

Prediction and Minimization of Fiber Optic Cable Pulling Tensions

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Abstract—This paper presents methods for the prediction and minimization of fiber optic cable pulling tension. Specialty products and installation procedures have been developed following field and laboratory research on cable tension as the fiber optic cable is pulled into conduit. Use of these products and procedures can significantly reduce the installed cost of fiber optic cable.

INTRODUCTION

TENSION on fiber optic cable during installation into conduit (or innerduct) is a primary concern for both the field installer and the cable system designer. Excessive tension, bending, or sidewall bearing pressure on fiber optic cables during installation can cause microfractures in the fibers. Microfractures significantly increase attenuation and reduce cable performance. Most fiber optic cable is designed to conservatively allow a maximum of 1800 N–4500 N (400 lbf–1000 lbf) of pulling tension during installation. On the other hand, it is desirable to install the longest lengths of uninterrupted cable possible. This reduces the number of costly splices, splice boxes, and the attenuation gain caused by these splices.

The use of fiber optic cable has shown significant growth over the last five years. Existing cable pulling products and lubrication methods, while effective for large, heavy, multi-pair copper cable, were found to be less effective for fiber optic cable placement.

There are a number of differences between fiber optic and conventional telephone or power cable pulling. First of all, fiber optic cable is lightweight, often less than 280 g/m (0.19 lb/ft) compared with more than 7.4 kg/m (5.0 lb/ft) for larger copper cable. Second, fiber optic cable is generally pulled much longer distances: 1500 m (5000 ft) or more versus 150 m–200 m (500 ft–700 ft) for larger cable. Fiber optic pulls are thus longer in duration than conventional cable pulls. Third, fiber optic cable has relatively low maximum tension specifications: 5800 N–14 500 N (400 lbf to 100 lbf) versus 36 kN to 145 kN (2500 lbf–10 000 lbf) for larger cable. Fourth, fiber optic cable is usually pulled into small conduit: 2.5 cm–3.1 cm (1.0 in–1.25 in) versus 8 cm–15 cm (3 in–6 in) conduit for larger communications cable. Finally, fiber optic cable is

usually pulled at higher speeds [25 cm/s–75 cm/s (50 ft/min–150 ft/min)] than copper cable [10 cm/s–25 cm/s (20 ft/min–50 ft/min)].

These differences result in the need for specialty products and procedures for fiber optic cable pulling. This paper reviews state of the art products and installation techniques for optimal fiber optic cable installation.

LUBRICATION AND INSTALLATION PRODUCTS

Field research demonstrates that certain products are necessary for effective fiber optic cable installation. Their desirable properties are summarized below.

Lubricants

The use of a specialty fiber optic cable pulling lubricant minimizes installation tension and allows maximum installed lengths of cable. While short straight fiber optic pulls can be made without a lubricant, an effective lubricant is an absolute necessity for multibend or long pulls. The lubricant is the major source of tension reduction and should be carefully selected. It should have the following properties.

Pourable Liquid: The lubricant should be a pourable liquid. Minimum fiber optic cable pulling tensions are obtained by preloading lubricant into the innerduct (conduit) and spreading it in front of the cable for the entire length of the run. Typical lubricant use quantities are 7.5 l (2 gal) per 300 m (1000 ft) of 3.2 cm (1.25 in) innerduct. On a 1500 m (5000 ft) pull, then 38 l (10 gal) of lubricant should be preloaded into the innerduct. This quantity of a flowable liquid can be easily pumped or poured (Fig. 1) into the innerduct. It is nearly impossible to preload appropriate quantities of gel or paste lubricants into a conduit [39 l (10 gal) occupies over 73 m (240 ft) of conduit]. It is also difficult to spread gel-type lubricants over long distances typical of fiber optic cable pulls. Liquid lubricants are easy to handle and apply with automatic lubrication equipment.

Superior Friction Reduction: The lubricant should provide the best friction reduction possible under all circumstances. There are two different types of friction that can occur during fiber optic cable pulling: hydrodynamic friction and boundary friction.

