Performance Aspects of a Novel Two-Rod, Dielectric Sheath Design for Central Tube Cables

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Abstract

Designs for dielectric cables include strength members comprised of multiple packages of glass and/or synthetic fibers, coupled together with varying amounts of crosslinked resin. These composite reinforcements cannot rival the mechanical properties per unit area nor the cost per unit length of their metallic counterparts. For these reasons, fabrication of dielectric cables that are cost-effective, compact, and sufficiently robust is a challenge for the cable designer.

This paper discusses the design and performance of a new central tube, dielectric cable sheath that employs two linearly applied composite rods. The new sheath design has been applied to a wide variety of core structures, including, tube-in-tube, filled ribbon and dry ribbon cores. The composite rods utilize novel coatings that provide optimized coupling between the rods and the cable jacket. This coupling is quantified through laboratory measurements of adhesion between rods and the cable jacket. Adhesion results are also compared with adhesion performance of rods that use other types of coatings.

Optimized coupling between the rods and the outer jacket results in excellent behavior in tensile, compressive and twisting deformations, as illustrated by cable-level mechanical tests. Most importantly, the new sheath design provides substantial improvements in installation performance. We report the results of a rigorous series of installation simulation tests, comparing results for this sheath design to alternate dielectric sheath designs.

Keywords

Outside Plant Cable; strength member; dielectric; fiber optic cable; coatings; fiber reinforced polymer rods (FRP); bending stiffness.

1. Introduction

In Outside Plant (OSP) fiber optic cable designs, product performance depends strongly on the cable strength system. The optical fibers housed within the cable are inherently fragile, and can fracture at low strains under tensile, compressive or torsional loading. In addition, optical fibers are subject to attenuation losses when bent. Strength members protect the optical fibers from loads encountered during cable manufacturing, installation and service.

For over ten years, the performance and reliability of central tube cables with linear metallic sheaths [1] has been demonstrated in the field. In the linear metallic design, the central core tube is wrapped by corrugated electrolytically chrome-coated steel (ECCS) armor. Reinforcement is provided by two linearly applied steel music wires that are embedded in the jacket. The strength, robustness and affordability of this metallic cable design cannot be matched. However, metallic designs are not suitable in areas where high lightning activity is prevalent, or in regions where metal corrosion could be a problem. In these situations, a dielectric cable design is the better solution. Dielectric cables are typically reinforced with nonmetallic materials, such as rigid fiber-reinforced polymer (FRP) rods, fiberglass or aramid yarns, or semi-flexible glass rovings.

One well-known family of dielectric central tube cable designs utilizes helically applied reinforcements [2][3]. These constructions, commonly referred to as "crossply" designs, typically contain one or more layers of rigid FRP rods, as well as rovings or yarns. Dielectric crossply central tube cable designs are flexible and compact, and typically have very high fiber packing density. Therefore, crossply cables are especially ideal for cable routes that use small ducts, including new right-of-ways that use "microducts" [4]. However, crossply designs can have relatively high raw materials costs, due to the use of many individual small reinforcements. In addition, these designs typically rely on incompressible cable gels to provide compression resistance. Therefore, dielectric crossply sheaths may be inappropriate for new types of reduced-gel central core cable designs [5].

Dielectric central tube cables with linearly applied strength members tend to be less expensive than crossply cables, and are typically easier to manufacture. However, these benefits can come at the cost of increased cable size, as the reinforcements in linear dielectric central core cables are typically much larger than the reinforcements in crossply cables. In order to minimize cable size and cost, linear dielectric central core cables often contain a combination of rigid FRP rods, which provide tensile and compressive stiffness, and less expensive semi-flexible rovings, which provide only tensile reinforcement. A common design uses six reinforcing members: two large rigid FRP rods, and four large semi-flexible rovings, which we will refer to as the "six-member design". Figure 1 is a schematic of the dielectric, two-rod/four-roving sheath design, detailing the individual components; a picture of a typical cable is shown in Figure 2. The two linear rigid glass/epoxy rods are diametrically opposite one another, and are located on the neutral axis of the cable. Rovings are located above and below the rods. In a typical six-member design, the reinforcements are designed to adhere strongly to the cable jacket, providing for a robust cable. Unfortunately, the high adhesion between the reinforcements and the jacket is also the source of undesirable preferential bend behavior. Six-member dielectric central tube cables can typically only be bent easily in the direction perpendicular to the two rigid FRP rods. Despite their robustness, these cables can be difficult to handle and install in the field.

In this paper, we present the development of a new two-rod, linear dielectric central-core sheath with substantially reduced preferential bending. Components of the new two-rod sheath are shown in the schematic in Figure 3, and a photograph of a ribbon cable with a two-rod sheath is presented in Figure 4. This cable sheath was originally introduced for a new tube-in-tube cable design [6]. After further optimization, the design is now commercially available for tube-in-tube, gel-filled, and totally dry [7] cable designs. An outdoor/indoor, riser-rated version of the sheath is available with both gel-filled and dry ribbon cores.

