# Aluminum Conductor Composite Reinforced Technical Notebook (795 kcmil family)

## Conductor and Accessory Testing

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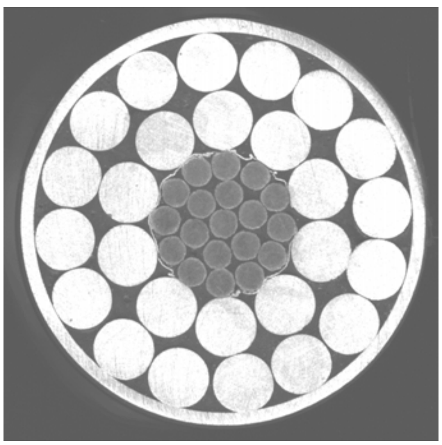
# Overview

With several regions of the world facing severe pressures on transmission line infrastructure, 3M has developed a new, high-performance conductor material that can provide transmission capacities up to three times greater than those of existing systems. The high-performance 3M Brand Composite Conductor, also known as Aluminum Conductor Composite Reinforced (ACCR), represents the first major change in overhead conductors since the conventional aluminum-steel reinforced conductor (ACSR) was introduced in the early 20th century.

Relying on a core of aluminum composite wires surrounded by temperature-resistant aluminum-zirconium wires, the 3M Composite Conductor can be installed quickly and easily as a replacement conductor on existing right-of-ways, with little or no modifications to existing towers or foundations. This additional capacity and increased efficiency, permits the upgrade of transmission capacity with minimal environmental impacts.



***The 3M Composite Conductor relies on a core of aluminum composite wires surrounded by aluminum-zirconium strands.***

## Summary of Benefits

The new conductor can help solve transmission bottlenecks, especially power flow restrictions concerned with operating lines at high temperatures. So, while this is not a total solution, it is believed this is an important part of a broad transmission grid solution. With its enhanced properties, the 3M Composite Conductor can address demanding applications. Line rebuilds can be avoided where clearance requirements change or additional capacity is needed. With only aluminum constituents, the conductor can be used in high-corrosion locations. Where heavy ice loads exist, a smaller-diameter conductor can be used to achieve higher ice-load ratings without structure modifications. In new construction, long-span crossings can be achieved with shorter towers. These can be accomplished using the existing right-of-ways and using all the existing tower infrastructure, thereby avoiding extensive rebuilding, avoiding difficult and lengthy permitting, and reduced outage times.

## Building on Experience

A 3M-led team has successfully installed small- (477-kcmil) and medium-diameter (795-kcmil) ACCR conductors. In a cooperative agreement with the U.S. Dept. of Energy-Chicago (DOE), the team is further advancing the ACCR conductor by developing and testing medium- and large-diameter (795- to 1272-kcmil) ACCR and accessories on multi-span, high-voltage lines.

***Using traditional installation methods, linemen install 3M Composite Conductor on the 230-kV WAPA Network.***

As a world leader in the manufacturing of metal matrix composite wire and high-strength aluminum-oxide fibers, 3M has forged a team of industry leaders, with a wealth of experience in the power transmission field. The additional team members include:

- Wire Rope Industries (WRI)
- Nexans
- Preformed Line Products (PLP)
- Alcoa Fujikura Ltd.
- The National Electric Energy Testing, Research and Applications Center (NEETRAC)
- Kinectrics Inc.
- Western Area Power Administration (WAPA)
- Oak Ridge National Laboratory (ORNL)
- Hawaiian Electric Company (HECO)

***A 46kV installation at Hawaiian Electric on the North Shore of Oahu, uses 3M Composite Conductor to solve corrosion concerns***

## Installed ACCR

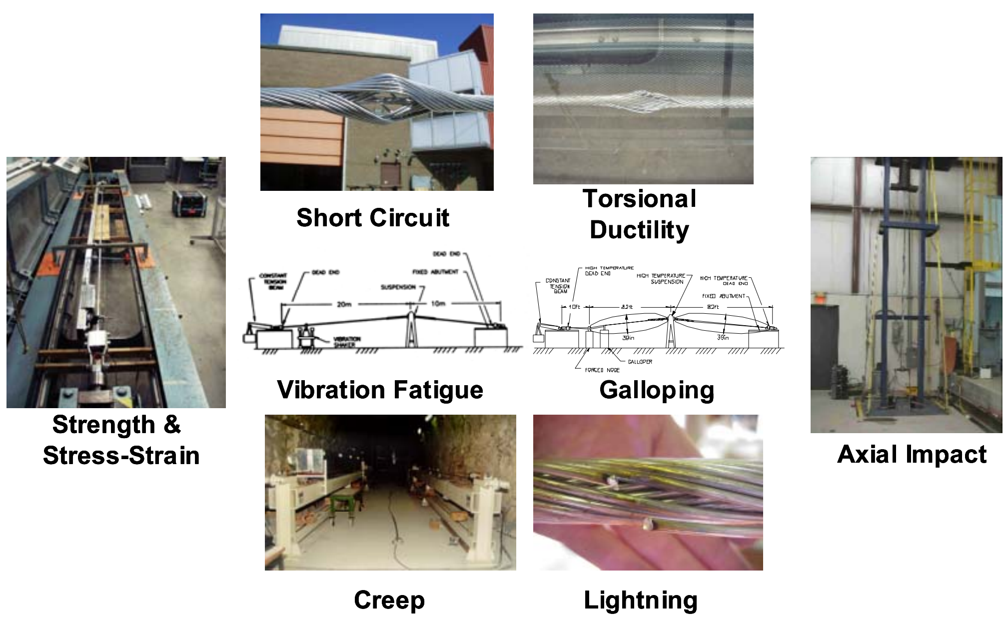
3M and other independent test laboratories has performed a variety of field and laboratory testing and has extensive data on the conductor and accessories. The 3M Brand Composite Conductor has been installed in a variety of different places. One installation was on a short span of 477 kcmil Composite Conductor in Xcel Energy's 115kV system in Minneapolis to feed power from a generation plant to the network. It replaces a conventional ACSR conductor to double the possible ampacity while keeping the same clearance and tower loads. Hawaiian Electric installed 477-kcmil Composite Conductor on the North shore of the island of Oahu, taking advantage of the excellent corrosion resistance of the conductor on their 46kv network, while also increasing the ampacity along the existing right-of-way by 72%. A section of 477-kcmil Composite Conductor was strung at a new outdoor test facility in Oak Ridge, TN. The line is highly instrumented, and will be used to study sag and tensions under high temperatures and severe thermal cycling conditions. Most recently, a 795-kcmil Composite Conductor was installed by WAPA on a 230kV line near Fargo, North Dakota. The conductor is well suited for the high ice loading and vibration conditions of the area.

***A span installed at Xcel Energy feeds power from a generation plant to the 115kV network.***

***400VDC outdoor test line installation at Oak Ridge, Tennessee.***

### Design Support

3M offers technical support resources and can tailor the 3M Composite Conductor to suit your specific needs. Our highly qualified engineers offer design support using ruling span calculations for a rapid assessment of the suitability of the 3M Composite Conductor in a given situation. In overhead power transmission, 3M has worked closely with customers to develop & understand a wide variety of solutions where the 3M Composite Conductor may be successfully used. Customer interaction is a key step to fully optimize the conductor, thus providing the expertise to successfully implement the 3M Composite Conductor, whether the needs are simply material properties or a complete design solution.




