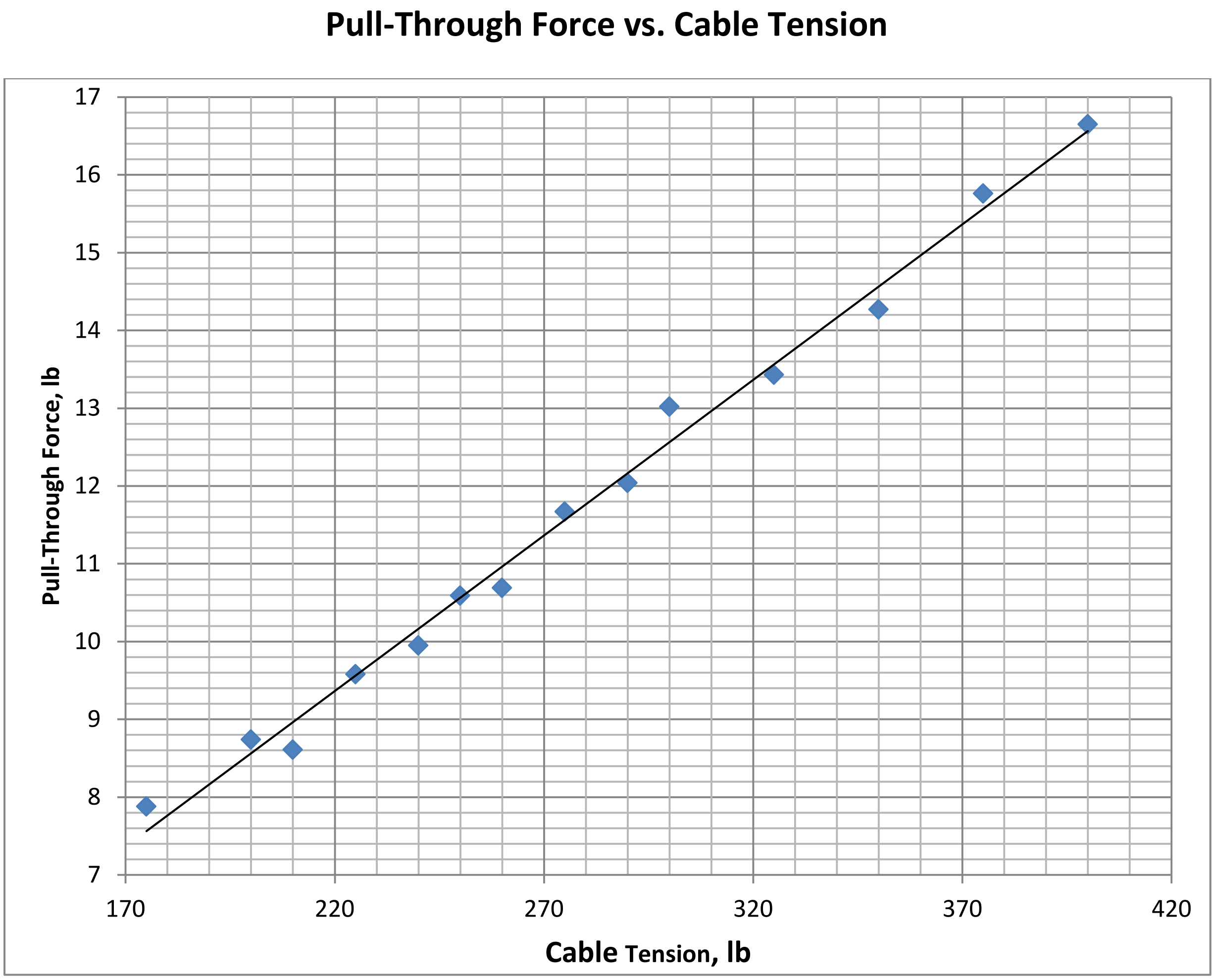
Results

The average net force required to pull a 4.0 in. diameter steel sphere through .125 in. diameter, 1x19 lay, 316 stainless cables spaced at 3.125 in. center to center, with 48.0 in. unsupported span is tabulated in Table 1. The values shown are for the cable tension levels of greatest interest.

