The Effect of Conduit Fill on Premises Cabling

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Introduction

Optimizing the fit of premises cable into conduit is an important issue of cost efficiency. Information on the effects of higher conduit fill levels is of interest to current standards developers. This paper looks at physical limits for installing cable at higher conduit fill levels.

Conduit fill is the volume of cables in a conduit as a percentage of the total volume of interior space. The National Electrical Code mandates conduit fill for electrical cable at approximately 40%. However, utilities, both telephone and power, have historically filled their conduits to considerably greater percentages than 40%. They have limited their cable pulls into conduit using the concept of clearance. A clearance minimum of one-half inch in four inch conduit (20% clearance) is typical (Reference 1) of large cable installation.

The purpose of this research is to apply the concept of clearance to data and communication installations. What clearance (and conduit fill) is appropriate so that cable is not damaged during the pull? What are the maximum clearance and fill based on installation practicality? The study consists of both theoretical analysis and controlled cable pulls.

Clearance

Clearance is the distance between the closest packed cable(s) and the wall of the conduit. That is, the diameter of a bundle of cables with no clearance is the same size as the diameter of the conduit. It tells whether or not the cables fit into the conduit. Clearance is a distance measurement typically expressed in inches (mm). It can also be specified as a percentage of conduit diameter. Clearances specified in utility pulling have typically been 10 to 20% of the conduit diameter. Such clearance allows for the ovalization of conduit around bends, expansion of cables, neck down at connections, or minor obstructions in the conduit.

Clearance can be theoretically determined based on the number of cables and cable formation. This calculation depends on conduit diameter and diameter of the cable(s). In a single cable in a conduit, the clearance is simply the difference between the diameter of the conduit (“D”) and the diameter of the cable (“d’). Equations that follow are for multiple cables with the same diameters.

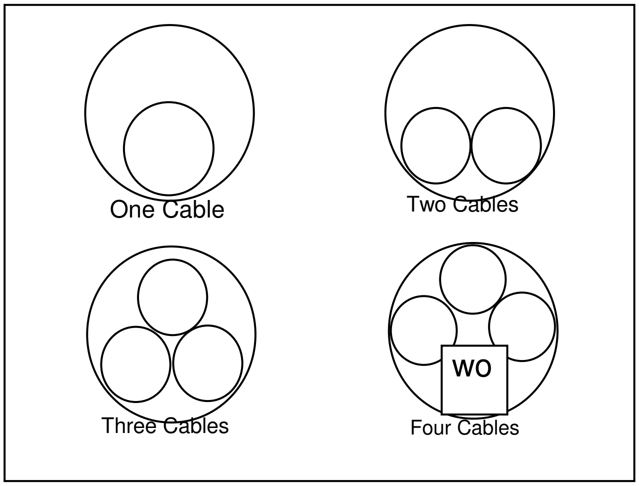


Figure 1

1 Cable: $\text{Clearance} = D - d$

2 Cables: $\text{Clearance} = D - 2d$

3 Cables (Triangular):

$$\text{Clearance} = \frac{D}{2} - 1.366d + \frac{D - d}{2}\sqrt{1 - \left(\frac{d}{D - d}\right)^2}$$

4 Cables (Diamond):

$$\text{Clearance} = (D - d) - \frac{2d^2}{(D - d)}$$

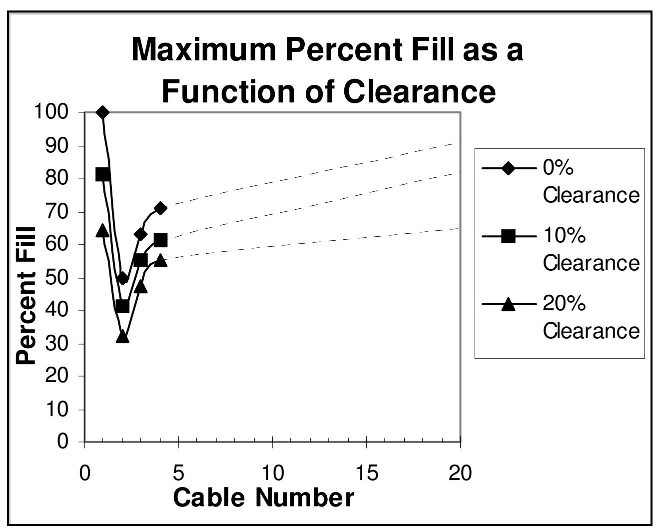
Relationship to Conduit Fill

As the equations show, the calculations for clearance get quite complicated with higher cable counts and even more so with cables of different diameters. Percentage conduit fill is much easier to calculate in the design portion of a cabling project, when conduit sizes are usually determined.