***Extensive laboratory testing has been performed with a variety of different tests passed.***

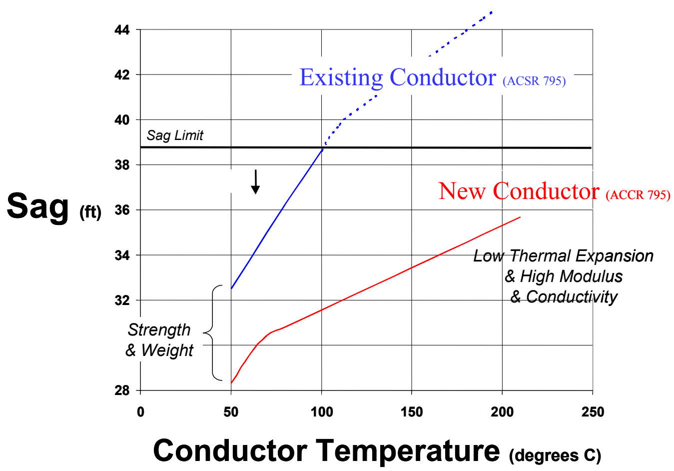
 

# Applications and Benefits

Due to its innovative materials, the 3M Brand Composite Conductor provides exceptional structural, mechanical, and electrical properties. A complete listing of properties is included in the **Material Properties** section of this document. Test results are included in the **Conductor Test Data** and **Accessory Test Data** sections. The enhanced properties translate into numerous benefits for utilities, including:

## Increased Ampacity

The 3M Composite Conductor provides high ampacities thanks to the ability to run at high temperatures (>200°C), and with the critical advantage of low sag within existing design clearances and loads. The sag-temperature chart below shows the tremendous advantage this brings. The

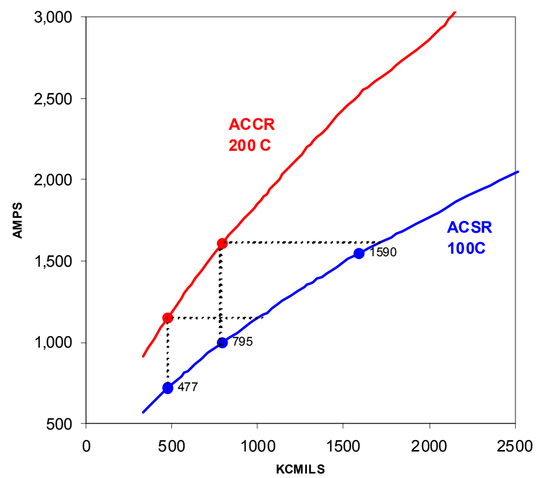



***Sag-Temperature chart showing ACCR provides larger ampacity by operating at higher temperatures, while also exhibiting reduced sag.***

blue line shows a conventional 795-kcmil ACSR installation, with the sag limit occurring when the conductor temperature reaches 100°C, which is the maximum safe operating limit for the conductor. Upgrade replacement of the ACSR with 3M Composite Conductor (ACCR) of the same size (795-kcmil), creates an improved sag-temperature response. When strung to the same tension, the initial sag is less (less weight). As temperature (ampacity) increases, the lower thermal expansion of the conductor permits heating to temperatures beyond 200°C without violating the original sag limit. This offers a large ampacity increase. This design space offers further options, such as use of a larger ACCR conductor with existing structures and right-of-ways, reducing tower loads, higher ice loads, and reduced tower heights in new construction.

## Large Increases in Power Transfer Along Existing Rights of Way

Where power increases on the order of 100% are needed to cover periodic emergency conditions, conventional approaches employ new lines, new right-of-ways or new towers on existing right-of-ways. The solution with the 3M Composite Conductor is to simply replace the existing conductor on the same right-of-way. This results in a 100% ampacity gain with no change in the conductor diameter, the same sag, no change in the tower loads, and the full use of existing towers. Electrical losses only accrue during the peak emergency periods, otherwise the improved conductor conductivity can reduce electrical losses. Thus the 3M Composite Conductor provides ampacities equivalent to much larger ACSR constructions as shown in the diagram below.




***ACCR provides ampacities equivalent to much larger ACSR constructions and has less sag at 200°C than ACSR at 100°C***

In the case where large power transfer increases are needed consistently due to heavy electrical loading, then the same conventional solutions apply as above. By using Compact constructions of the 3M Composite Conductor, power increases of 100-200% result, with small (10-15%) conductor diameter increases, the same sag, use of the same towers but perhaps with some reinforcement in some sections. Electrical losses are roughly half the existing line or equal to a new conventional line.

### Extremely Large Increases in Power Transfer

To obtain power increases in the 200-500% range, conventional solutions would require new lines and new right-of-ways. By using a Compact version of the 3M Composite Conductor together with a voltage increase, the same power increases may be achieved using existing structures and right-of-ways. Some tower modifications may be needed for reinforcement and phase spacing.

### Contingency Situations

Situations in which the bulk lines may be limited by underlying (n-1) reliability, conventional approaches employ new lines, new right-of-ways or new towers on existing right-of-ways. The solution with the 3M Composite Conductor is to simply replace the existing conductor. This results in a 100% power gain with no change in the conductor diameter, the same sag, no change in the tower loads, and the full use of existing towers.

### Changing Clearance Requirements

Often, clearance requirements change but the need to maintain power transfer persists. Typically, the structures would need to be raised or new structures built, whereas with the 3M Brand Composite Conductor, a simple replacement with a new reduced sag conductor is all that is needed, with no change in diameter or tower loads.

### Long Span Crossings

Conventional approaches to increase power transfers across long spans typically require tower replacements with taller towers. The 3M Composite Conductor offers the possibility to merely replace the existing conductor, yielding 100-600% ampacity gains, while maintaining the same conductor diameter, sag, towers, and the same or reduced tower loads, and greatly reduced electrical losses. Reduced tensions add to improved safety for long span installations.

### Reduced Installation Time

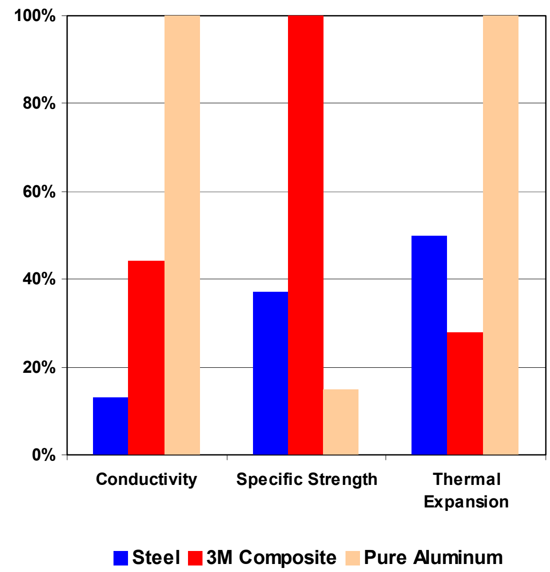
The 3M Composite Conductor can be installed quickly using conventional equipment and without heavy construction equipment. This simple solution also reduces service interruption.

### Reduced Environmental Impacts

With the increased ampacity and lower weight of the 3M Composite Conductor, transmission lines can be upgraded without requiring line rerouting, new-right-of-way, or tower modifications – construction activities which create environmental impacts.

### Innovative Materials

The tremendous advantages of the new conductor are brought about due to new innovations in the materials used. Compared to steel, the new composite core is lighter weight, equivalent strength, lower thermal expansion, higher elastic modulus, and higher electrical conductivity. This permits the use of higher operating temperatures, which in turn leads to higher ampacities.




***Comparison of Conductor Constituent Properties***


***3M Composite Conductors can provide solutions to demanding transmission problems***

# Material Properties

The 3M Brand Composite Conductor consists of high-temperature aluminum-zirconium strands covering a stranded core of aluminum oxide fiber-reinforced composite wires. Both the composite core and the outer aluminum-zirconium (Al-Zr) strands contribute to the overall conductor strength and conductivity.

## Composite Core

The composite core contains 3M metal matrix composite wires. Depending on the conductor size, the wire diameters range from 0.073" (1.9 mm) to 0.114" (2.9 mm). The core wires have the strength and stiffness of steel, but with much lower weight and higher conductivity. Each core wire contains many thousand, small diameter, ultra-high-strength, aluminum oxide fibers. The ceramic fibers are continuous, oriented in the direction of the wire, and fully embedded within high-purity aluminum, as shown in Figure 1. Visually, the composite wires appear as traditional aluminum wires, but exhibit mechanical and physical properties far superior to those of aluminum and steel. For example, the composite wire provides nearly 8 times the strength of aluminum and 3 times the stiffness. It weighs less than half of an equivalent segment of steel, with greater conductivity and less than half the thermal expansion of steel, as shown in Table 1.

***Table 1: Properties of Composite Core***

| Property | Value |
|---|---|
| Tensile Strength (min.) | 200 ksi (1380 MPa) |
| Density | 0.12 $lbs/in^3$ (3.33 g/cc) |
| Stiffness | 31-33 Msi (215-230 GPa) |
| Conductivity | 23-25% IACS |
| Thermal Expansion (20°C) | $3.3 \times 10^{-6}$ / °F ($6 \times 10^{-6}$ / °C) |
| Fatigue Resistance (Endurance) | > 10 million cycles at 100 ksi (690 MPa) |
| Emergency Use Temperature | > 570°F (300°C) |

***Table 2: Properties of Aluminum – Zirconium Wire***

| Property | Value |
|---|---|
| Tensile Strength (<0.153" diameter) # | >23.5 ksi (162 MPa) |
| Tensile Strength (>0.153" diameter) # | >23.0 ksi (159 MPa) |
| % Tensile Elongation[1] | > 2% |
| Tensile Strength Retention, 280°C/1hr # | > 90% |
| Density | 0.097 $lbs/in^3$ (2.7 $g/cm^3$) |
| Conductivity / Resistivity at 20°C | >60%IACS <br> <$28.73 \times 10^{-9}$ Ohm.m |
| Continuous use temperature | 210°C |
| Emergency use temperature | 240°C |

# 10 in. (250 mm) gauge length

Source: *Properties of Heat-Resistant Aluminum-Alloy Conductors For Overhead Power-Transmission Lines*, K. Kawakami, M. Okuno, K. Ogawa, M. Miyauchi, and K. Yoshida, Furukawa Rev. (1991), (9), 81-85.