Cable Tension	Pull-Through Force
175 lb	7.88 lb
200 lb	8.74 lb
225 lb	9.58 lb
250 lb	10.59 lb
275 lb	11.67 lb
300 lb	13.02 lb

Table 1

All of the average pull-through force results are plotted below in Graph 1.



Graph 1

While the results show some scatter, it is clear that pull-through force is linearly related to cable tension.

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Recommendations

Based on these results, it is our recommendation that Ultra-tec® cable railing infill be installed per the following guidelines:

Cable Spacing, Center to Center:	3.125 in.
Maximum Unsupported Span:	48.0 in.
Cable Tension:	225 lb

All Ultra-tec® cable railing infill should be so installed, regardless of cable diameter.

The 225 lb cable tension provides an additional margin of safety of 10% beyond the safety factor of 2.0 applied for dynamic loading. (Using the 9.58 lb avg. push force result from the test data.)

Cable railing infill which is capable of resisting an 8.7 lb load to a 4.0 in sphere is more robust than the requirements of 2015 IBC/IRC, since the IBC/IRC codes only specify the size of the infill openings and make no mention of force required to expand them to a larger size.

Section B

Engineering Analysis of Sphere Pass-Through Requirement of International Building Code

The 2015 International Building Code (IBC) and 2015 International Residential Code (IRC) require that guardrail intermediate railings be spaced so as to prevent a 4.0 in. diameter sphere from passing through them. (IBC 1015.4/IRC R312.1.3) However, the code does not state that a load is to be applied to the 4.0 in. sphere. While the absence of that load specification is not critical to solid railing members, it may be important for wire rope railing infill, since it is flexible. Therefore, in the absence of IBC/CBC guidelines, a rational load requirement has been developed based on the following:

The 2015 IRC Section R301.5 does address a requirement for railing infill by stating that railing infill must withstand a load of 50 lb applied over a 1.0 square foot area, applied horizontally and perpendicular to the railing plane. Applying that pressure over the projected area of a 4.0 in. diameter sphere, the resulting load on the sphere is calculated as follows:

$$F = 50\ \text{lb/sq ft} \times 144\ \text{sq in/sq ft} \times \frac{\pi \times (4.0\ \text{in})^2}{4} = 4.36\ \text{lb}$$

To allow for dynamic/impact loading, a conservative safety factor of 2.0 is applied:

$F_{MAX} = 4.36 \times 2.0 = 8.72$ lb

Therefore, 8.7 lb is used as the standard force applied to a 4.0 in. diameter sphere, which cable railing infill must not allow to pass in order to be IBC/CBC compliant.

The railing infill case to be analyzed is for:

.125 in. diameter, 1x19 construction, 316 stainless cables

48.0 in. unsupported cable span

3.125 in. cable spacing, center to center

This represents the thinnest cable in our Ultra-tec® line, hence the largest space between cables, given our standard center to center cable spacing of 3.125 in. The 48 in. cable unsupported span was chosen to be convenient for both design and installation of the railing system.

The geometry of two adjacent cables, the cable guides, and the 4.0 inch test sphere are shown in Fig. 1.