Hydrodynamic or "thick-film friction" (Fig. 2) occurs on low tension straight sections of conduit. Under these

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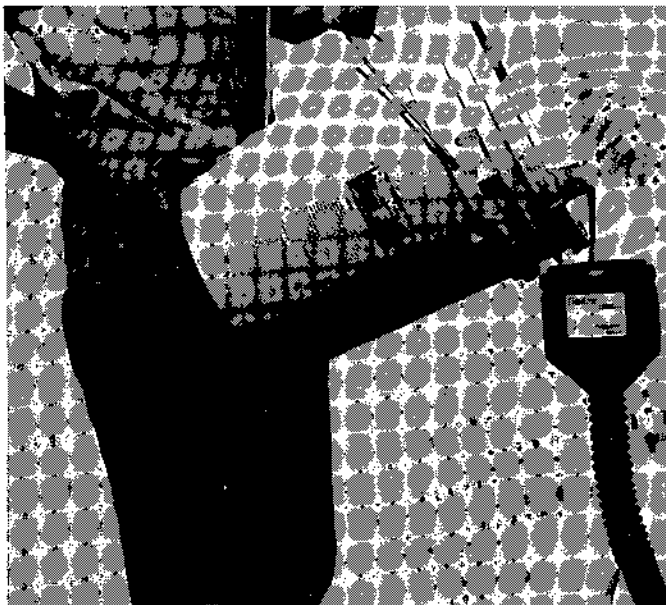


Fig. 1. Specialty liquid fiber optic lubricant can be easily poured into 3.2 cm (1.25 in) innerducts.

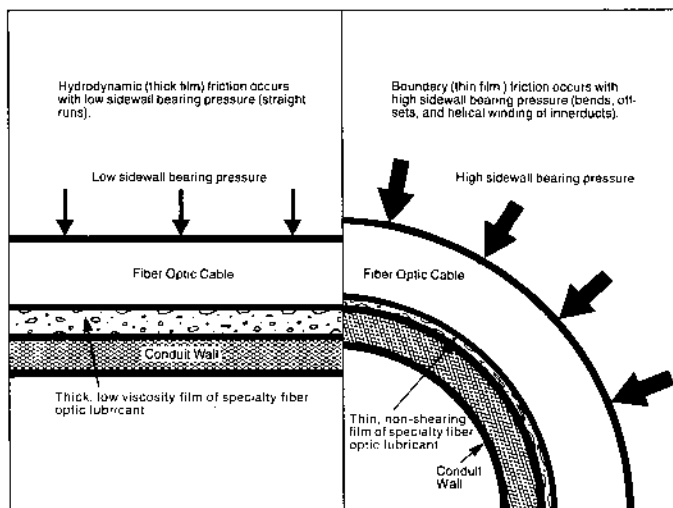


Fig. 2. A specialty fiber optic cable lubricant combines low viscous drag at low sidewall bearing pressure and nonshear character at high sidewall bearing pressure for optimal friction reduction.

conditions, the cable actually floats on a thick film of lubricant. For this type of friction, field and laboratory measurements show that high-viscosity gel lubricants actually add to cable tension through the lubricant's internal shear strength. Low-viscosity liquid polymer lubricants, on the other hand, allow the cable to "float" and thus show the lowest "thick film" friction (typical of short straight pulls).

The lubricant must also provide superior boundary or "thin-film" friction. Boundary friction occurs when the sidewall bearing pressure (normal pressure) between the cable and conduit is high. These conditions exist around bends and in high-tension straight sections. Under high sidewall bearing pressure, lubricants get squeezed into a thin film (Fig. 2) and many break down and lose effective-