This paper describes the design of new reinforcements for this application, as well as prove-in testing of the new sheath in laboratory and installation simulation tests. In section 2, we discuss development of reinforcements that bond to the cable jacket by "frictional adhesion". Section 3 reviews the cables available with the new two-rod sheath, and details the model two-rod and six-member cables manufactured for quantitative comparison of the two sheath designs. Section 4 provides a summary of experiments characterizing the tensile and bending performance of the two designs. Compared to the six-member design, the two-rod design has similar tensile performance. However, the new two-rod design exhibits significantly reduced preferential bending, due to the frictional adhesion between the rods and the cable jacket. Reduced preferential bending provides for improved field handling and installation performance, as discussed in Section 5. A detailed study presented in section 5 quantifies the excellent performance of the two-rod sheath in blowing installation. Additionally, a simple model presented in Section 5 describes how the improved performance of the two-rod cables can provide cable installers with significant savings in both time and cost.

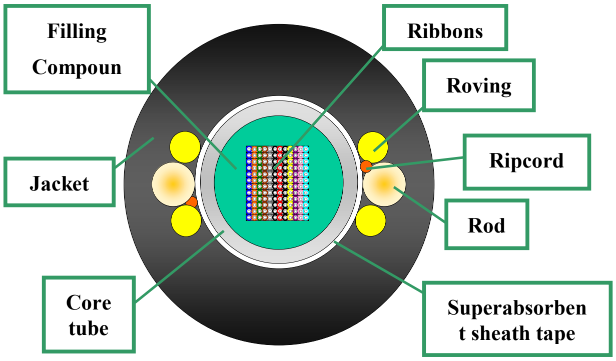

Figure 1 – Schematic of Six-Member Dielectric Central Tube Cable Design

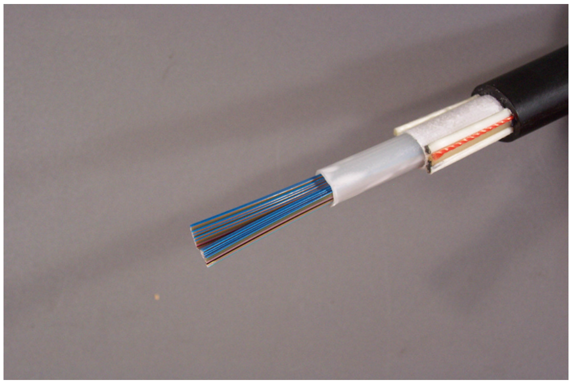

Figure 2 – Photograph of Six-Member Dielectric Central Tube Cable Design

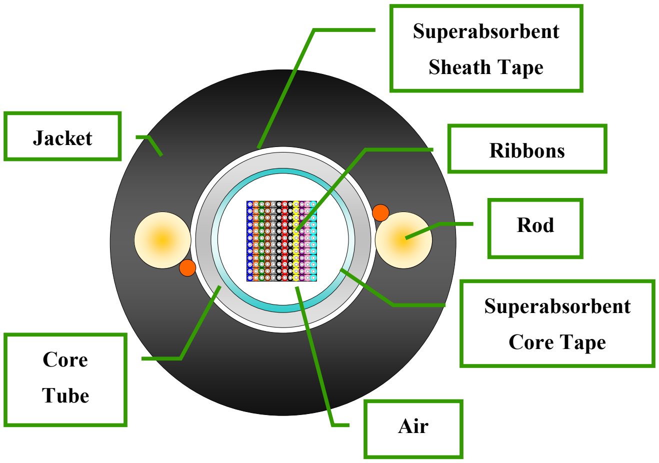

Figure 3 – Schematic of Two-Rod Dielectric Central Tube Cable Design

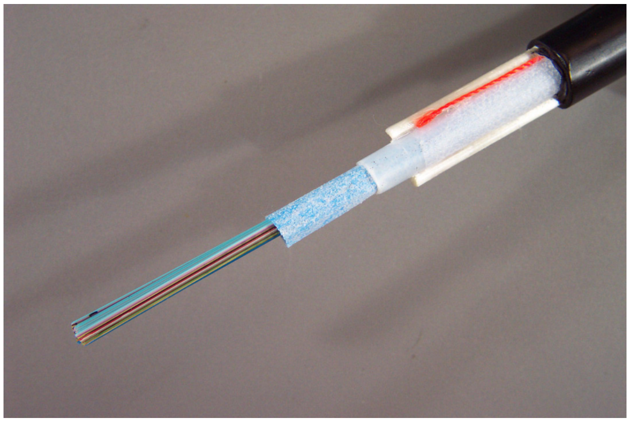

Figure 4 – Photograph of Two-Rod Dielectric Central Tube Cable Design

2. Reinforcement Design and Characterization

In order to develop a new linear dielectric sheath with reduced preferential bending, it was necessary to design and develop new cable reinforcements with sufficient tensile stiffness, compressive stiffness, and coupling to the cable jacket.