D = Sphere Diameter $\quad$ S_c = Center-Center Cable Spacing

d = Cable Diameter $\quad$ L_{CG} = Cable Unsupported Span

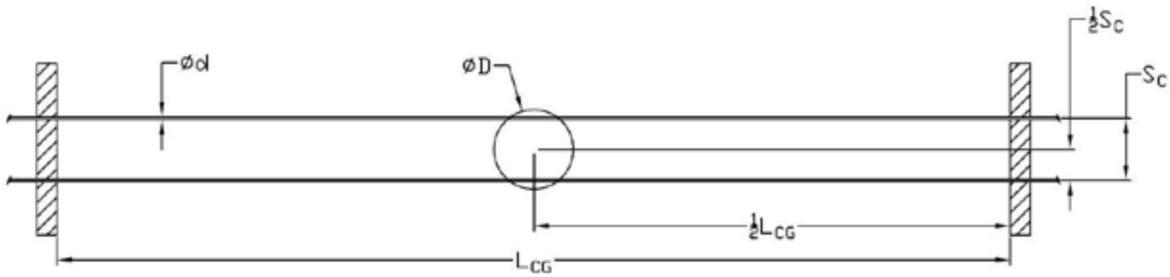


Fig. 1

The deflection due to the sphere having been forced between the two cables is shown in Fig. 2. (Deflection shown at maximum.) Note that the cables are not fixed to the cable guides, but that they pass freely through them, and are ultimately fixed at a total cable length of L_{CT}.

Δ = Deflection of one Cable

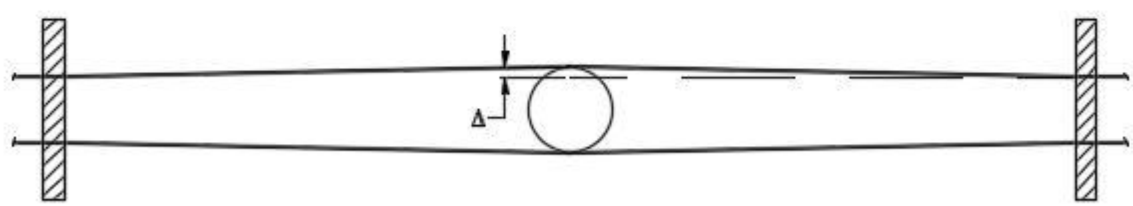


Fig. 2

The force that a cable exerts against the sphere is then calculated based on the deflection of the cables. The cables exert no force on the sphere until they are deflected from their rest position. Once deflected, the force of a cable on the sphere is calculated by trigonometry. The geometry and associated forces of one half of one cable are shown in Fig. 3

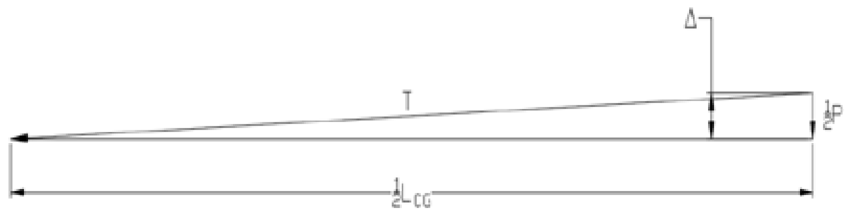


Fig. 3

A Mathcad worksheet was created to analyze the cable forces as a function of the cable deflection, Δ. The relationship of cable force on the sphere, P, to deflection, Δ**,** is described by:

$$P(\Delta) := 2T\left[\frac{\Delta}{\sqrt{\Delta^2 + \left(\frac{L_{CG}}{2}\right)^2}}\right] \qquad \textbf{Eq. 1}$$

Where:

T = Cable Tension P = Force of One Cable on Sphere

The vertical component of T acting on the sphere is proportional to the sine of the cable angle from horizontal, which is calculated by the term within the parentheses of Eq. 1. Since the cable tension acts on the sphere on either side, the net force of the cable on the sphere is double the vertical component of T.

The cable tension increases as the sphere deflects and stretches the cable. The increase of cable tension with respect to deflection is calculated below:

Calculate Tension Increase Due to Cable Deflection, Δ

$$T_i(\Delta) := 2\cdot\left[\frac{\left[\Delta^2 + (.5\cdot L_{CG})^2\right]^{.5} - .5\cdot L_{CG}}{L_{CT}}\right]\cdot\frac{(d)^2}{4}\pi\cdot E_{125}$$

Eq. 2

L_{CT} is the entire length of the cable between fixed ends.

E_{125} is the effective Young's Modulus of .125" diameter, 1x19 construction, type 316 stainless steel cable, which was determined by pull testing such cable and recording its elongation vs. applied tension. It is designated as an effective modulus since is it calculated based on the cross sectional area of a smooth rod of the same diameter as the nominal diameter of the stranded cable tested. Doing so then allows the cable to be treated as a solid rod for simplified calculation of its extension under load.