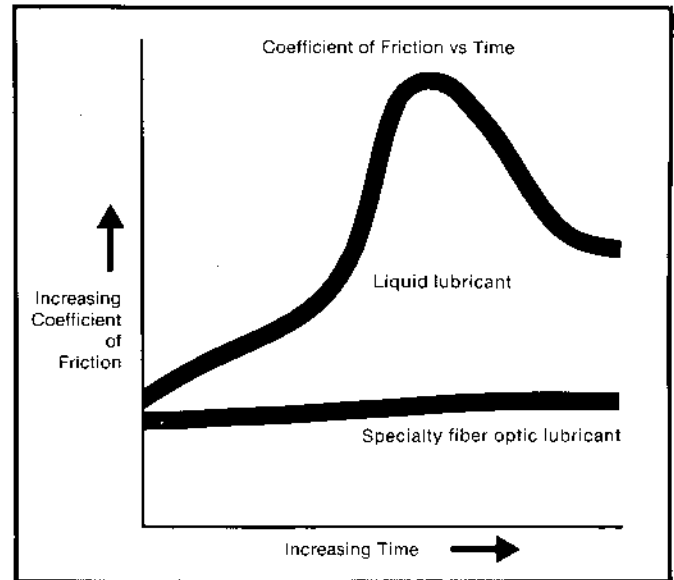


Fig. 3. A plot of coefficient of friction versus time shows the superior nondrying performance of the specialty fiber optic cable lubricant.

ness. A specially formulated fiber optic *liquid* lubricant has been developed to provide superior friction reduction under high sidewall bearing pressure. This results in maximum reduction of both types of friction and overall superior performance for all types of fiber optic cable pulling.

Friction performance of cable lubricants can be measured according to the procedure described in [1]. Hydrodynamic and boundary-measured coefficients of friction should be less than 0.16 for optimal field performance.

Slow Drying and Slippery Residue: In long distance fiber optic cable pulling, there is a large surface area of cable jacket exposed for a small volume of lubricant used. This promotes drying of evaporating lubricants. This drying is accelerated by the continual rubbing of the cable on the duct. Fig. 3 shows the friction performance of two liquid lubricants drying over time. Note the specially-formulated fiber optic lubricant remains effective for an indefinite period. The other lubricant dries and becomes tacky while pulling over long distances. While stopping a cable pull is not recommended, sometimes it is unavoidable. For these reasons, the lubricant chosen should continue to lubricate even after its water base has evaporated.

The drying performance of a lubricant can be measured as a function of time using the methods described in [1]. The dried friction coefficients should not exceed 150 percent of the "wet" coefficients.

Coatability: The lubricant should coat onto the cable jacket completely and stay coated indefinitely. A number of lubricants do not stay completely coated on fiber optic cable. They tend to nonwet on the plastic cable jacket. In Fig. 4, on the left, a specially compounded fiber optic lubricant is coated on cable, with a contrasting lubricant on the right. Note that within two minutes of coating both lubricants, one lubricant (the right-hand side) has non-wetted and dripped off, while the specially-compounded fiber optic lubricant (the left-hand side) has not.

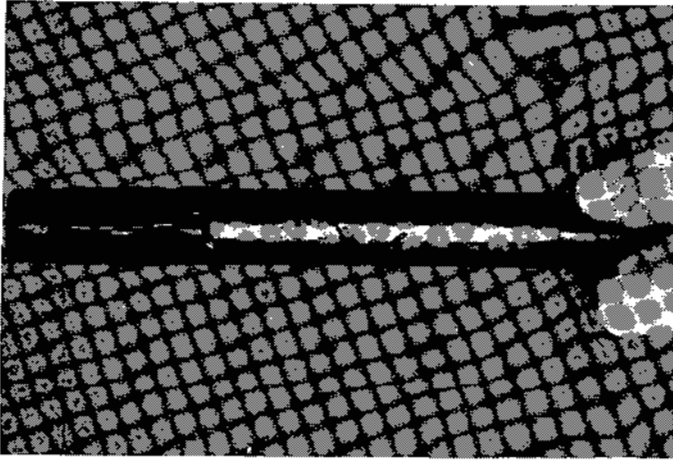


Fig. 4. Note the even coat of the specially engineered fiber optic cable lubricant on the left versus the "beading up" of conventional liquid lubricants.

Coating character is very important when it comes to fiber optic cable pulling. Because it is lightweight, fiber optic cable often rubs on the top and the sides of a long duct system, even in "straight" conduits. The cable should be completely covered with lubricant at all points of cable/conduit contact for optimal friction reduction.

Coatability can be simply measured by applying lubricant to the entire surface of a cable and observing it with time.

