Polywater®

In this paper you will learn:

- The tension equations for cable pulled through horizontal bends
- When the use of a simplified bend equation is appropriate
- When the full form horizontal bend equation improves the accuracy of cable tension prediction

Polywater Analysis of the Horizontal Bend Pulling Tension Equations

Abstract

Cable tension equations for pipe-type cable installations were developed in the 1950s. They include bend equations that generally indicate a multiplier times the incoming tension. In preparing for cable pulls that involve large, sweeping bends common in trenched or bored duct simplified versions of bend equations can't be applied. The cable weight in large radius bends is significant and cannot be ignored. Using the full horizontal bend equation produces more accurate tension prediction, as this type of small displacement bend acts more like a straight line.

Cable pulling tension can be predicted using several horizontal bend pulling equations. Equation 1 is what we call the "full" form equation. Equation 2 is an approximation derived from Equation 1.

Equation 1 (full): $$T_{out} = T_{in}\cosh(w\mu\theta) + \left(\sinh(w\mu\theta)\sqrt{T_{in}^2 + (WR)^2}\right)$$

Equation 2 (simplified): $$T_{out} = T_{in}\, e^{w\mu\theta}$$

Where:

- T_{out} = tension coming out of the bend
- T_{in} = tension coming into the bend
- w = weight correction factor
- μ = coefficient of friction
- θ = angle of the bend (in radians)
- W = weight of the cable (per unit of length)
- R = radius of the bend

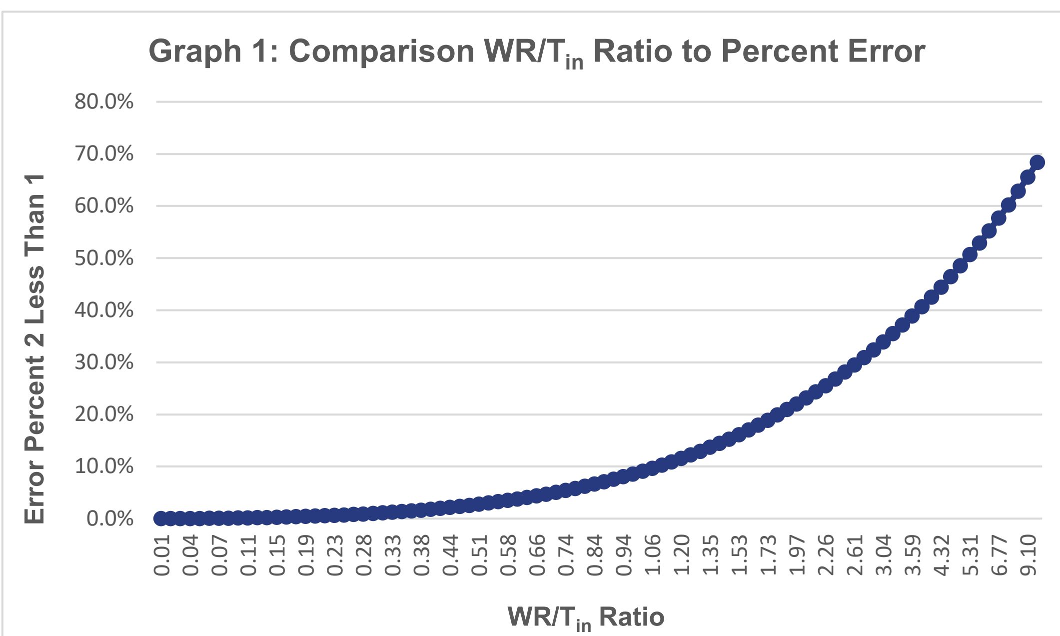
It's important to note that the analysis below does not specify force units. The analysis holds for any appropriate unit (typically lbf, kgf, or N), as long as the weight (typically lb./ft, kg/m, or N/m) and radius (ft, m, and m) use the equivalent unit.

Equation 2 derives from equation 1 when $T_{in} >> WR$. In this case, the last term in Equation 1 $\sqrt{T_{in}^2 + (WR)^2}$) approaches T_{in} and the equation simplifies to:

$T_{out} = T_{in}$ (cosh($w\Theta\mu$) + sinh($w\Theta\mu$)), which further simplifies to $T_{out} = T_{in}\, e^{w\mu\Theta}$.

The simplified equation 2 does not contain the cable weight, W. Thus, this equation does not vary with the weight of the cable in the bend. Equation 2 always calculates to a lower tension than the full equation 1. When is the approximation in equation 2 reasonable?

While the exact calculational differences between the two equations depends on the specific w, μ, Θ, W, and R values, the percent difference in tension coming out of the bend T_{out} can be compared. As T_{in} becomes much larger compared to the total cable weight, (WR) the ratio, $\frac{WR}{T_{in}}$ becomes smaller. Graph 1 below shows the typical percent difference or error magnitude plotted against ($\frac{WR}{T_{in}}$) ratios from 0.01 to 10.



Because the resolution on this graph is limited, specific data points are presented below to clarify.

$\frac{WR}{T_{in}}$	*Error (%)*
0.01	*0.001*
0.10	*0.111*
0.31	*1.095*
0.51	*2.574*
1.02	*9.085*
10.22	*63.385*

The approximation in equation 2 has now diverged from equation 1 by ~1% at a $\frac{WR}{T_{in}}$ ratio of 0.31. AEIC Publication CG-5-15 suggests the validity of the simplified equation 2 at $\frac{WR}{T_{in}}$ ratios < 0.5, which is about a 2.5% error. So, when do ratios above this range occur in cable pulling?