The term within the parentheses calculates the strain imparted by the stretching of one half of the cable between the cable guides, which is then multiplied by the cable area and the effective modulus to give the tension increase imparted by the deflection.

The resulting tension increase per deflection, $T_i(\Delta)$, is added to the cable's installed tension, T, for the following calculations.

Fig. 3 shows a free-body diagram of the sphere and the forces acting on it. The cable contact points are at the tips of the force vectors, P.

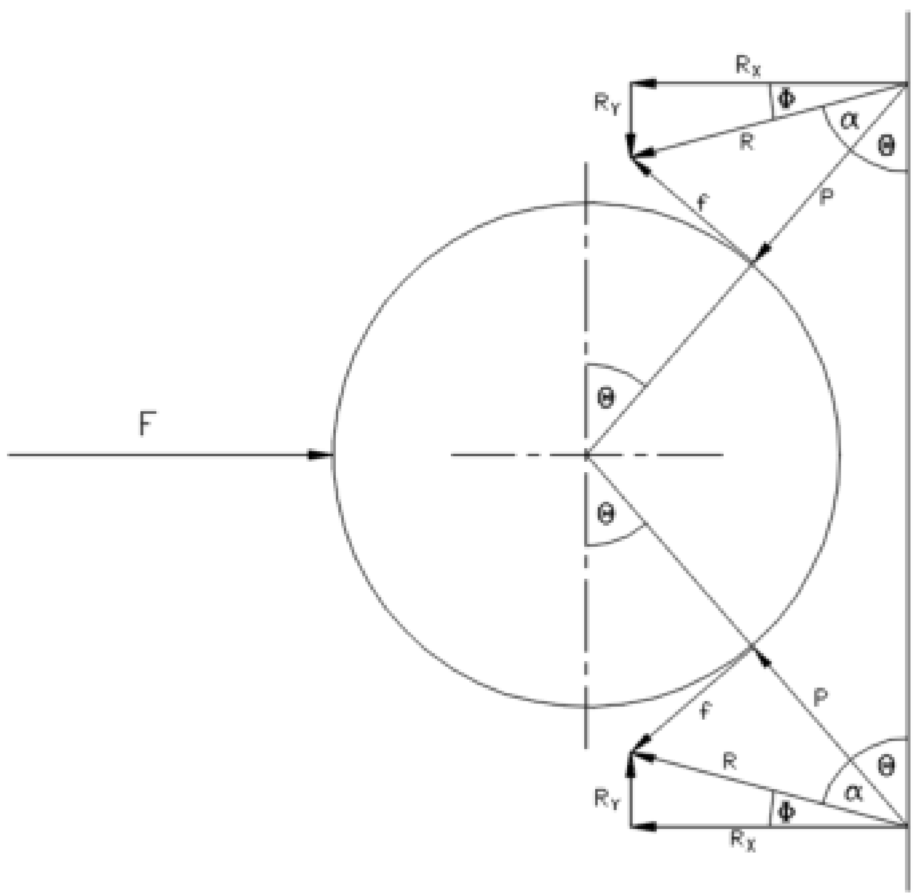


Fig. 3

For simplicity, it is assumed that the cables move only in the vertical plane.

The friction force, f, of the cables against the sphere is shown for clarity, but is not used in the following equations, since the friction angle, α, is determined from the friction coefficient, μ, as follows:

$$\alpha := \operatorname{atan}(\mu)$$ **Eq. 3**

Next, angle Θ, is developed as a function of deflection, Δ:

$$\theta(\Delta) := \operatorname{acos}\left[\frac{(.5 \cdot S_C + \Delta)}{.5(D + d)}\right]$$ **Eq. 4**

The following equations are then developed as functions of the cable deflection, Δ.