Compatibility: The lubricant should be compatible with the fiber optic cable jacket and conduit material. It should not stress crack low-density polyethylene and should be safe to handle and nontoxic. Check with the cable manufacturer for specific approval.

Lubrication Equipment

Application of lubricant by hand results in inconsistent and often inadequate lubrication. Because of the high pulling speeds [25 cm/s–75 cm/s (50 ft/min–150 ft/min)] of fiber optic cable pulling, it is nearly impossible to apply lubricant thoroughly to the cable by hand. Automatic lubricant applicators are the most practical way to apply lubricant evenly to the fiber optic cable as it enters the conduit.

Typically, automatic applicators are wraparound devices, where the cable passes through a lubricant reservoir. The device applies lubricant to the entire cable jacket surface with no waste or mess. Fig. 5 shows a specially developed gravity feed applicator that both cleans and lubricates the cable as it is pulled.

Hand-operated lubricant pumps are used to preload quantities of lubricant into the innerduct before the pull. Fig. 6 shows a pump with a large stroke volume for quick application. A seal-off adapter on the hose end prevents lubricant backflow from the innerduct.

Sponge rubber spreader devices are used to spread lubricant throughout the entire innerduct system. This insures lubrication at all points of cable/conduit contact during pulling. Fig. 7 shows an available cylindrical foam rubber

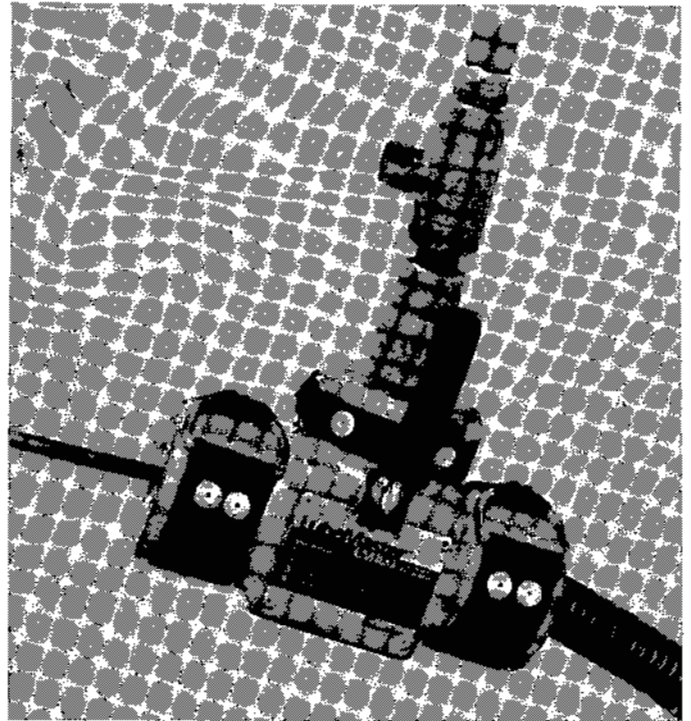


Fig. 5. A lubricant applicator with gravity feed system is used to clean and lubricate fiber optic cable as it enters the conduit.