But clearance can be directly related to conduit fill. Once a minimum clearance is set as a percentage of conduit diameter, the maximum cable diameter that allows for this clearance can be calculated from the equations. Once this maximum cable diameter is determined in terms of the conduit diameter, the maximum fill percentage can be calculated.
In the calculations, both the conduit and cable diameters cancel out and we see the maximum percentage fill is dependent on number of cables and the cable formation, but is independent of the conduit interior diameter. For example, the maximum cable diameter is 0.5 inch if two cables are put into a 1-inch duct (with zero clearance). If the duct has a 2-inch diameter, the maximum cable diameter is 1 inch. Either way, the conduit fill is the same, 50%.

These calculations show that maximum fill levels are highest for one large cable and lowest for two cables in conduit. When two cables are pulled through a conduit, the two diameters cannot exceed the interior diameter of the conduit. If the two cables are of equal size, with zero clearance, the maximum fill is only 50% ($0.5^2 + 0.5^2$). With a 20% clearance, the maximum fill for two cables is only 32%.

Cable counts over two pack more closely and the maximum cable fill increases with the number of cables. This is shown in the graph below. The three lines represent a clearance of 0%, 10%, and 20% of the conduit diameter. The "maximum" fill at each clearance for one to four cables is shown as data points on Graph 1.



Graph 1

Multiple Cables

The analysis of more than four cables becomes quite complex, although both geometric or graphing methods are possible. As larger numbers of cables are added to the system, the cable becomes more tightly packed, leaving less "air" space. The fill approaches an asymptotic maximum.

We can theoretically determine this maximum. Closest packed circles are the same as closest packed cylinders (cables). Closest packed circles (or cylinders) occupy 91% of the available space. For multiple small cables, this indicates that 91% fill is the absolute maximum for 0% clearance, 83% fill is absolute maximum for 10% clearance, and 65% fill is the absolute maximum for 20% clearance. This is indicated by the dotted line in Graph 1 and is clarified in the Figure 2 below.

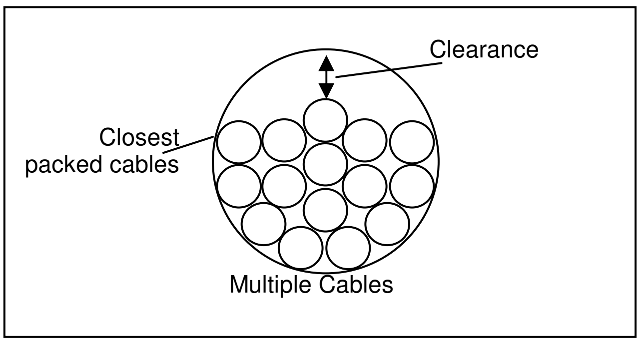


Figure 2

Thus far, the discussion has centered on multiple cables of equal diameters. This is the most conservative case. When cables of unequal sizes are analyzed, the packing is closer and clearances greater.

Laboratory Testing

This theoretical analysis leads to <u>acceptable fills considerably above 40%</u>. Actual pulls with varying conduit fills were needed to confirm the acceptability of higher fills.
In this test method, cables are pulled through multiple conduit bends to build tension quickly. By measuring the incoming (back) tension on the cable and the pulling force, we can calculate the "effective" coefficient of friction. Variations of this method have been used in a number of studies in electrical cable pulling (References 2 & 3).

This multi-bend pulling test method has several advantages. The method produces data relatively quickly and is reasonably space compact, yet actually pulls cable. A number of inputs can be varied, including conduit type, cable jacket type, lubricant type, back tension level, and our major focus, conduit fill and number/size of cables.

Testing was done using conditions described in Bellcore test procedure TR-TSY-00356 Sections 4.1.3 and 4.1.4. In this method the duct is wrapped 420° around a three foot diameter. A weight is suspended from a pulley as shown in Figure 3 below. The weight (incoming tension) was varied from 2 lbs to 25 lbs. Cable was pulled with a winch at a set rate of 65 feet per minute. A load cell attached to the winch rope measured pulling tension every half-second.