2.1 Design Goals for New Reinforcements

Although other components of a cable do have load-carrying capacity, the strength members provide most of the tensile stiffness of a cable sheath. For a two-rod design rated at 2700N (600 lb.), each rod should be capable of carrying a minimum load of 1380N (310 lb.) at 0.5% strain, with a preferred nominal load at 0.5% strain of at least 1560N (350 lb). In addition to having the necessary tensile and compressive stiffness, it is desirable for these FRP rods to be as compact as possible, to minimize the overall size of the cables.

In the standard six-member design, the FRP reinforcements are typically coated with a hot-melt adhesive. During jacketing extrusion, this coating melts and subsequently forms a strong adhesive bond with the jacket upon cooling. As a result, when a six-member dielectric cable is handled in the field, it exhibits a preferential bend. It is relatively easy to bend the cable in the plane perpendicular to the rigid FRP strength members. However, as shown below in Section 4.2, it is difficult to bend the cable in the plane parallel to the rigid rods.

To minimize preferential bend in an improved design, the rods must be able to relax locally when the cable is bent. However, the rods still must be able to couple sufficiently with the jacketing material and the rest of the cable to provide the necessary tensile performance. To balance these potentially conflicting needs, we set a goal of developing a new means of coupling the reinforcements to the sheath through "frictional coupling". Instead of forming an adhesive bond with the cable jacket, the desired reinforcements would couple to the jacket through a high coefficient of friction between the rod surface and the jacketing material. This would provide for reinforcement of the cable during application of tensile loads, while still allowing for local slippage of the rods in bending. In order to meet these goals, a new type of coating was needed: a material that does not melt when the jacketing material is extruded, but is still soft enough to exhibit high friction with the jacket.

2.2 Characterization of Candidate Reinforcements

Two different types of temperature-resistant materials were identified as candidates for the "frictional" coating: soft thermoplastics, and soft UV-cured materials. Samples of rigid rods coated with these types of materials were obtained from multiple manufacturers of rigid FRP reinforcements. Tests in our laboratory found that all of the materials met the minimum load-bearing target of 1380N (310 lb.) at 0.5% strain. All of the reinforcements had diameters smaller than 2.80 mm (0.110 in.).

In order to characterize adhesion of the rods to high-density polyethylene jacketing materials, we utilized a test method based on ASTM D1871, "*Adhesion of Single-Filament Steel Wire to Rubber*" [8]. Two 5.1 x 20.8 x 0.95 mm (2.0 x 8.0 x 0.38 in.) plaques of typical high-density polyethylene (HDPE) jacketing material are first prepared by compression molding. Then, multiple samples of a candidate FRP rod are compression-molded between the two plaques, such that a 5.1mm (2.0 in.) gauge length of each sample is encased in the plastic. Each sample is then individually pulled out of the plastic using a MTS ReNew electro-mechanical tensile testing machine, at a crosshead speed of 5.1 mm/min. (2.0 in./min.). For each sample, adhesion is quantified as the maximum pull-out force recorded during the test. For each of the candidate rods described below, at least five samples were tested.

After initial screening, we chose to focus on four candidate rods: one with a soft thermoplastic coating, and three with soft UV-curable coatings. These rods will be referred to as rods "A" through "D". Results of adhesion tests at 23°C are summarized below in Table 1. A standard rigid FRP rod, coated with a typical hot-melt adhesive, was included as a control. This rod will be referred to as rod "E". Despite the differences in coating material, the adhesion of rods A, B and C is similar, while the adhesion of rod D is substantially higher. However, the adhesion of all of the candidate rods is much less than that of rod E, the control material. Each candidate in the A-D series was found to meet the design goal of coupling to the jacketing material through frictional adhesion.

Table 1 – Adhesion of reinforcements to HDPE at 23°C

Rod	Coating Type	Adhesion at 23°C, N (lb.)	Standard Deviation, N (lb.)
A	Soft thermoplastic	270 (61)	31 (7.0)
B	Soft UV-cured	270 (61)	30 (6.8)
C	Soft UV-cured	250 (57)	35 (7.9)
D	Soft UV-cured	630 (140)	78 (18)
E	Hot melt adhesive	1250 (280)	91 (21)

During field service, outside plant cables jacketed with carbon-black-filled polyethylene can frequently reach temperatures of 50°C (122°F) or higher. These high temperatures could conceivably affect coupling between the reinforcements and the cable jacket. With standard hot-melt adhesive coatings, a strong bond is maintained between the rod and jacketing material at any temperature below the melting point of the adhesive. For the new "frictional" coatings, the coupling between the cable jacket and the reinforcements is designed to be less than that provided by hot melt coatings. In order to characterize the performance of the new coatings at elevated temperatures, we repeated the adhesion test described above at a temperature of 55°C (131°F). For these experiments, the MTS ReNew electromechanical tensile testing machine was fitted with a forced-air environmental chamber equipped with a calibrated thermometer. Samples were allowed to condition at 55°C for 5 minutes before the test. Results of the tests for rods A-D are given below in Table 2.