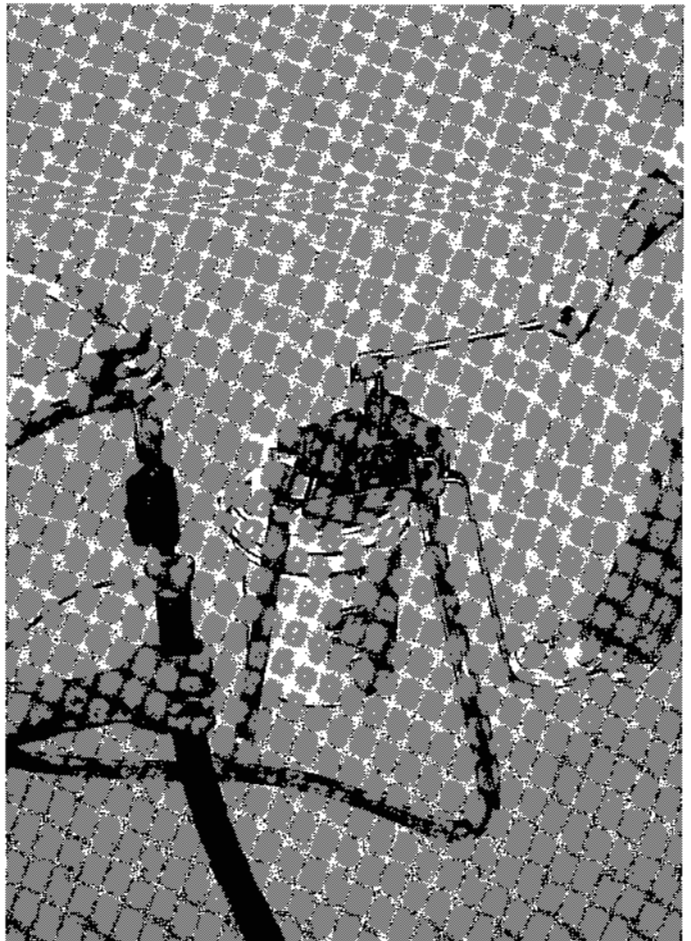


Fig. 6. Lubricant pumps with large stroke volumes are used to preload lubricant into the conduit.

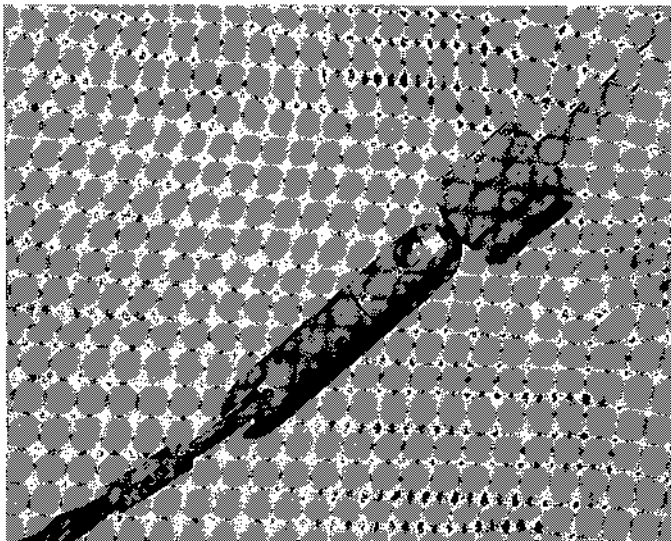


Fig. 7. Sponge rubber spreaders with fluted sides are used to evenly distribute lubricant throughout the conduit system.

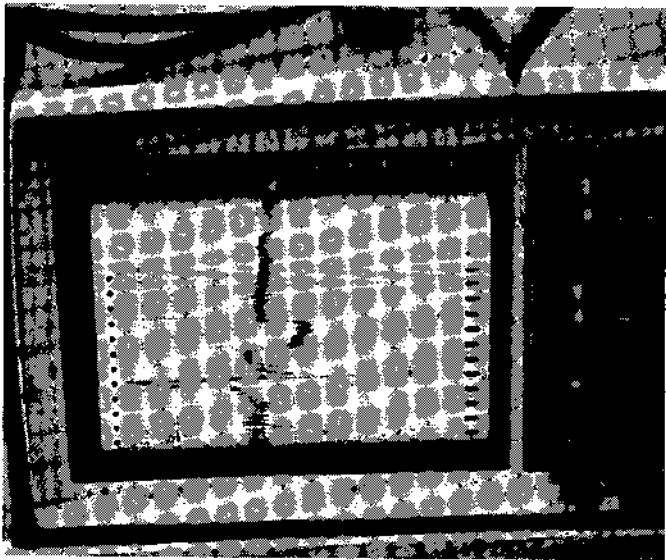


Fig. 8. Visual readout of the cable tension during installation helps the operator maintain acceptable tension.

spreader with longitudinal flutes. It deposits a metered amount of lubricant throughout the duct.

Installation Equipment

Fiber optic cable pullers should be of high quality. They normally have adjustable speed control for gradual start-ups, easy stops, and optimum pulling speed.