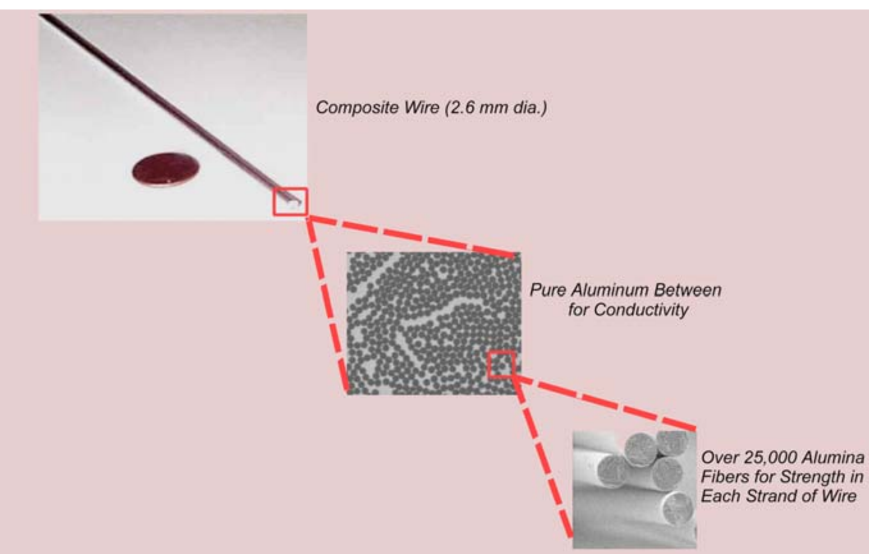



***Figure 1: The composite wire provides high strength and conductivity at low weight.***

## Outer Strands

The outer strands are composed of a temperature-resistant aluminum-zirconium alloy (Figure 2), which permits operation at high temperatures (210ºC continuous, 240ºC emergency). The Al-Zr alloy is a hard aluminum alloy with properties and hardness similar to standard 1350-H19 aluminum. However the microstructure is designed to maintain strength after operating at high temperatures; that is, it resists annealing. In contrast, 1350-H19 wire rapidly anneals and loses strength with excursions above 100ºC. The temperature-resistant Al-Zr alloy wire has equivalent tensile strengths and stress-strain behaviors to standard 1350-H19 aluminum wire, as shown in Table 2.

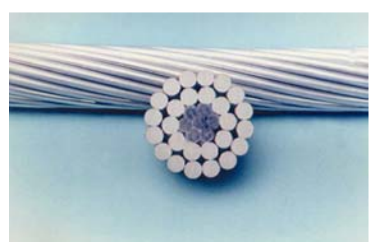


***Figure 2: The outer strands made from an Al-Zr alloy maintain strength after operating at high temperatures.***

## Properties of Standard Constructions

Standard constructions for 3M Brand Composite Conductors range in size from 336 kcmils to 1,590 kcmils. Theoretical properties for these constructions are shown in the Tables 3 and 4. Table 3 displays the properties in English units; Table 4 shows metric units. Both tables cover type 13 and type 16 constructions, where *type* is the ratio of core area to aluminum area, expressed in percent. The stranding represents the ratio of the number of outer aluminum strands to the number of core wires.

Following these tables, values of key properties obtained in actual field and laboratory tests are presented in the **Conductor Test Data** and **Accessory Test Data** sections. These summarize the behavior for the medium size, 26/19, constructions. Testing was performed at a variety of laboratories including NEETRAC, Kinectrics Inc., Preformed Line Products, and Alcoa-Fujikura.

### *Table 3: Typical Properties of 3M Composite Conductors (English Units)*

**Conductor Physical Properties**

| Designation | | 336-T16 | 397-T16 | 477-T16 | 556-T16 | 636-T16 | 795-T16 | 954-T13 | 1033-T13 | 1113-T13 | 1272-T13 | 1351-T13 | 1590-T13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stranding** | | 26/7 | 26/7 | 26/7 | 26/7 | 26/19 | 26/19 | 54/19 | 54/19 | 54/19 | 54/19 | 54/19 | 54/19 |
| **kcmils** | kcmil | 336 | 397 | 477 | 556.5 | 636 | 795 | 954 | 1,033 | 1,113 | 1,272 | 1,351 | 1,590 |
| **Diameter** | | | | | | | | | | | | | |
| **indiv Core** | in | 0.088 | 0.096 | 0.105 | 0.114 | 0.073 | 0.082 | 0.080 | 0.083 | 0.086 | 0.092 | 0.095 | 0.103 |
| **indiv Al** | in | 0.114 | 0.124 | 0.135 | 0.146 | 0.156 | 0.175 | 0.133 | 0.138 | 0.144 | 0.153 | 0.158 | 0.172 |
| **Core** | in | 0.27 | 0.29 | 0.32 | 0.34 | 0.36 | 0.41 | 0.40 | 0.41 | 0.43 | 0.46 | 0.47 | 0.51 |
| **Total Diameter** | in | 0.72 | 0.78 | 0.86 | 0.93 | 0.99 | 1.11 | 1.20 | 1.24 | 1.29 | 1.38 | 1.42 | 1.54 |
| **Area** | | | | | | | | | | | | | |
| **Al** | in^2 | 0.264 | 0.312 | 0.374 | 0.437 | 0.500 | 0.624 | 0.749 | 0.811 | 0.874 | 0.999 | 1.061 | 1.249 |
| **Total Area** | in^2 | 0.307 | 0.363 | 0.435 | 0.508 | 0.579 | 0.724 | 0.844 | 0.914 | 0.985 | 1.126 | 1.195 | 1.407 |
| **Weight** | lbs/linear ft | 0.380 | 0.449 | 0.539 | 0.630 | 0.717 | 0.896 | 1.044 | 1.130 | 1.218 | 1.392 | 1.478 | 1.740 |
| **Breaking Load** | | | | | | | | | | | | | |
| **Core** | lbs | 8,204 | 9,695 | 11,632 | 13,583 | 14,843 | 18,556 | 17,716 | 19,183 | 20,669 | 23,622 | 25,089 | 29,527 |
| **Aluminum** | lbs | 5,773 | 6,704 | 7,844 | 9,160 | 10,248 | 12,578 | 15,041 | 16,287 | 17,548 | 20,055 | 21,301 | 25,069 |
| **Complete Cable** | lbs | 13,977 | 16,398 | 19,476 | 22,743 | 25,091 | 31,134 | 32,758 | 35,470 | 38,217 | 43,677 | 46,389 | 54,596 |
| **Modulus** | | | | | | | | | | | | | |
| **Core** | Msi | 31.4 | 31.4 | 31.4 | 31.4 | 31.4 | 31.4 | 31.4 | 31.4 | 31.4 | 31.4 | 31.4 | 31.4 |
| **Aluminum** | Msi | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 7.4 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 | 8.0 |
| **Complete Cable** | Msi | 11.2 | 11.2 | 11.2 | 11.2 | 11.2 | 10.7 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 | 10.6 |
| **Thermal Elongation** | | | | | | | | | | | | | |
| **Core** | 10^-6/F | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 |
| **Aluminum** | 10^-6/F | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 | 12.8 |
| **Complete Cable** | 10^-6/F | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 | 9.2 |
| **Heat Capacity** | | | | | | | | | | | | | |
| **Core** | W-sec/ft-C | 9 | 11 | 13 | 15 | 17 | 22 | 21 | 22 | 24 | 28 | 29 | 35 |
| **Aluminum** | W-sec/ft-C | 137 | 162 | 194 | 226 | 259 | 324 | 390 | 423 | 455 | 520 | 553 | 650 |