For all of the candidate rods, adhesion to the jacketing material decreases at high temperature. However, upon heating to 55°C, the adhesion of rod "A", with the soft thermoplastic coating, is much less than the adhesion of any of the rods coated with soft UV-curable materials. Since Rod D exhibits the highest adhesion to standard HDPE jacketing at elevated temperature, we selected this material as the best candidate for further development.

Table 2 – Adhesion of reinforcements to HDPE at 55°C

Rod	Coating Type	Adhesion at 55°C N (lb.)	Standard Deviation, N (lb.)
A	Soft thermoplastic	64 (14)	9.8 (2.2)
B	Soft UV-cured	150 (34)	10 (2.3)
C	Soft UV-cured	210 (47)	38 (8.5)
D	Soft UV-cured	280 (64)	22 (4.9)

The balance of the paper focuses on characterization and prove-in of two-rod cables using rod D, including laboratory tests of cable mechanical properties and installation simulation tests. At each step, we compare performance this new two-rod cable design to that of the standard six-member linear dielectric design.

3. Cable Designs

The six-member linear dielectric design has been commercially available for over 10 years. Gel-filled ribbon cores are currently offered in two different sizes and accommodate fiber counts ranging from 12 to 216. The new two-rod linear dielectric sheath is available in three different cable sizes, also accommodating fiber counts from 12 to 216. The new sheath design is available with multiple core configurations: tube-in-tube [4] a gel-filled ribbon core, or a new dry ribbon core [7]. Both two-rod and six-member sheath designs have a tensile rating of 2700N. Table 3 summarizes the configurations and fiber counts of commercially available linear dielectric cables.

For quantitative comparisons of the performance of the new two-rod linear dielectric design to the six-member design, the study will focus on model, central tube cables with 216-fiber ribbon cores. A series of four prototype 18.5 mm (0.710 in.) 216-fiber ribbon cables were manufactured for qualification testing, as summarized in Table 4. These included one cable with "live" fibers for optical, mechanical, and installation-simulation testing, and three cables with "filler" fibers that were only used for limited mechanical and installation-simulation tests. Two of the cables had gel-filled cores, while the other two cables had a new totally dry central-core design that is described in a companion paper [7]. Taken together, these four cables allow examination of the effects of sheath design (two-rod vs. six-member) and cable weight (gel-filled vs. dry).

Table 3 – Construction and fiber counts of commercially available dielectric cables

Cable Construction	Dielectric Strength Member System	Fiber Count	Core OD mm (in)	Cable OD mm (in)
Dry 12-fiber ribbon core	Two rod	12 to 48	6.0 (0.236)	13.0 (0.510)
Tube-in-tube core (12 fiber tubes)	Two rods	12 to 48	6.0 (0.236)	13.0 (0.510)
Dry 12-fiber ribbon core	Two rods	60 to 144	7.9 (0.310)	15.5 (0.610)
Gel-filled 12-fiber ribbon core	Six members or two rods	12 to 144	7.9 (0.310)	15.5 (0.610)
Tube-in-tube core (12 fiber tubes)	Two rods	48 to 84	7.9 (0.310)	15.5 (0.610)
Dry 12-fiber ribbon core	Two rod	156 to 216	10.4 (0.410)	18.0 (0.710)
Gel-filled 12-fiber ribbon core	Six members or two rods	156 to 216	10.4 (0.410)	18.0 (0.710)
Tube-in-tube core (12 fiber tubes	Two rods	96 to 144	10.4 (0.410)	18.0 (0.710)

Table 4 – Prototype cables manufactured for qualification testing

Cable	Cable Diameter, mm (in)	Reinforcement System	Core Design	Fiber Count	Fiber Type
1	18.0 (0.710)	Six-member	Gel-filled	216	Filler
2	18.0 (0.710)	Six-member	Dry	216	Filler
3	18.0 (0.710)	Two-rod	Gel-filled	216	Filler
4	18.0 (0.710)	Two-rod	Dry	216	Live

4. Cable Mechanical Performance

4.1 Tensile Performance

The Automated Long Gauge-Length Tensile Tester (ALTET) is a device developed in our laboratory for mechanical tests of long-length cable samples. In this device, 4.6 m (15.0 ft) lengths of cable are mounted horizontally, held by flexible wire mesh grips. Tensile force is supplied by a motor and screw jack system, and strain is measured by a pair of independently mounted optical encoders 1.80m (71 in.) apart in the center of the device. This apparatus allows for accurate testing of long lengths of cable independent of end effects, and as such is an excellent simulation of field loading conditions.