Knowing Θ and α allows the net resultant force, R, to be determined, which is the combination of the effects of cable tension and friction.

$$R(\Delta) := \frac{P(\Delta)}{\cos(\alpha)}$$ **Eq. 5**

Next, angle ϕ is determined from $\theta(\Delta)$ and α:

$$\phi(\Delta) := \frac{\pi}{2} - \theta(\Delta) - \alpha$$ **Eq. 6**

Which then allows R_X, the horizontal component of the net force, R, to be determined:

$$Rx(\Delta) := R(\Delta) \cdot \cos(\phi(\Delta))$$ **Eq. 7**

Since there are two cables acting on the sphere, there are two horizontal forces, R_X, resisting the force driving the sphere against the cables, F.

$$F := 2Rx(\Delta)$$ **Eq. 8**

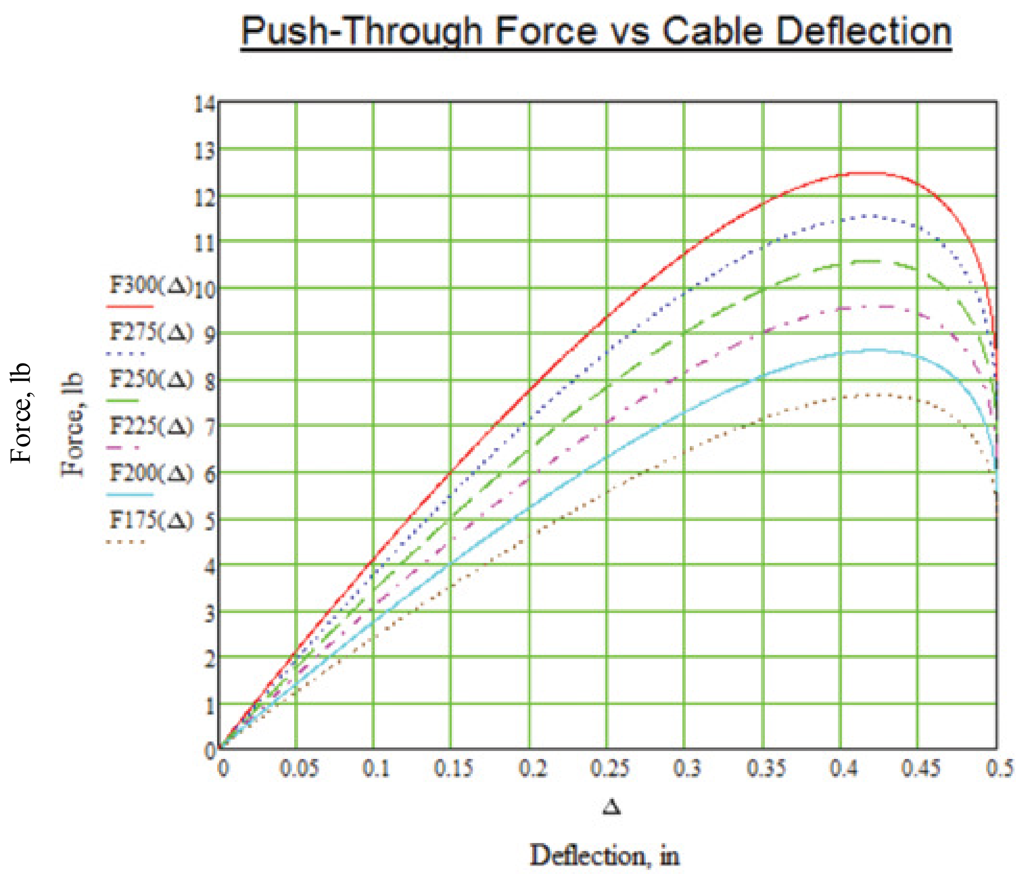
This final equation is then solved for several levels of cable tension over the full range of possible cable deflection, Δ.

For the following conditions:

L_{CG} = 48.0 in. d = .125 in. S_C = 3.125 in. D = 4.0 in.

T = 175, 200, 225, 250, 275, 300 lb μ = .285

The value for μ was chosen to match the calculated push-through force for T=225 lb to that obtained by testing the actual pull-through force of a steel sphere through tensioned cables.