**Conductor Electrical Properties**

| Resistance | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DC @ 20C** | ohms/mile | 0.2597 | 0.2198 | 0.1832 | 0.1569 | 0.1375 | 0.1100 | 0.0933 | 0.0862 | 0.0800 | 0.0700 | 0.0659 | 0.0560 |
| **AC @ 25C** | ohms/mile | 0.2659 | 0.2250 | 0.1875 | 0.1606 | 0.1407 | 0.1126 | 0.0955 | 0.0882 | 0.0819 | 0.0717 | 0.0675 | 0.0573 |
| **AC @ 50C** | ohms/mile | 0.2922 | 0.2473 | 0.2061 | 0.1765 | 0.1547 | 0.1237 | 0.1050 | 0.0970 | 0.0900 | 0.0787 | 0.0741 | 0.0630 |
| **AC @ 75C** | ohms/mile | 0.3185 | 0.2695 | 0.2247 | 0.1924 | 0.1686 | 0.1349 | 0.1145 | 0.1057 | 0.0981 | 0.0858 | 0.0808 | 0.0687 |
| **Geometric Mean Radius** | ft | 0.0244 | 0.0265 | 0.0290 | 0.0313 | 0.0335 | 0.0375 | 0.0404 | 0.0420 | 0.0436 | 0.0466 | 0.0480 | 0.0521 |
| **Reactance (1 ft Spacing, 60hz)** | | | | | | | | | | | | | |
| **Inductive Xa** | ohms/mile | 0.4508 | 0.4407 | 0.4296 | 0.4202 | 0.4121 | 0.3986 | 0.3895 | 0.3847 | 0.3801 | 0.3720 | 0.3684 | 0.3585 |
| **Capacitive X'a** | ohms/mile | 0.1040 | 0.1015 | 0.0988 | 0.0965 | 0.0945 | 0.0912 | 0.0890 | 0.0878 | 0.0867 | 0.0847 | 0.0838 | 0.0814 |

## *Table 4: Typical Properties of 3M Composite Conductors (Metric Units)*

**Conductor Physical Properties**

| **Designation** | | 336-T16 | 397-T16 | 477-T16 | 556-T16 | 636-T16 | 795-T16 | 954-T13 | 1033-T13 | 1113-T13 | 1272-T13 | 1351-T13 | 1590-T13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stranding** | | 26/7 | 26/7 | 26/7 | 26/7 | 26/19 | 26/19 | 54/19 | 54/19 | 54/19 | 54/19 | 54/19 | 54/19 |
| **Diameter** | | | | | | | | | | | | | |
| **indiv Core** | mm | 2.2 | 2.4 | 2.7 | 2.9 | 1.9 | 2.1 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.6 |
| **indiv Al** | mm | 2.9 | 3.1 | 3.4 | 3.7 | 4.0 | 4.4 | 3.4 | 3.5 | 3.6 | 3.9 | 4.0 | 4.4 |
| **Core** | mm | 6.7 | 7.3 | 8.0 | 8.7 | 9.3 | 10.4 | 10.1 | 10.5 | 10.9 | 11.7 | 12.1 | 13.1 |
| **Total Diameter** | mm | 18.3 | 19.9 | 21.8 | 23.5 | 25.2 | 28.1 | 30.4 | 31.6 | 32.8 | 35.1 | 36.2 | 39.2 |
| **Area** | | | | | | | | | | | | | |
| **Al** | mm^2 | 170 | 201 | 241 | 282 | 322 | 403 | 483 | 523 | 564 | 645 | 685 | 806 |
| **Total Area** | mm^2 | 198 | 234 | 281 | 328 | 374 | 467 | 545 | 590 | 635 | 726 | 771 | 908 |
| **Weight** | kg/m | 0.566 | 0.669 | 0.802 | 0.937 | 1.067 | 1.333 | 1.553 | 1.682 | 1.812 | 2.071 | 2.200 | 2.589 |
| **Breaking Load** | | | | | | | | | | | | | |
| **Core** | kN | 36.5 | 43.1 | 51.7 | 60.4 | 66.0 | 82.5 | 78.8 | 85.3 | 91.9 | 105.1 | 111.6 | 131.3 |
| **Aluminum** | kN | 25.7 | 29.8 | 34.9 | 40.7 | 45.6 | 55.9 | 66.9 | 72.4 | 78.1 | 89.2 | 94.7 | 111.5 |
| **Complete Cable** | kN | 62.2 | 72.9 | 86.6 | 101.2 | 111.6 | 138.5 | 145.7 | 157.8 | 170.0 | 194.3 | 206.4 | 242.9 |
| **Modulus** | | | | | | | | | | | | | |
| **Core** | GPa | 216 | 216 | 216 | 216 | 216 | 216 | 216 | 216 | 216 | 216 | 216 | 216 |
| **Aluminum** | GPa | 55 | 55 | 55 | 55 | 55 | 51 | 55 | 55 | 55 | 55 | 55 | 55 |
| **Complete Cable** | GPa | 78 | 78 | 78 | 78 | 77 | 74 | 73 | 73 | 73 | 73 | 73 | 73 |
| **Thermal Elongation** | | | | | | | | | | | | | |
| **Core** | 10^-6/C | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 |
| **Aluminum** | 10^-6/C | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 | 23.0 |
| **Complete Cable** | 10^-6/C | 16.5 | 16.5 | 16.5 | 16.5 | 16.6 | 16.3 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 | 17.5 |
| **Heat Capacity** | | | | | | | | | | | | | |
| **Core** | W-sec/m-C | 31 | 36 | 44 | 51 | 57 | 71 | 68 | 74 | 79 | 91 | 96 | 113 |
| **Aluminum** | W-sec/m-C | 449 | 530 | 636 | 743 | 849 | 1,062 | 1,280 | 1,386 | 1,494 | 1,707 | 1,813 | 2,134 |

**Conductor Electrical Properties**

| **Resistance** | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DC @ 20C** | ohms/km | 0.1614 | 0.1366 | 0.1138 | 0.0975 | 0.0854 | 0.0683 | 0.0580 | 0.0535 | 0.0497 | 0.0435 | 0.0409 | 0.0348 |
| **AC @ 25C** | ohms/km | 0.1652 | 0.1398 | 0.1165 | 0.0998 | 0.0875 | 0.0700 | 0.0594 | 0.0548 | 0.0509 | 0.0445 | 0.0419 | 0.0356 |
| **AC @ 50C** | ohms/km | 0.1816 | 0.1536 | 0.1281 | 0.1097 | 0.0961 | 0.0769 | 0.0652 | 0.0603 | 0.0559 | 0.0489 | 0.0461 | 0.0391 |
| **AC @ 75C** | ohms/km | 0.1979 | 0.1675 | 0.1396 | 0.1195 | 0.1048 | 0.0838 | 0.0711 | 0.0657 | 0.0610 | 0.0533 | 0.0502 | 0.0427 |
| **Geometric Mean Radius** | cm | 0.7424 | 0.807 | 0.884 | 0.9552 | 1.021 | 1.1416 | 1.2302 | 1.2801 | 1.3288 | 1.4205 | 1.464 | 1.5882 |
| **Reactance (1 ft Spacing, 60hz)** | | | | | | | | | | | | | |
| **Inductive Xa** | ohms/km | 0.2817 | 0.2754 | 0.2685 | 0.2626 | 0.2576 | 0.2491 | 0.2434 | 0.2404 | 0.2376 | 0.2325 | 0.2302 | 0.2241 |
| **Capacitive X'a** | ohms/km | 0.065 | 0.0635 | 0.0618 | 0.0603 | 0.0591 | 0.057 | 0.0556 | 0.0549 | 0.0542 | 0.0529 | 0.0524 | 0.0509 |

# Conductor Test Data

## Tensile Strength

Three tensile tests were performed in laboratory settings with the ends of the 795-kcmil 3M Brand Composite Conductor potted in epoxy, as shown in Figure 3. One was performed at the National Electric Energy Testing, Research, and Applications Center (NEETRAC) using a 19-ft (5.8-m) gauge length, and the other two were tested at 3M facilities using a 10-ft (3-m) gauge length. Care was taken during handling, cutting and end preparation to ensure individual wires did not slacken, as this could decrease strength values. The breaking load was then determined by pulling the conductor to a 1000-lb (4.4-kN) load, and then further loading to failure at 10,000 lbs/min (44 kN/min). As shown in Table 5, the breaking loads for all three tests closely reached the Rated Breaking Strength (RBS), which is 31,134 lbs (138.5 kN) for this construction. It is particularly difficult to get full strength in laboratory testing at short lengths of 10ft (3m) with this size of conductor, thus reaching this target is very satisfactory. Subsequent testing at longer lengths using dead-end hardware reported in the accessory section, further confirmed the rated strength of the conductor.