To illustrate the tensile performance of the new cable design, we compare the ALTET test performance of two 216-fiber cables: a grease-filled cable with a standard six-member sheath (Cable 1), and a dry cable with the new two-rod sheath (Cable 4). 4.6 m (15.0 ft) lengths of each cable were loaded at a speed of 0.43 m/minute (1.4 ft/minute). Strain vs. load curves for each cable are shown below in Figure 5. For clarity, only half of the actual data points collected are plotted in Figure 5. The tensile stiffness of each cable may be calculated by a linear regression fit to the data between 0.25% and 0.5% strain. Results of these fits are shown below in Table 5. The data indicate that the tensile stiffness of the two-rod cable is slightly less than that of the six-member design. However, based on the data, the stiffness of each cable is more than sufficient to carry a 2700N (600 lb) load at 0.5% strain, as required by the Telcordia GR-20 standard [9] in North America

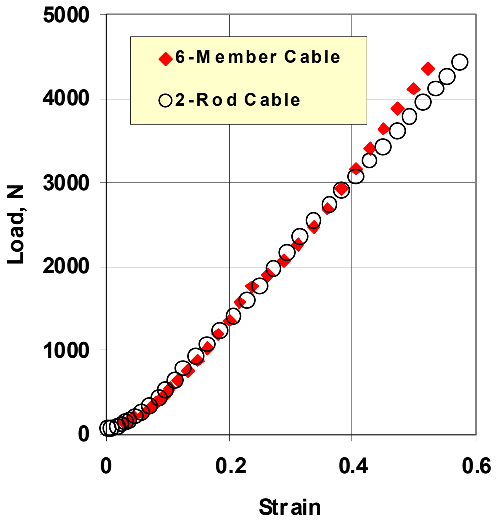

Figure 5 – Load versus Strain Behavior in ALTET Tensile Testing of Cables

Table 5. Tensile stiffness of representative 216-fiber dielectric cables

Cable Number	Cable Construction	Tensile Stiffness, N/% strain (lb./% strain)
1	Six-member, grease-filled	9700 (2200)
4	Two-rod, dry core	8200 (1800)

4.2 Bending Stiffness

A three-point bend test was used to compare the bending stiffness of the six-member and two-rod linear dielectric designs. The test was loosely modeled after ASTM D 790-98 "*Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*" [10]. A three-point flexure test jig was designed and machined for this application. As required in this specification, the jig bearing edges have radii less than or equal to 1.6 times the cable diameter. The fixture is adjustable, such that lengths of cable ranging from 2 to 24 inches may be tested.

A 29.7 cm (11.0 in.) sample length was used for these tests. For this length, a flexural deflection of approximately 50.8mm (2 in) will closely model the minimum bending radius of these cable designs. All testing was performed on a MTS ReNew electro-mechanical test system at room temperature, approximately 23ºC (73ºF). Special care was taken to assure the cable sample was completely straight before beginning each test. Samples were bent at a speed of 5 mm (0.2in) per minute, and each test was run long enough to allow for at least 50.8 mm (2 in.) displacement. Using an external displacement gauge, values of load and displacement were measured as the cable was bent. Tests were performed for cables with the flexural loading applied both perpendicular and parallel to the plane of the rods, as shown in Figure 6.

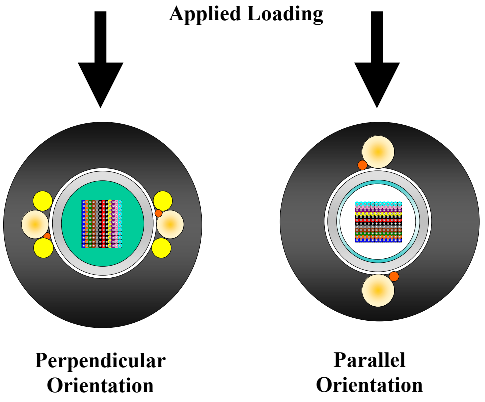

Figure 6 – Schematic of Sample Orientation in Bending Stiffness Tests

The general equation describing the small-strain deflection of a beam constructed from a linear elastic material [11] is:

$$B = \left[\frac{d^3}{48}\right]\left[\frac{F}{\Delta Y}\right] \qquad (1)$$

where the variables are defined as :

$B \equiv$ bending stiffness (N·m² or lb-in^2)
$D \equiv$ distance between supporting points (m or in)
$F \equiv$ Force needed to bend the cable over a distance ΔY (N or lb)
$\Delta Y \equiv$ displacement (m or ft)

For purposes of evaluating cable bending, this equation may be re-expressed in terms of specific variables:

$$EI = \left[\frac{l^3}{48}\right]\left[\frac{P}{y}\right] \qquad (2)$$

where:

$EI \equiv$ bending stiffness (N·m² or lb-in^2)
$l \equiv$ span length (between supporting points) (m or in)
$P \equiv$ Load needed to bend the cable over a distance y (N or lb)
$y \equiv$ displacement (m or ft)

Using the relationship in Equation 2, the bending stiffness may be determined from a tangential curve fit to a plot of load vs. displacement. This method provides a reasonable quantitative assessment of a cable's bending stiffness, especially for cables with a non-linear response. The bending stiffness, *EI*, was consequently calculated over a range of corresponding load (ΔP) and displacement (Δy) values.