Fiber optic cable pullers should have tension monitoring capability with an automatic shut-off. This shut-off prevents the puller from pulling cable above the maximum-allowed tension. Visual readout and/or printout of the tension is helpful to the puller operator (Fig. 8).

The winch line selected should be lightweight and non-stretch. Stretchy winch ropes can cause surging which can result in damage to the cable.



Fiber Optic Cable Can Rub on All Sides of Conduit.

Fig. 9. Plastic innerduct often retains some "helical set" when pulled into a conduit, creating a series of gently sweeping bends on seemingly straight conduit sections.

Procedure

1) The first step is to preplan the cable pull. Computer programs [2] contain the tension equations [3] and are easy to use. These programs require entry of the specific conduit and cable data, along with coefficient of friction information. They can provide an accurate estimate of the cable tension. Easy adjustment of the conduit system parameters allow the length of the pull to be maximized.

"Effective" coefficients of friction should be obtained by taking actual field pulling tensions and back-calculating. This back-calculation is also performed by the computer program described above. Laboratory measured coefficients of friction, while accurate, have shown limited value as predictors of actual tensions unless properly related to the specific job (conduit, cable jacket hardness, and environment).

A major consideration in the ease of fiber optic cable pulling is the condition and configuration of the innerduct. Because innerduct is supplied on reels, it tends to retain some of its "helical set" when pulled into a conduit (Fig. 9). This creates a series of gentle sweeping bends on seemingly straight conduit sections. This increases cable tension. Other factors include dirt in the conduit, lubrication effectiveness, and pulling practices. All of these field variables are included when an "effective" coefficient of friction is calculated. Alternative methods to tension calculations made with an "effective" coefficient of friction have been studied and are discussed in [4].

2) Calculate the quantity of lubricant required for each pull by using the following equation:

$$Q = 0.0015 \times L \times D \quad \text{Metric} \quad Q = 0.0073 \times L \times D$$

where

Q	Quantity required in gallons.	Q	liters.
L	Length of conduit in feet.	L	meters.
D	Diameter of conduit in inches.	D	centimeters.

The quantity calculated is the average amount required for a straight pull into newer conduit. Older ducts, pulls with several bends, or pulls into corrugated conduit require more lubricant. These calculations can be reduced to tables for easy field use (see Table I).

3) Before hooking up the winch rope or pulling tape to the pulling eye or swivel, insert the winch line through a proper-sized spreader sponge or swab. A properly-sized

TABLE I
AVERAGE LUBRICANT QUANTITY REQUIRED

Length of Pull (Feet)	Conduit I.D.											
	1"			1.25"			1.5"			2"		
	Total Amt.	Lube In Conduit	Lube On Cable	Total Amt.	Lube In Conduit	Lube On Cable	Total Amt.	Lube In Conduit	Lube On Cable	Total Amt.	Lube In Conduit	Lube On Cable
500	.75	.50	.25	.94	.62	.31	1.1	.75	.37	1.5	1.0	.50
1,000	1.5	1.0	.50	1.9	1.2	.62	2.2	1.5	.75	3.0	2.0	1.0
1,500	2.2	1.5	.75	2.8	1.9	.94	3.4	2.2	1.1	4.5	3.0	1.5
2,000	3.0	2.0	1.0	3.7	2.5	1.2	4.5	3.0	1.5	6.0	4.0	2.0
2,500	3.7	2.5	1.2	4.7	3.1	1.6	5.6	3.7	1.9	7.5	5.0	2.5
3,000	4.5	3.0	1.5	5.6	3.7	1.9	6.7	4.5	2.2	9.0	6.0	3.0
3,500	5.2	3.5	1.7	6.6	4.4	2.2	7.9	5.2	2.6	10.5	7.0	3.5
4,000	6.0	4.0	2.0	7.5	5.0	2.5	9.0	6.0	3.0	12.0	8.0	4.0
4,500	6.7	4.5	2.2	8.4	5.6	2.8	10.1	6.7	3.4	13.5	9.0	4.5
5,000	7.5	5.0	2.5	9.4	6.2	3.1	11.2	7.5	3.7	15.0	10.0	5.0
5,500	8.2	5.5	2.7	10.3	6.9	3.4	12.4	8.2	4.1	16.5	11.0	5.5
6,000	9.0	6.0	3.0	11.2	7.5	3.7	13.5	9.0	4.5	18.0	12.0	6.0
6,500	9.7	6.5	3.2	12.2	8.1	4.1	14.6	9.7	4.9	19.5	13.0	6.5
7,000	10.5	7.0	3.5	13.1	8.7	4.4	15.8	10.5	5.2	21.0	14.0	7.0

*Double the lubricant quantity for corrugated innerducts.