***Figure 3: A test bed was used to conduct stress-strain and tensile strength measurements on a 795-kcmil conductor.***

***Table 5: Tensile Strength Tests***

| Test No. | Breaking Load, lbs (kN) | %RBS | Gage Length, ft (m) |
|---|---|---|---|
| 1 | 31,870 (141.8) | 102% | 19 (5.8) |
| 2 | 31,040 (138.1) | 100% | 10 (3.0) |
| 3 | 30,720 (136.6) | 99% | 10 (3.0) |

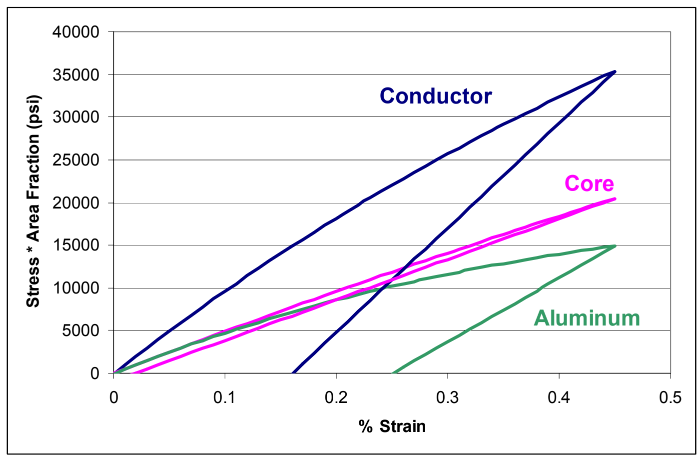



***Figure 4: Stress vs. Strain Curves for 795-kcmil Conductor and Constituents***

## Stress-Strain Behavior

The stress-strain behavior of the 795-kcmil 3M Composite Conductor was determined in accordance with the 1999 Aluminum Association Standard entitled, "A Method of Stress-Strain Testing of Aluminum Conductor and ACSR." On the conductor, the test was started at 1000 lbs (4.4 kN) and the strain measurement set to zero. Load was then incrementally increased to 30%, 50%, 70%, and 75% of RBS, with the load relaxed to 1000 lbs between each increase. Finally, the conductor was pulled to destruction. A repeat test was performed on the core, loading to the same strains as measured in the conductor test.

Curve fitting was applied per the Aluminum Association Standard, including derivation of the aluminum constituent. A set of curves without the creep addition for the 795-kcmil Composite Conductor and constituents is shown in Figure 4. In the graph, the core and aluminum curves are multiplied by their respective area fraction in the conductor.

***Equations for 795 kcmil Stress-Strain Curves***

| | |
|---|---|
| Conductor Initial: | Stress (psi) = $-17{,}424*(\%Strain)^4 + 35{,}102*(\%Strain)^3 - 66{,}240*(\%Strain)^2 + 103{,}029*(\%Strain) - 73$ |
| Conductor Final: | Stress (psi) = $122{,}238*(\%Strain) - 19{,}646$ |
| Initial Elastic Modulus: | 10,055,000 psi |
| Core Initial: | Stress (psi) = $-50{,}165*(\%Strain)^4 + 58{,}264*(\%Strain)^3 - 89{,}616*(\%Strain)^2 + 362{,}547*(\%Strain)$ |
| Core Final: | Stress (psi) = $343{,}705*(\%Strain) - 6{,}444$ |
| Aluminum Initial | Stress (psi) = $-20{,}220*(\%Strain)^4 + 40{,}733*(\%Strain)^3 - 65{,}838*(\%Strain)^2 + 61{,}795*(\%Strain) - 85$ |
| Aluminum Final | Stress (psi) = $86{,}746*(\%Strain) - 21{,}762$ |

NOTE: These equations are not normalized by the constituent area fraction

The resulting polynomial curves are corrected to pass through zero for the initial curves, and the final curves are translated to descend from 0.45% strain. The polynomial equations derived from the testing and fitted to a $4^{th}$ order are shown in the box above.

## Electrical Resistance

The electrical resistance of the (26/19), 795-kcmil 3M Brand Composite Conductor was measured and compared with the calculated resistance, as shown in Table 6. Data is corrected to 20°C. Equalizers were welded at either end of a 20ft (6.1m) length of conductor. A four-wire resistance measurement was then made. The results were in excellent agreement and validated the predicted values.

*Table 6: Conductor Resistance*

| Property | Value | Value |
|---|---|---|
| Conductivity (aluminum wire) [1] | 60.0% IACS | |
| Conductivity (core wire) [2] | 25.7% IACS | |
| Measured conductor resistance | 0.0685 ohm/km | 0.1096 Ohm/mile |
| Calculated conductor resistance | 0.0687 ohm/km | 0.1100 Ohm/mile |

[1] Al-Zr specification
[2] 3M data

## Axial Impact Strength

This test is usually employed to investigate slippage in conductor terminations. However, given the different nature of the ACCR core material, this test helps investigate whether, high shock loads (>100% RBS) could be sustained by the 795-kcmil Composite Conductor under high rate axial loading. The shock load may be comparable to loading rates experienced during ice jumps, galloping events, and impact from storm-blown objects. The test set-up is similar to a tensile test, excepting the sample is suspended vertically and load is applied by dropping a 1300 lb weight from an elevation twelve feet above the sample (Figure 5).

***Figure 5: Impact test tower used to evaluate shock-loading behavior***

Impact velocity is 24ft/sec, with an initial nominal pre-tension of 400 lbs. The sample is pulled to nominal tension at the bottom using a fabric strap fitted to a steel bar through an eye at the end of a PLP helical rod dead-end. A load cell measures the applied impact load and the data is recorded as a graph of load vs. time (Figure 6). The impact weight almost stopped dead after the blow, rather than undergoing a usual series of rebounds, and absorbs approximately 16,000 ft-lbs of energy. The peak load signals were "clipped" due to an incorrect setting in the scopemeters that move the data from the load-cell to the data acquisition system. However, these were extrapolated from the adjacent signals (shown in red in Figure 6). The first load peak exceeds 45,000 lbs which seems unreasonably high, but the width of the peak suggests it may have contained two peaks.

The next peak appears to be a single peak, occurring at 32,800 lbs (105% RBS). Since the first peak is almost certain to have been a higher load than the second, it may be stated with high confidence, that the breaking load under the impact condition is well above the rated breaking strength. Failure of the conductor occurred inside the helical rod dead-end. The outer rods of the dead-end also appeared to slip about six inches relative to the inner rods. Since failure is above 100% RBS, this shows the conductor to have a positive strain-rate effect, and thus would not anticipate field problems due to shock loads. This confirms similar data from a 477-kcmil Composite Conductor.

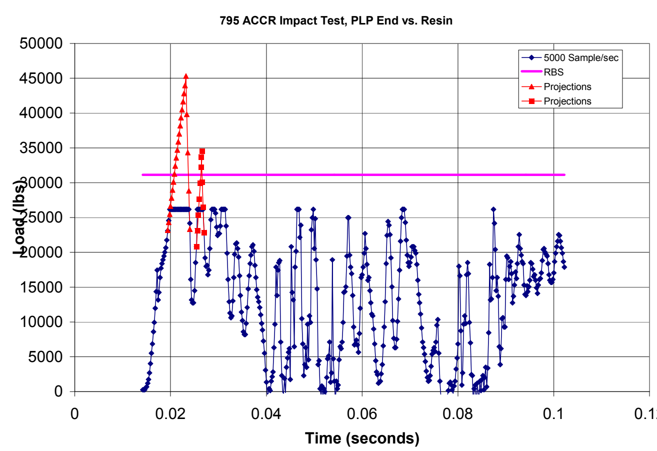



***Figure 6: Load vs. time for the 795- kcmil Impact test showing the impact-breaking load exceeds the RBS value Composite Conductor Composite Conductor***

## Torsional Ductility

This test evaluates how well the 795-kcmil Composite Conductor tolerates twisting loads that can occur during installation. Resin end-fittings were applied to a length of conductor. One end is connected to a load actuator and the other to a steel link, connected to a swivel bearing. The conductor was loaded to 25% RBS (7784 lbs) and then rotated in the positive direction (tightens outer aluminum strands) until strand breaks were observed.

At four full positive rotations (1440 degrees) the torque reached 123 ft-lbs (167 Nm) and gripping problems with the equipment developed. This is 88 degrees/ft. It was not possible to create strand failures. To fail the core, the outer aluminum strands were removed, which retracted approximately one inch, and then further rotations were applied. The inner aluminum strands bird-caged so all the load was on the core. It required 8.125 full rotations (2925 degrees) to fail the first core wire. This establishes the torsion limit for the conductor at greater than 88 degrees/ft and even higher before core failure at 180 degrees/ft.