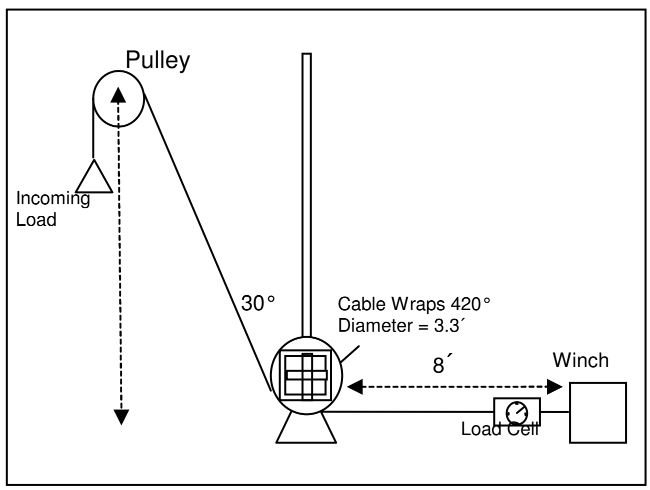
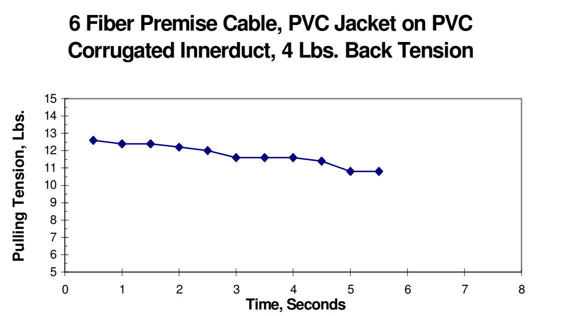


Figure 3

The data was fed directly into a PC spread sheet which averaged the pulling tension and calculated the coefficient of friction. The spreadsheet macros also eliminated the tensions measured before the pull started and after it stopped. Graph 2 shows typical data from a test pull. Tension (in pounds force) is plotted against time. The visible data points were those selected for the averaging and calculation process.



Graph 2

This demonstration graph above shows information from a pull with an average pulling tension of 11.7 lbs. It was for a single 6-fiber premises cable with lubrication, 4 lbs. back tension, and an effective coefficient of friction of 0.15.

Coefficient of Friction

The pulling tension and incoming tension are used to calculate the "effective" coefficient of friction. Coefficient of friction was calculated using the following formula:

$$\mu = \frac{ln\left(\frac{T_{out}}{T_{in}}\right)}{\theta}$$

where:

μ = Kinetic coefficient of friction (dimensionless)

T_{out} = Average pulling tension measured on moving cable (lbs.)

T_{in} = Incoming tension or set load (lbs.)

θ = Total angle of duct around bend or 7.33 radians

This equation is common for pulling cables around a bend. (For more information, see References 4, 5, & 6). The coefficient of friction calculation normalizes the varying incoming tension and adjusts for the sidewall pressure from the multiple bends. Interestingly, note that there is no weight factor in the bend equation. This means that heavier (i.e. multiple cables) will pull with approximately the same tension as lighter cables if the friction coefficient is the same and all other variables are constant. Variables effecting the coefficient include temperature, cable stiffness, cable jacket type, conduit type, lubricant, and, potentially, increasing conduit fill levels. We call the calculated value an "effective" coefficient of friction.

To isolate on the conduit fill variable and eliminate the jacket and conduit variables in the coefficient of friction, we used cable with a common jacket type with four different diameters. The conduit came from the same reel. Lightweight multifiber premises cable with a soft PVC jacket was pulled into a flexible, corrugated PVC innerduct. The cable was pulled over a series of days in the same week to minimize differences in ambient conditions. As conduit fill is varied, any differences measured in the "effective" friction coefficient should be the direct effect of the fill itself.

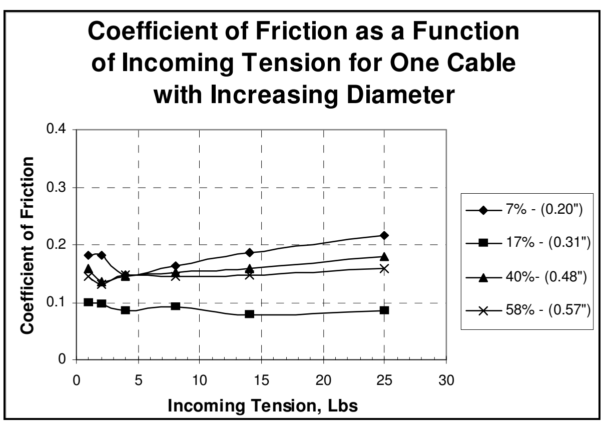
Lubricated Versus Unlubricated

The PVC cables tested had an unlubricated coefficient of friction in the 0.5 to 0.8 range. This produced pulling tensions above 300 lbs, abrading the jacket and destroying the smaller cables. A specialty pulling lubricant made for premises cable lowered the coefficient of friction to values in the 0.15 to 0.21 range. This produced tensions under 100 lbs in most cases. To get any data then, it was necessary to run all the tests on well-lubricated cables and cable bundles. Such lubrication would be an ordinary part of field installations anyway.

Single Cables

Graph 3 plots effective coefficient of friction against incoming tension for pulls with a single cable of increasing diameter. The cables ranged from 6-fiber with an outside diameter of 0.2 inch to 36-fiber with an outside diameter of 0.57 inch. Each cable was pulled into corrugated innerduct with an inside diameter of 0.75 inch to give cable fill volumes of 7 to 58 percent.