Graph 1

The maximum values of F are then determined for each curve plotted in Graph 1.

First, the deflection, Δ, at which the maximum force, F, occurs is found.

From the Mathcad analysis:

Establish range of interest for Δ :

$\Delta := .3$

Given:

$.3 < \Delta < .5$

Determine Δ at which Push-Through Force is Maximum:

Maximize (F175,Δ) = 0.42382	Maximize (F255,Δ) = 0.4192
Maximize (F200,Δ) = 0.42197	Maximize (F275,Δ) = 0.41813
Maximize (F225,Δ) = 0.42046	Maximize (F300,Δ) = 0.41722

The maximum force required to push the sphere through the cables is found using those values for Δ :

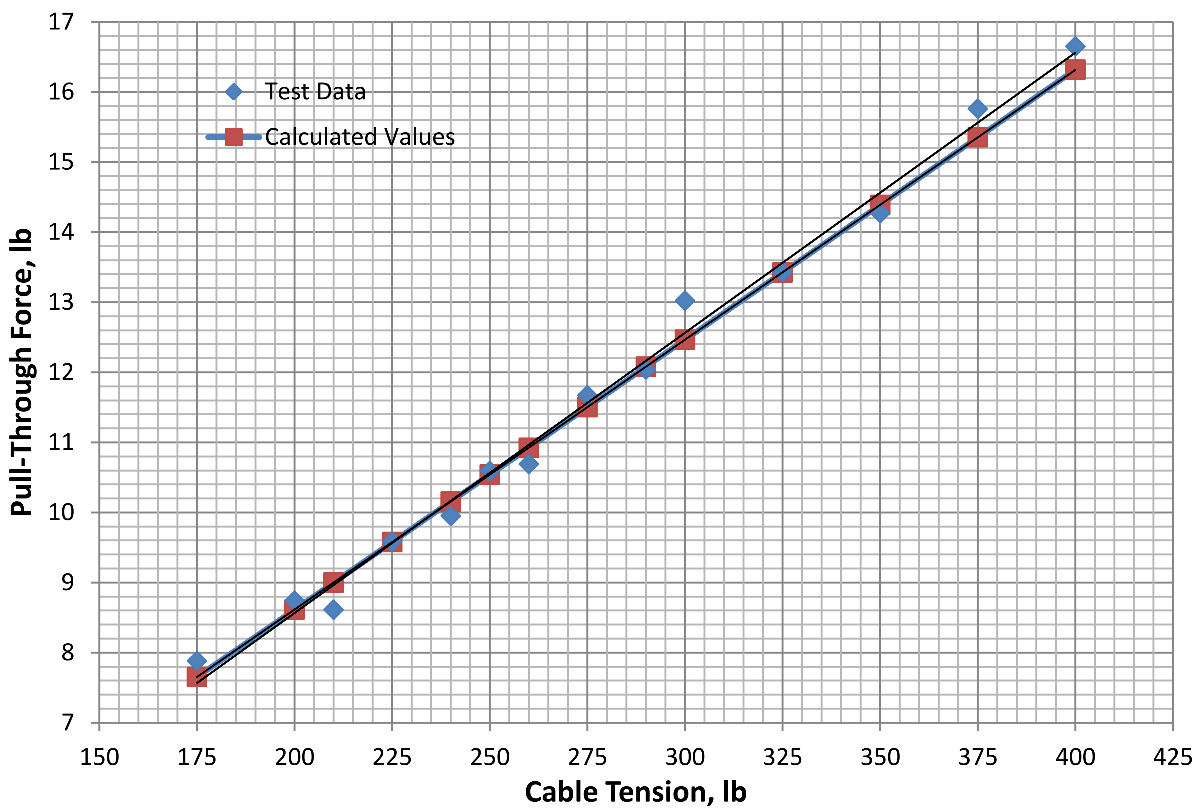
F175(Δ) = 7.651 lb	F250(Δ) = 10.536 lb
F200(Δ) = 8.613 lb	F275(Δ) = 11.502 lb
F225(Δ) = 9.577 lb	F300(Δ) = 12.464 lb

As described earlier, the choice of value for the coefficient of friction, μ, was chosen to match the peak force value to the experimental data for T = 225 lb. That value, μ **=** .285, was then used throughout this analysis.