Thus it is anticipated torsion loading will not cause problems that are any more severe than with AAC (All Aluminum Conductor) and ACSR conductors, since the aluminum outer layer would fail first, well before any core wire. The torque required to reach the torsion limit was very large, suggesting it is beyond any realistic field or construction loads.

## Short Circuit Behavior

This test compared the behavior of the 795-kcmil 3M Brand Composite Conductor (ACCR) with a 795 "Drake" ACSR conductor. Conductors were mechanically and electrically linked in series, and held under a tension of 10% RBS by compression dead-ends. This ensured the same mechanical tension and short-circuit current was applied to both. Current was applied through the compression terminations. From initial temperatures of 40°C, the conductor was subject to a current (I) applied over a time (t), with the range of RMS current settings 36-38,000 Amps (88-95,000 Amps peak) and a time duration of 0.6-2.1 seconds. The short circuit value of $I^2t$ ranged from 800-3000 $kA^2s$, by manipulation of both I and t. Measurement of the temperature rise of the conductors was taken from thermocouple locations; (i) between core wires, (ii) between core and aluminum wires, and (iii) between surface aluminum wires. The goal was to increase the short circuit condition until either the temperature reached 340°C or some physical limitation was reached (e.g. birdcage).

Figure 7 shows the maximum temperatures reached as a function of $I^2t$, with the starting temperature being 40°C. Both the core and the surface aluminum strands ran cooler in ACCR than in ACSR. At 3000 $kA^2s$, where the temperatures reached 270-330°C, the ACCR ran at a lower temperature by an average of 43°C at the core, 74°C at the aluminum/core interface, and 50°C at the surface. The surface to core difference was also lower in ACCR (47°C) versus ACSR (54°C). The test was finally stopped at 3062 kA2s, due to the formation of a bird-cage in both conductors (Figure 8). Overall, the behavior of ACCR appears to be satisfactory.

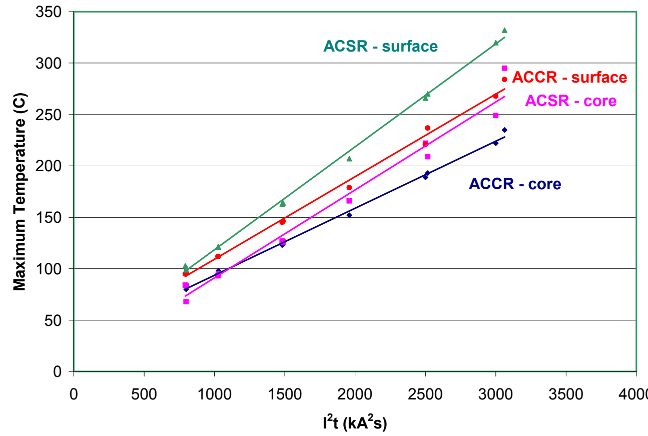



***Figure 7: Maximum temperature rise vs. $I^2t$ for surface and core locations in both 795-kcmil ACCR and ACSR***

***Figure 8: Birdcage in ACCR at 3062 $kA^2s$ (300-340°C)***

## Crush Strength

A crush test on the 795-kcmil Composite Conductor is used to simulate possible damage during shipping and installation, such as a line truck running over a conductor. This applies loads similar to that stipulated in IEEE 1138 for OPGW. A section of conductor was crushed between two 6 inch steel platens. Load was held at 756 lbs (126 lbs/linear inch) for one minute and then released. Visual inspection showed surface marks but no detectable deformation or other damage. All the aluminum and core strands were subsequently disassembled and tensile tested, and exhibited full strength retention.

## Lightning Resistance

A comparative test was performed between 795-kcmil Composite Conductor (ACCR) and ACSR of similar "Drake" construction. A lightening arc was struck across a 6 in (15 cm) gap between an arc-head electrode and a 40 ft (12 m) long conductor strung at 15% RBS. Increasing charge levels were delivered to the conductor ranging from 50 coulombs (mild to moderate strike) to 200 coulombs (very severe strike). Typical currents were 100-400 amps with durations of 200-500 ms. Comparisons were made between degree of strand damage for different conductors and charge levels. Figure 9 shows the visual damage for ACCR and ACSR conductors. Damage was generally of three kinds; individual strand breaks, "splatter" of aluminum, or major and minor degrees of strand melting. These could occur on multiple wires and as is typical of lightening hits, there is substantial scatter in the number of affected wires for the same strike condition. Most importantly, the damage was always restricted to the outer aluminum layers. The type and amount of damage seemed to be similar for both ACCR and ACSR, and appeared to increase with increased charge level (Figure 10).

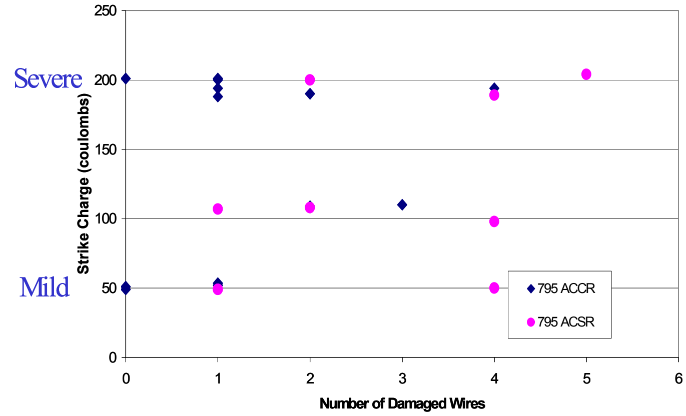



***Figure 10: Charge vs. number of damaged wires. The number of damaged wires increases with charge level, with little difference between conductor types.***

Characterization of strike damage is subjective and the visual damage may not reflect the severity of strength loss. However this aside, it appears the ACCR has a similar Lightening Strike Resistance to ACSR.

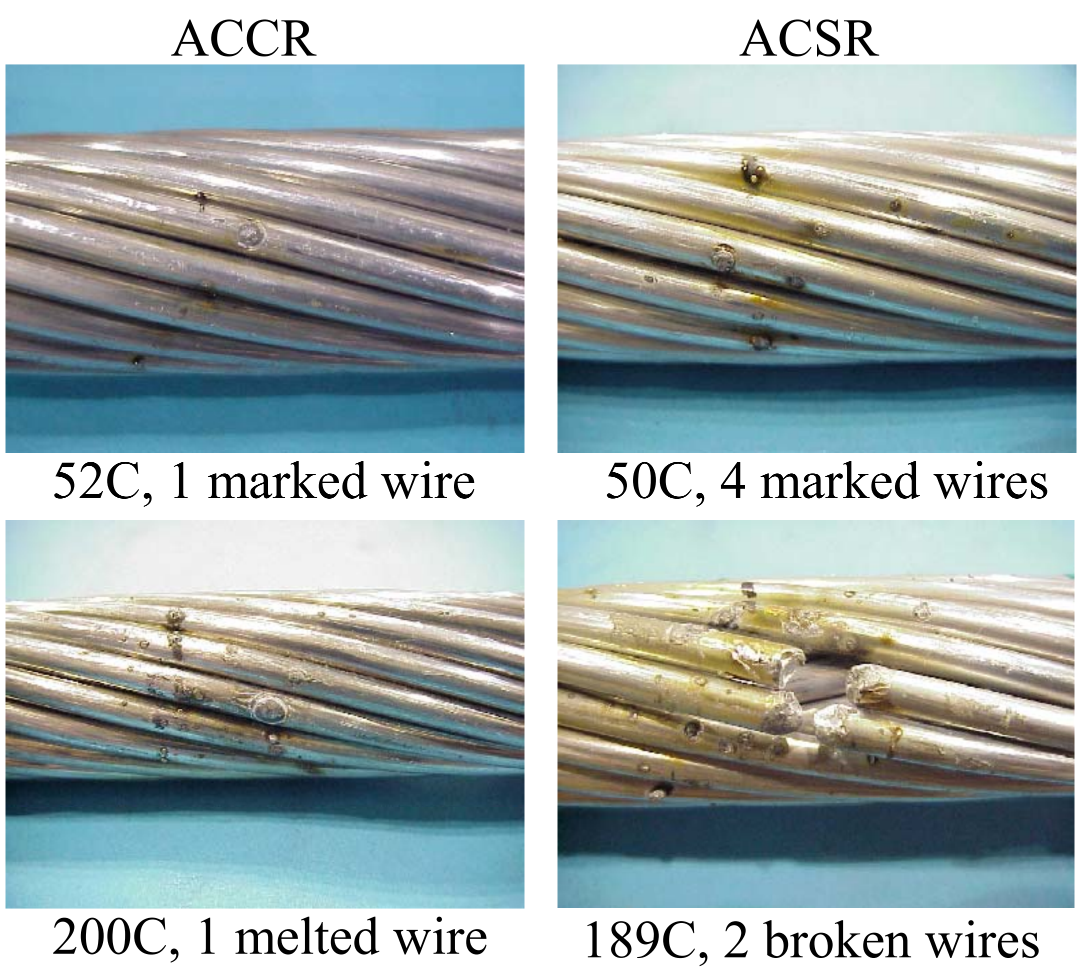



***Figure 9: Simulated Lightning Strike experiments comparing the damage of outer aluminum wires in both ACCR and ACSR at different coulomb (C) charge levels***

# Accessory Test Data

As with conventional conductors, a variety of accessories are needed for successful operation of composite conductors. 3M has undertaken a thorough series of tests on accessories, in partnership with accessory suppliers.