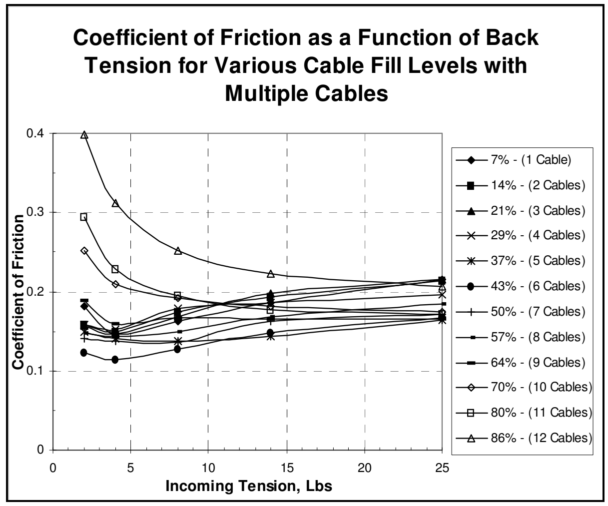
Graph 3 shows no significant increases in effective coefficient of friction with increasing cable fill volumes. In fact, the 0.31 inch diameter cable pulls at lower tensions than all the others. We believe this reflects differences in cable jacket and construction. Remember when studying this data that friction coefficients in the 0.15 to 0.2 level are low and make the cable "installable". Friction coefficients in the 0.4 to 0.8 range increase tension dramatically and make this cable difficult to pull. The graph indicates that single cable pulls with up to 58% fill do not show any significant increase in tension. We were limited in the cables available for this study. However, in similar tests with outside plant cables, we have seen similar behavior at up to 90% fill levels.



Graph 3

Multiple Cables

In the second test, only the smallest cable (6 fiber premises cable) with a diameter of 0.2 inch was used. After each pull, an additional 6 fiber cable was added to the bundle. The cables were pulled and the tension was measured as before. What we were doing was increasing the conduit fill. In the pulls, the cables tend to align themselves rather than twisting or kinking. Note that cable fills up to the 65% range had no noticeable effect on the pulling tensions (see Graph 4).



Graph 4

At some of the intermediate fills (4-7 cables), we actually see a decrease in pulling tensions with the additional cables. This may be due in part to the gravitational weight of the multiple cables counter-acting the set load on the other side of the pulley. It may also be due to the dissipation of sidewall force over more cable jacket surface area.

However, at fills of 70%, 80%, and 86%, we begin to see increasing friction coefficients at the lower back tensions. These are very high conduit fills: 12 cables represents the limit to what we could "stuff" into the conduit. The higher coefficient of friction values observed at the lower incoming tensions for fills above 70% are most likely the effect of "jamming" due to a lack of clearance. Presumably, when the differences disappear at higher incoming tensions, the cables are pulled hard enough to force close packing and eliminate any clearance problem. It is also possible that the cables were stretched or compressed to a different diameter or shape.

Chart 1 below shows the magnitude of the tension values measured in this testing. Increasing back tension as the cable is pulled through multiple bends requires higher pulling tensions. The pulling force at 4 lbs. incoming tension increases from the 10 lb. range for most of the cables to 20 - 40 lbs. for 10 - 12 cables.

# Cables	4 Lbs.	14 Lbs	25 Lbs.
1	11.8	54.6	122.1
2	12.0	57.9	120.4
3	11.7	59.7	121.9
4	12.3	54.9	106.2
5	11.1	40.0	83.4
6	9.3	41.3	84.9
7	10.9	46.4	88.5
8	11.5	47.9	96.8
9	12.9	47.1	84.5
10	18.7	53.0	89.7
11	21.4	51.8	87.4
12	39.3	72.0	113.5

Chart 1

Other Considerations

This study looks at the theoretical and physical limits to installing multiple cables within a conduit. Cable installations with fill levels of 65% or less will produce predictable pulling tensions.

However, this study did not measure any effect of compression from the packing weight of additional cables on top of cables. We did not test the integrity of the fiber after the pull was completed. Future studies may also examine the feasibility of pulling cable on top of cable when existing duct systems are being upgraded.

Conclusions

This work indicates that from an installation perspective, it seems reasonable to set cable fill maximums based on a clearance of 20% of the conduit diameter. Thus, the maximum fill for systems with more than six cables would be in the 65% range. The experimental data from the multiple cable pulls supports this fill with a friction coefficient increase at fill levels of 70% and above. This increases the maximum fill allowance from current standards. Percent fill levels could be set individually from one to five cables and then generalized for systems with multiple (more than six) cables.

References

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