The actual forces required to push a 4.0 in. diameter sphere through .125 in. diameter, 1x19 construction, 316 stainless cables which were spaced at 3.125 in. center to center, with 48.0 in. unsupported span were tested for a fairly large number of cable tensions. The results are listed below. Each force value represents the average result of 20 trials at each tension level.

T = 175 lb	F = 7.88 lb	T = 275 lb	F = 11.67 lb
T = 200 lb	F = 8.74 lb	T = 290 lb	F = 12.04 lb
T= 210 lb	F= 8.61 lb	T= 300 lb	F= 13.02 lb
T = 225 lb	F = 9.58 lb	T = 325 lb	F = 13.43 lb
T= 240 lb	F= 9.95 lb	T= 350 lb	F= 14.27 lb
T= 250 lb	F= 10.59 lb	T= 375 lb	F= 15.76 lb
T= 260 lb	F= 10.69 lb	T= 400 lb	F= 16.65 lb

The predicted pull-through force was calculated for each of the above cable tension levels and plotted against the actual forces in Graph 2.



Graph 2

Graph 2 shows very good correlation between the calculated values and the experimental data, which indicates that the assumptions for the analysis are reasonable.

While this analysis is not strictly necessary, given that the sphere push force has been accurately determined by testing, it is useful as an aid to further understand the behavior of cable railing infill.

Based on these results, it is our recommendation that our cable railing infill be installed per the following guidelines:

Cable Spacing, Center to Center:	3.125 in.
Maximum Unsupported Span:	48.0 in.
Cable Tension:	225 lb

All Ultra-tec® cable railing infill should be so installed, regardless of cable diameter.

The 225 lb cable tension provides an additional margin of safety of 10% beyond the safety factor of 2.0 applied for dynamic loading. (Using the 9.58 lb avg. push force result from the test data.)

Cable railing infill which is capable of resisting an 8.7 lb load to a 4.0 in sphere is more robust than the requirements of 2015 IBC/IRC, since the IBC/IRC codes only specify the size of the infill openings and make no mention of force required to expand them to a larger size.

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Section C

SUMMARY OF LOADS BY PART

Part No.	Description	Ultimate Load (Lbs.)	Average Allowable Load (Lbs.)
A-J62	Adjust-A-Jaw® Tensioner	2173	1085
A-J82	Adjust-A-Jaw® Tensioner	3134	1565
A-J122	Adjust-A-Jaw® Tensioner	4262	2130
A-JTB6	Adjust-A-Body® Tensioner	2022	1011
A-JTB8	Adjust-A-Body® Tensioner	3320	1660
A-JTE62	Adjust-A-Body® Tensioner	2120	1060
A-JTE82	Adjust-A-Body® Tensioner	3364	1682
F-4	Ferrule	1416	705
F-6	Ferrule	2022	1010
F-8	Ferrule	3134	1565
F-10	Ferrule	4262	2130
F-12	Ferrule	3560	1780
F-J62	Fixed Jaw	2317	1155
F-J82	Fixed Jaw	4010	2005
F-J122	Fixed Jaw	4315	2155
R-6-12 thru R-6-52	Receiver	2652	1326
R-8-22 thru R-8-52	Receiver	3248	1624
R-12-32 thru R-12-52	Receiver	3994	1997
RF-4	Radius Ferrule	1580	790
RF-6	Radius Ferrule	2286	1143
RF-8	Radius Ferrule	4092	2045
RF-10	Radius Ferrule	4068	2034
RF-12	Radius Ferrule	3762	1881
S-4	Threaded Stud	1537	765
S-6	Threaded Stud	2786	1393
S-8	Threaded Stud	3783	1891
S-10	Threaded Stud	5691	2845
S-12	Threaded Stud	3994	1995
TT-6B	Threaded Tab	2173	1086
TT-8B	Threaded Tab	3134	1567