## Terminations and Joints/Splices

Terminations (also called dead-ends) and joints (also called mid-span splices or full-tension splices/joints) are commercially available from Preformed Line Products (PLP), and from Alcoa-Fujikura Ltd. Both companies furnished the terminations used in the tests, the former provides helical rod type and the latter compression type hardware. Data are shown for the development of hardware for a 795-kcmil 3M Brand Composite Conductor.

### Compression-Type Hardware

The compression-type hardware from Alcoa-Fujikura uses a modified two-part approach for separate gripping of the core and then an outer sleeve to grip the aluminum strands, as shown in Figure 11. This approach is similar to the approach used in ACSS, although modified to prevent crushing, notching, or bending of the core wires. The gripping method ensures the core remains straight, to evenly load the wires, and also critically ensures that the outer aluminum strands suffer no lag in loading relative to the core. The hardware is rated for high-temperature operation.

***Figure 11: Alcoa-Fujikura compression-type hardware.***

#### *Tensile Strength*

Testing of compression dead-ends from Alcoa-Fujikura, was performed with a gauge length of 10 ft (3.05 m), in which one end was terminated with the compression dead-end, and the other with an epoxy end-fitting. To test the joint, a 40 ft (12 m) gauge length was used, and two conductor sections were connected using the joint, and then the two free ends were terminated with epoxy end-fittings. The samples were tested to failure in tension.

***Table 7: Strength Data for Compression-type Dead-Ends and Joints***

| Load (lbs) | Load (kN) | % RBS | Failure Location | Hardware Type |
|---|---|---|---|---|
| 31,420 | 139.8 | 101 | Inside dead-end | Dead-end |
| 31,600 | 140.6 | 101 | Inside dead-end | Dead-end |
| 31,636 | 140.7 | 102 | Inside Joint | Joint |
| 31,420 | 139.8 | 101 | 6ft from Joint | Joint |
| 31,444 | 139.9 | 101 | 6ft from Joint | Joint |

Results are shown in Table 7, where the %RBS is based on an RBS of 31,134 lbs (138.5 kN), and the requirements for joints is to reach 95% RBS. In all tests, the terminations and conductor achieved full load.

#### *Sustained Load*

A sustained-load test was performed at 20°C following ANSI C119.4. A length of 795-kcmil 3M Composite Conductor was terminated with two types of dead-end. One was a compression-style dead-end and the other a helical rod type dead-end with the resulting gauge length being 28 ft (8.6 m). The sample was then held under tension at 77%RBS (23,980 lbs) for 168 hours. Thereafter, the sample was unloaded and then pulled in tension to failure. The failure load was 31,150 lbs (100% RBS). This shows the dead-end adequately passes the sustained load requirement.

#### *Sustained Load at Elevated Temperature*

A modified sustained load test was also performed at elevated temperature to verify the ability to carry load at the maximum temperature. A test sample consisted of a compression dead-end at one end, and an epoxy fitting on the other. The sample was run at 240°C for 168 hours, using a gauge length of 40 ft (12 m,) under a tension of 15% RBS, after which the sample was pulled to failure in tension at room temperature (20°C). The dead-end failed at 31,976 lbs (103% RBS) in the conductor gauge length. Thus full strength was achieved after a sustained load at elevated temperature.

## Helical Rod-Type Hardware

Helical rod-type hardware available from PLP, as shown in Figures 12 and 13, has been developed by PLP for use with the 3M Brand Composite Conductor at high operating temperatures. It uses the helical rod design, which places minimal compression loading on the conductor. A multi-layer design maximizes both the holding strength and heat dissipation, and has the advantage of easy installation.

***Table 8: Strength Data for Helical-Rod Dead-End and Joint/Splice Assemblies***

| Load (lbs) | Load (kN) | % RBS | Failure Location | Hardware Type |
|---|---|---|---|---|
| 30,213 | 134.4 | 97 | Mid-span | Dead-end |
| 30,319 | 134.9 | 97 | Mid-span | Dead-end |
| 30,200 | 134.3 | 97 | Mid-span | Dead-end |
| 29,569 | 131.5 | 95 | Mid-span | Joint |

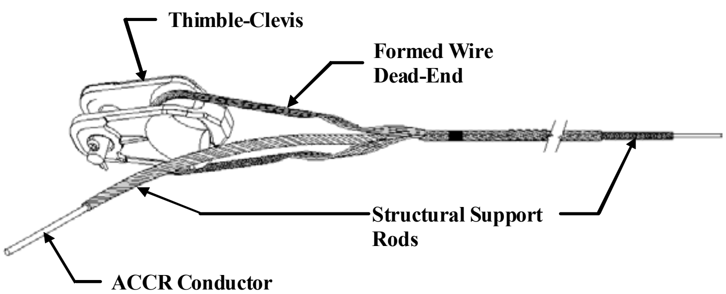



***Figure 12: Helical-rod dead-end assembly***

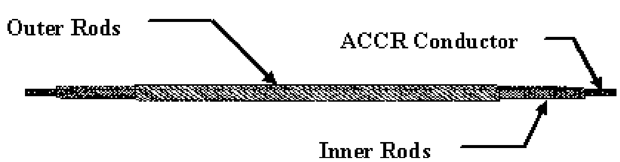



***Figure 13: Helical-rod full-tension splice / joint assembly***

### *Tensile Strength*

Tensile tests were performed using a 50ft long sample terminated at both ends with dead-ends. This created a gauge length of 25 ft (7.6 m). To evaluate joints, the same configuration was cut in the center, and then re-connected using a joint. This demonstrated satisfactory support for >95% RBS of the conductor. Data are shown in Table 8 for the 795-kcmil 3M Composite Conductor, tested at room temperature. The %RBS is based on an RBS of 31,134 lbs (138.5 kN).

### *Sustained Load*

Additionally, a sustained-load test was performed at 20°C following ANSI C119.4. A 65 ft-long (19.8 m) sample was terminated with two helical-rod dead-end assemblies, and then held under tension at 77% RBS (23,970 lbs) for 168 hours. Thereafter, the sample was pulled in tension to failure, as shown in Figures 14. The failure load was 32,180 lbs (103% RBS). This shows the dead-end adequately passes the sustained load requirement. A similar test performed on a full-tension mid-span splice/joint, resulted in a retained failure load of 29,630 lbs (95% RBS), thus meeting the 95% strength requirement stated in ANSI C119.4.

***Figure 14: Testing of helical-rod joint to destruction in a tensile test.***

An additional sustained load test was performed at elevated temperature. This test was conducted on a 65 ft (19.8 m) long sample, configured with PLP helical rod dead-ends at either end of the sample. The sample was held at 15% RBS and 240°C for 168 hours. At this conductor temperature, the helical rods ran much cooler at 105°C. The residual strength was measured thereafter at room temperature (20°C), and was found to be 32,210 lbs (103% RBS), and thus passes the test. A similar test was performed to assess a full-tension mid-span splice/joint, which resulted in a retained failure load of 31,876 lbs (102% RBS).

### *High-Voltage Corona (RIV)*

Testing was conducted to determine radio influenced voltage (RIV) noise on a dead-end and on a midspan splice/joint. The ends of the helical rods had a standard "ball-end" finish. No noise (corona onset) was detected up to 306 kV (phase-phase) for the splice/joint in a single conductor configuration. The dead-end had a corona onset at 307 kV (phase-phase) for a single conductor configuration.

## Suspension Assemblies

Preformed Line Products (PLP) provided and tested suspension assemblies for the 3M Brand Composite Conductor, as shown in Figure 15. These accessories are based on field-proven ARMOR-GRIP® Suspensions. The multi-layer design maximizes the mechanical protection and heat dissipation, while minimizing heat transfer to mating hardware and insulators. A cushioned insert provides protection against wind and ice loads. The helical rods also provide local stiffening to the conductor, which reduces the bending strains on the conductor.