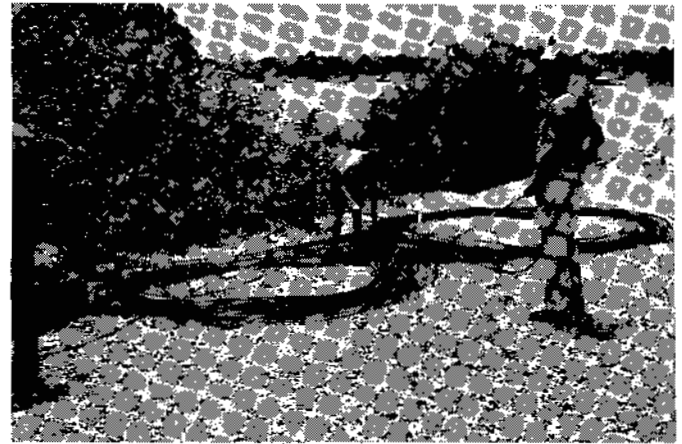


Fig. 10. Cable is placed in a "figure-eight" pattern on the ground to enable longer uninterrupted lengths of installed fiber optic cable.

spreader sponge will fit snugly inside the innerduct. The rope can then be attached to the swivel or cable eye as usual.

4) Preload two-thirds of the lubricant into the innerduct. For short pulls requiring the preloading of less than 7 l (2 gal) of lubricant, use a funnel and pour the recommended quantity of lubricant directly into the conduit entrance.

For longer pulls requiring the preloading of more than 7 l (2 gal) of lubricant, use a pump to preload the lubricant into the conduit.

5) Pull the winch rope, swivel and front end of the cable (all the bulges) into the conduit. Slip a wraparound lubricant applicator around the cable and onto the end of the conduit. The lubricant can be gravity fed to the applicator from an 18 l (5 gal) pail. Start the pull. Pull quickly and avoid stopping. Kinetic friction (sliding) is less than static (starting) friction.

6) For pulls with intermediate access points, proportion the lubricant among the segments of the run. Follow the same procedure described above except treat each manhole as the beginning/end of a run.

The use of this procedure will result in lubrication at all points of rub for maximum friction and tension reduction. However, there will be limits to the length of pull no matter how effective the lubrication is. Two options for longer, uninterrupted lengths are possible: backfeeding (figure-eighting) and intermediate tension assist.

During backfeeding, cable is pulled in two directions from an intermediate manhole. Typically, one direction is pulled, then enough cable for the rest of the pull is unwrapped and laid on the ground in a figure-eight pattern. It is then pulled in the opposite direction.

Figure-eighting is similar except that excess cable is pulled all the way through the conduit, then laid on the ground in a figure-eight (Fig. 10). The excess is then pulled through the next section(s) of conduit. This can be repeated many times and theoretically result in unlimited, unbroken lengths of fiber optic cable in conduit.

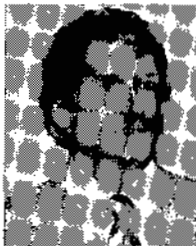
Mid-assist pulling is the use of a cable puller (usually specially modified) at an access point to power the tension on the cable to near zero. Although the pull is done continuously, it effectively represents a number of shorter pulls. Often, mid-assist by hand can lower cable tension enough to make a marginal pull.

CONCLUSION

Conventional methods of lubrication and installation are not effective for fiber optic cable installation into innerduct. Specialty products and procedures, along with careful planning, can enable significantly longer installations of fiber optic cable, resulting in a major reduction in cost.

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