Higher $\frac{WR}{T_{in}}$ ratios are quite common in trenched or directionally bored duct. Directional boring creates large radius bends, often of relatively small angle displacement. In these types of bends, the total weight of the cable is higher compared to the total bend angle. How do the equations work in this situation?

Graph 2 compares the calculated tension of the two equations as the degree of the bend varies. Specifically, graph 2 shows equation 1 and 2 calculations in a large radius bend and uses the inputs listed below:

Calculation inputs in Graph 2:

T_{in} = 3,500 (incoming tension) W = 5 (cable weight per length)

μ = 0.2 (coefficient of friction factor) w = 1 (weight correction factor)

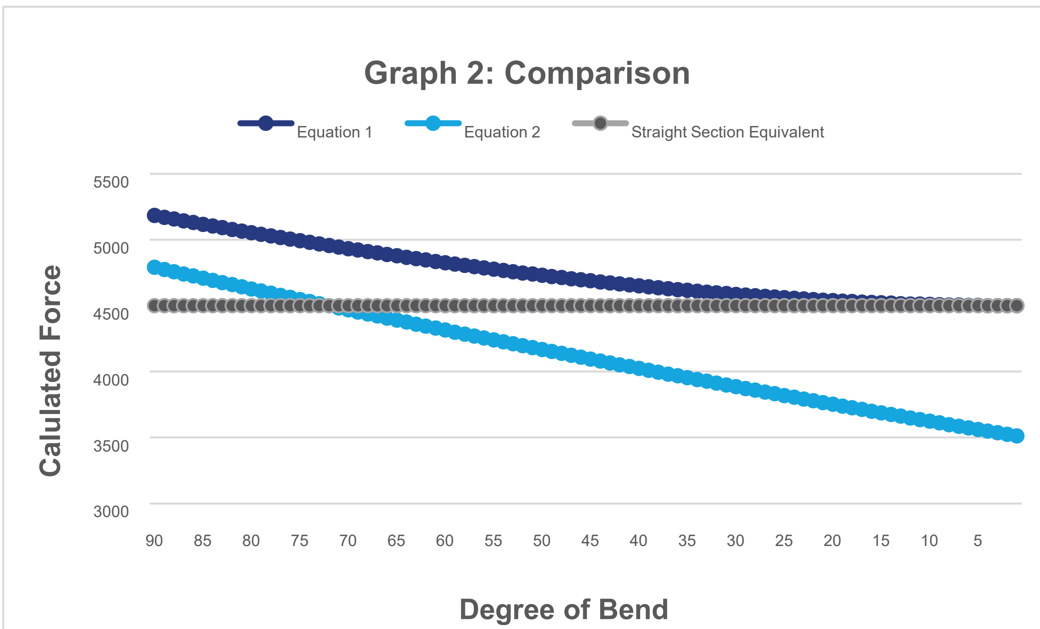
ϴ = bend angle is variable from 90 to 0 degrees

R = bend radius is variable from 636.6198 increasing as the angle decreases to produce a constant cable length of 1,000 in the bend arc.

As the radius increases, the cable weight and incoming tension are held constant. The ratio, $\frac{WR}{T_{in}}$ = starts at 0.91 and continues to increase. There is already a notable difference at the start (90 degrees). Equation 1 (full) calculations are in blue and Equation 2 (simplified) in orange.

But a new perspective on the bend calculations comes from the tension calculated as if the length of cable in the bend arc were a straight run (grey line). Because this example was set up with a constant length of cable in the arc, there is a constant calculated straight section add-on of 1,000 or a total of 4,500 when added to the incoming tension (3,500).

$T_{out} = T_{in} + \mu WL$ (straight line equation)



This graph reinforces the importance of the full form equations in such large radius directional boring bends. The calculated tensions from equation 1 approach the straight section tension as the bend angle decreases and the bend physically approaches being a straight section. That is what we intuitively expect.

But in the simplified equation 2, as the bend angle approaches 0, the multiplier approaches unity, thus predicting no add-on at all to incoming tension. This is obviously not correct. The simplification is not valid for this ratio area.

Graph 2 also shows that large-radius horizontal bends with displacement angles < 15 degrees calculate very close to a straight section with the same amount of cable. When the total bend is only a few degrees, this displacement can be ignored, and the section can be calculated as straight if desired. You would still need to do side math to determine total bend arc length, and enter the data as a straight section, using the arc length.

American Polywater's Pull-Planner™ 4.0 Software uses the long-form equations in all horizontal bend calculations. There is no downside to this approach since the software does the difficult work (the more complex calculation), and the calculations are valid regardless of the $\frac{WR}{T_{in}}$ ratio.

This analysis applies only to horizontal bends. A future analysis will focus on similar limitations with the vertical component bend equations.

For more information, contact:

Sheri Dahlke, Technical Director, Polywater, sheri.dahlke@polywater.com

For Pull-Planner or product information:

support@polywater.com

global@polywater.com

Reference

Underground Extruded Power Cable Pulling Guide, AIEC Publication CG-5-15, 3rd Edition,

Association of Edison Illuminating Companies (AEIC), January 2015.