Results of curve fits to flexural load-displacement curves are shown in Table 6. When the cables are loaded perpendicular to the plane of the strength members, there is no significant difference in the bending stiffness of the two designs. For bending parallel to the plane of the rods, the behavior of the two designs is quite different. The bending stiffness of the six-member cable in the "parallel" orientation is approximately 430% greater than the bending stiffness in the "perpendicular" orientation. As a result, the six-member design exhibits strong preferential bending behavior. In contrast, for the two-rod

Table 6 - Bending stiffness results

Cable Number	Cable Strength System	Rod orientation to applied loading	Bending Stiffness (N-m^2 [lb-in^2])
2	Six Member	Perpendicular	1.02 (356)
4	Two Rod	Perpendicular	1.04 (364)
2	Six Member	Parallel	4.43 (1543)
4	Two Rod	Parallel	1.28 (446)

design, the bending stiffness in the "parallel" orientation is only about 25% higher than that in the "perpendicular" orientation. Therefore, the new two-rod design does have a slight tendency towards preferential bending. However, compared to the six-member design, the new two-rod design exhibits dramatically reduced preferential bending.

This difference in bending behavior is directly related to the coating of the reinforcements in each design. In the six-member design, the hot-melt adhesive coatings rigidly bond the reinforcements to the jacketing. In the two-rod design, the "frictional adhesion" coating allows the rod to locally decouple from the sheath during bending. As a result, the rods can move locally to accommodate any bending deformation, reducing preferential bending substantially. When the bending deformation is removed, the new rods can re-couple with the jacket, due to the high friction with the cable jacket.

5. Installation Simulation Tests

5.1 Summary of Installation Simulation Tests

The installation performance of the new two-rod cable design was evaluated at OFS' installation simulation test facility in Chester, NJ. The testing emulates both standard and abusive field installation practices. This testing is not required by any standards body, although we find these tests are a valuable model of field installation performance. As part of the prove-in for the new two-rod sheath design, Cable 4 was subjected to a full battery of installation simulation tests, as described below in Table 7. Performance of in all of these tests was excellent.

A two-rod dielectric, 48-fiber, 13.0 mm (0.510 in.) diameter dry central tube ribbon cable has also been tested using these procedures. Detailed results of installation simulation tests for the 48-fiber cable are presented in a companion paper [7]; the results are typical of the performance for cables made using this new two-rod dielectric sheath design.

5.2 Installation Performance

As described above in Section 4.2, the new two-rod dielectric central core design exhibits much less preferential bending than the standard six-member design. This reduction in preferential bending substantially improves handling and installation. Compared to the six-member design, manipulation of the new two-rod cables in tight spaces such as manholes or handholes is easier. In underground duct installations, because of the reduction in preferential bend, the new two-rod cables can relax locally to accommodate bends or turns in the cable route. In pulling installations, the reduced weight and reduced preferential bend of the new dielectric dry core ribbon design [7] are expected to provide superior installation performance.

5.2.1 Performance in Blowing Installation

To illustrate the improved performance of the new two-rod design, we focus on the performance of six-member and two-rod cables in blowing installation tests. The cable blowing tests were performed in an underground conduit facility in Chester, NJ. The conduit run includes six manholes connected by 101.6 mm (4 in) diameter PVC conduit. The six manholes are joined together in a tortuous loop as shown in Figure 7. The outside perimeter of the conduit run is 435 m (1428 ft) long and includes ten 90° horizontal-plane bends.

Six innerducts are installed around the outside perimeter of the conduit run: three of 25.4 mm (1 in.) inner diameter, and three of 31.8 mm (1-¼ in.) inner diameter. The innerducts can be coupled in the second manhole (MH 2) to form as many as three continuous loops of innerduct. Access to the innerduct is provided at MH 2 via auxiliary 4-inch duct and surface mounted handholes. Short sections of innerduct are installed through the handholes and auxiliary duct to provide a cable path in and out of MH 2. The surface access is used to simplify cable installation and retrieval during the tests. The cable blowing tests were performed using a Sherman & Reilly, Inc. Hydraulic Superjet™. An Ingersoll-Rand P260 air compressor was used for the air supply. The tests were conducted in Dura- Line Corporation

Table 7 – Installation simulation tests for two-rod, 216-fiber, dry central tube ribbon cable

Test	Description
Initial attenuation measurement	Pre-test baseline
Pulling grip	Determine performance of pulling grips
Cable blowing	Determine cable blowing in underground duct
Underground placing	Determine cable behavior during underground placing
Tension/Bending	Pull cable around quadrant block and various sheaves
Capstan Assist	Determine performance on intermediate capstan assist winch
Aerial Coiling	Attenuation performance in coils
Direct Buried Plowing	Performance during plowing operation
Abusive Tests	Truck run-over, cable kinking
Final attenuation measurement	Comparison to baseline
Ultimate strength tests	Attenuation at ultimate tensile load
Sheath Dissection	Evaluate internal components for test-related damage
Ribbon Inspection	Evaluate ribbons for test-related damage

Silicore®[1] smooth-wall innerduct, and the innerduct was lubricated with Sherman & Reilly Cablejet Lube™.

The intent of the cable blowing tests was to compare the installation performance of the two different cable designs. Consequently, with the exception of the cable design, each test is performed under similar circumstances. A dry foam plug is first blown through the innerduct to remove any water or debris that may have accumulated during a previous test. This step also verifies the integrity of the innerduct and couplings. Next, the innerduct is pre-lubricated using manufacturer-recommended procedures and quantities of lubricant. Finally, the cable is always installed in a clockwise direction around the conduit run, and both ends of the innerduct are terminated in the handholes adjacent to MH 2.

The first installation test of a particular cable design is usually conducted using two continuous loops of innerduct. Two loops of innerduct provide a test bed that is 893 m (2930 ft.) in length (including the short sections of innerduct used to gain access to MH 2). If cable installation is successful, the cable is removed from the innerduct, and a third loop of innerduct is added. The third loop of innerduct provides a 1328 m (4358 ft.) long test bed. The cable-blowing test is then repeated. All of the installation tests included in this series were conducted using the 31.8 mm (1-¼ in.) diameter innerduct.

Table 8 displays a summary of the cable blowing trials for six-member and two-rod linear dielectric cables in the 1328 m (4358 ft.) test bed. In order to examine the effect of cable weight, we tested both designs with gel-filled and dry core ribbon constructions. The results in Table 8 clearly show that in all aspects the blowing performance of the two-rod design is superior to that of the six-member construction. For both filled and dry cables, the six-member design stalled, and failed to complete the experimental conduit run. The effect of weight is illustrated by the comparison between the dry and filled six-member cables: the dry cable blew approximately 80m farther, at a higher average velocity. In contrast, both dry and gel-filled two-rod cables completed the 1328m (4358ft) long test bed with no significant decrease in velocity. Based on these results, we were unable to differentiate the blowing performance of the dry and filled two-rod cables; a longer test bed would be needed to determine if these cables perform differently.

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[1] Silicore is a registered trademark of Dura-Line Corporation.

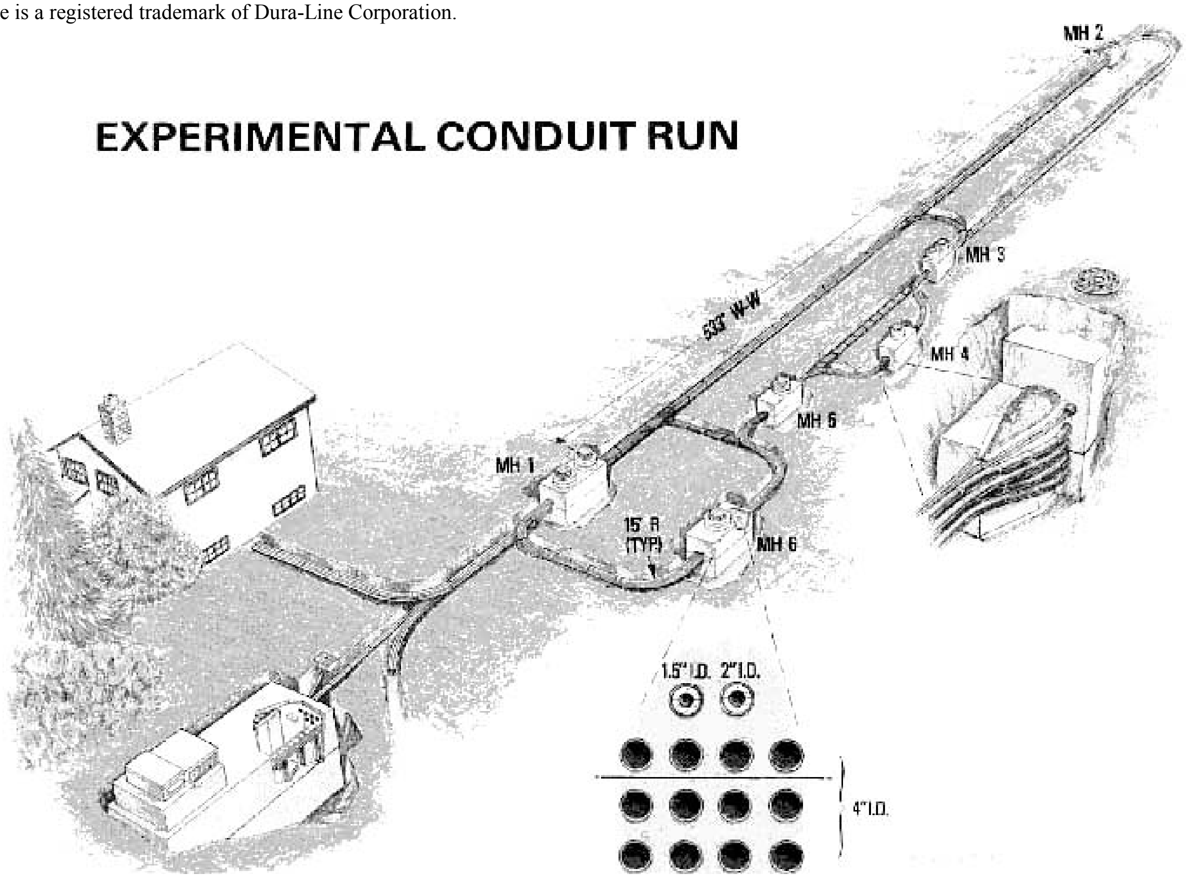

Figure 7 – Underground Conduit Facility Used for the Cable Blowing Tests

TABLE 8 – Summary of cable blowing tests

Cable Number	Reinforcement system	Core design	Ambient Temperature (ºC [ºF])	Initial Blowing Velocity (mpm[fpm])	Final Blowing Velocity (mpm[fpm])	Average Blowing Velocity (mpm[fpm])	Total Blowing Distance (m[ft])
1	Six-member	Gel filled	28 (82)	56.4 (185)	0	33.2 (109)	1160 (3804)
2	Six-member	Dry	26 (79)	57.9 (190)	0	42.4 (139)	1242 (4074)
3	Two-rod	Gel filled	21 (70)	59.4 (195)	54.9 (180)	56.7 (186)	**1328 (4358)***
4	Two-rod	Dry	16 (61)	57.9 (190)	56.4 (185)	57.3 (188)	**1328 (4358)***

*** Full length of duct route**

The average velocity of both two-rod cables was approximately 35% higher than that of the dry six-member cable, and about 80% higher than that of the gel-filled six-member cable.

5.2.2 Benefits for Cable Installers: Time Savings Resulting from Improved Blowing Performance

Actual blowing performance will depend on many factors, including ambient temperature and weather; topology of the duct system; condition of the duct system; and performance of the blowing equipment. However, deployment of the new two-rod design instead of the standard, gel-filled six-member design could provide installers significant savings in time and cost. Using the results of the blowing study described above in Section 6.2, we can construct a simple model that compares installation of the two designs for a long-haul route. As in the case of the installation study above, 216-fiber cables are installed in underground duct with an inner diameter of 31.8 mm (1 ¼ in.). The assumptions made in this model are summarized below in Table 9.

Table 9 – Blowing installation scenario assumptions

Length of route	150km (93.2 miles)
Length of cable per reel	6.0km (3.72 miles)
Frequency of manholes/handholes	One per kilometer
Length of work day	6 hours
Average installation velocity for six-member cable	31 m/min. (102 ft/min.)
Average installation velocity for two-rod cable	57 m/min. (187 ft/min.)

We also assume that the cables are being installed using “cascading” blowing equipment at each manhole or handhole. Through use of cascading equipment, the entire 6km length of each cable may be installed at once, without intermediate coiling or figure-eighting of the cable. This minimizes the overall time required to place cable along the route.

Given these assumptions, the time required to place the of the gel-filled six-member cables in the duct system will be 53.6 hours, or 8.9 working days. In contrast, placement of the two-rod cables would only require 29.2 hours, or 4.9 days. In this scenario, compared to the six-member design, installation of the two-rod cable takes 45% less time, saving four working days.

6. Conclusions

This paper describes the design and performance of a novel dielectric central-core cable sheath that employs two linearly applied FRP composite rods. The novel coating of the composite rods provides optimized frictional coupling between the rods and the cable jacket. The coating allows decoupling of the rods and jacket in bending or torsional deformations. However, once these types of loads are relieved, the coatings allow the rods to re-couple to the jacket.

The new sheath design has been applied to a variety of core structures, including tube-in-tube, filled ribbon and dry ribbon cores. These cables are available in fiber counts ranging from 12 to 216, utilizing 12-fiber tubes or 12-fiber ribbons. The new sheath design has a tensile rating of 2700N (600 lb.).

Coupling of the FRP rods to the cable jacket through frictional adhesion provides a robust cable sheath with minimal preferential bending. As a result, the installation and handling performance of the new two-rod linear dielectric design is superior to that of the industry-standard six-member linear dielectric design. The improved performance of the two-rod design in blowing can substantially reduce cable installation time and cost.

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