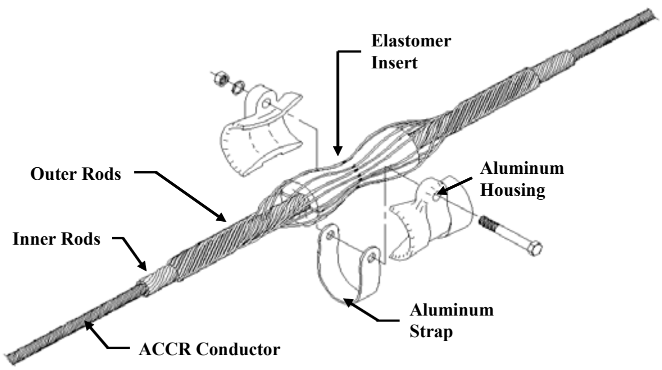



*Figure 15: Helical-Rod Suspension Assembly from PLP.*

### Turning Angle

Turning angle tests ensure the 3M Composite Conductor can carry high mechanical tensile loads through a 32° turning angle without failure in the bending region, as shown in Figure 16. For the 795-kcmil Composite Conductor, no damage or wire failures were reported at the peak 40% RBS tensile loading. This was confirmed after the full disassembly of each of the suspension and conductor layers. In actual field use where large turning angles are required (e.g. 60°), two suspension assemblies would be used placed 18-24 inches (50-70 cm) apart with a continuous layer of rods through both assemblies.

*Figure 16: Suspension Assembly for 795-kcmil 3M*

### Unbalanced Load

Unbalanced load tests simulate situations where neighboring spans have very different loads, such as those due to ice accumulation. To mitigate this, the assembly is designed to allow the conductor to slip, which then changes the sags of the adjacent spans and permits more equal tensions on the spans. In the test, a 795-kcmil suspension assembly was anchored, and a length of new, un-weathered, conductor was pulled in an attempt to pull it through the assembly, as shown in Figure 17. Two tests both exhibited no slip up to 15% RBS tension and then continuous slip at 20% RBS. Subsequent disassembly of the suspension and the conductor layers revealed no evidence of damage to the conductor or suspension components. Thus the suspension assembly provides satisfactory behavior.

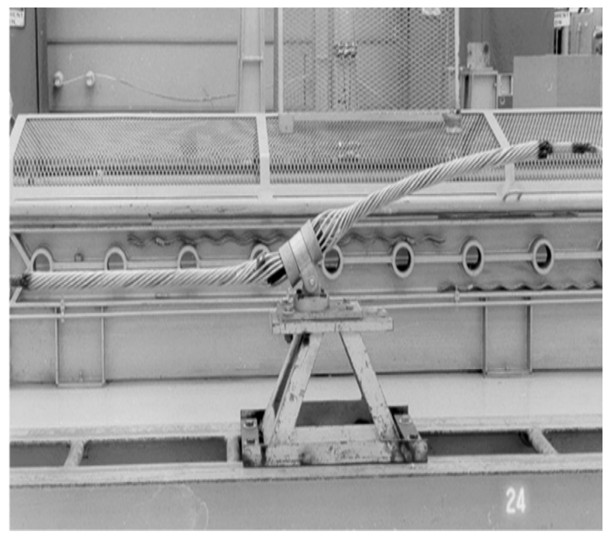


*Figure 17: Unbalanced load test carried 15%RBS before slipping.*

### Elevated Temperature

As with terminations and joints, the temperature differences between the conductor and the suspension assembly must be clearly understood to ensure the assembly retains its strength. In the test, the conductor was heated to 240°C while under a tension of 15% RBS for 168 hours. Using embedded thermocouples, the temperature was monitored at the elastomer insert for a 795-kcmil 3M Composite Conductor. It was found to be 54°C when the conductor was at 240°C. Based on this temperature information and the rating of the elastomer material to 110°C, it is believed that these materials have sufficient durability at the maximum temperatures at which the suspension operates.

### Galloping

*Galloping*, a high-amplitude vibration that occurs in transmission lines under certain resonant conditions, was tested at PLP's facilities following IEEE 1138 test procedures. In these tests the goal was to measure the endurance limit and to characterize any damage to suspension hardware or conductor. A length of 795-kcmil Composite Conductor was terminated at each end using helical-rod dead-end assemblies with a helical rod Suspension Assembly at a 5° turning angle in the center, as shown in Figure 18. This produced two spans each of 82 ft (25m). The conductor was held under a constant tension of 25% RBS. An actuator created low frequency (1.8 Hz) vibrations and produced a maximum vibration amplitude of 39 inches (1m). In the test, 100,000 cycles were successfully completed with no damage to either the conductor or suspension hardware. The conductor was disassembled for visual inspection, which further indicated no damage.

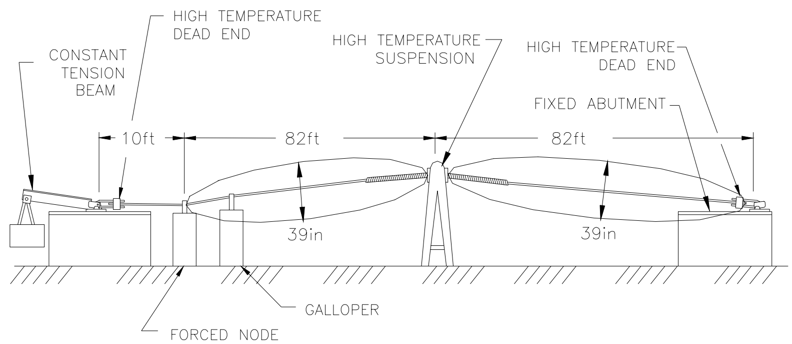



***Figure 18: Schematic of the test setup to evaluate resistance to galloping of the helical-rod dead-end and suspension assemblies.***

### Aeolian Vibration

The purpose of this testing is to demonstrate that the conductor accessories will protect the 3M Brand Composite Conductor when it is subjected to dynamic, wind induced bending stresses. Laboratory aeolian vibration testing at higher levels of activity than found in the field, is commonly used to demonstrate the effectiveness of accessories under controlled and accelerated conditions. The only published industry test specification for aeolian vibration testing is for vibration testing of Optical Ground Wire (OPGW). This specification is IEEE 1138 and was adopted for the testing of the 3M Composite Conductor.

Using a vibration shaker (Figure 19), a 20m sub-span of 795 kcmil Composite Conductor was tensioned to 25% RBS using a beam/weight basket, and maintained at a vibration frequency of 29 hertz, and an anti-node amplitude of 0.37" peak-to-peak, (one-third of conductor diameter), for a period of 100 million cycles. Visual observations were made twice daily of the conductor and the Suspension Assembly (5° turning angle) during the test period. At the completion of the test period the Suspension Assembly was removed and carefully inspected for wear or other damage. The section of the conductor at the Support Assembly was cut out of the span and dissected to determine if any wear or damage had occurred to the Al-Zr outer strand, the aluminum tape or to the composite core. After 100 million cycles of severe aeolian vibration activity there was no wear or damage observed on the components of the Suspension Assembly, nor on any of the conductor constituents.

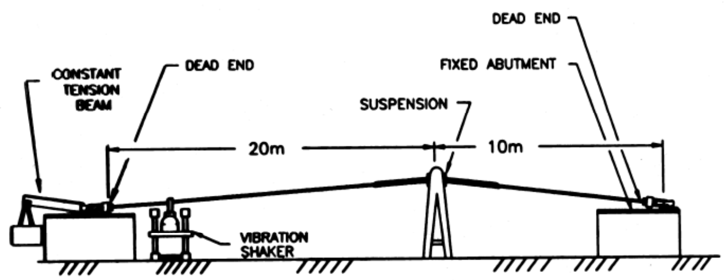



***Figure 19: Aeolian Vibration Test Arrangement for Suspension Assembly***

### High Voltage Corona (RIV)

Testing was conducted to determine radio influenced voltage (RIV) noise on a suspension assembly. The ends of the helical rods had a higher quality "parrot-bill end" finish for use with a single conductor. No noise was detected up to 289 kV (phase-phase) for a single conductor. For a twin bundle test, the more typical "ball-end" rods were used and no noise was detected up to 510kV.

## Dampers

*Dampers*, available from Alcoa-Fujikura, are used to reduce the vibration amplitude by absorbing a portion of the wind-induced energy, as shown in Figures 20 and 21. This results in a reduction of bending amplitudes near the conductor attachment points. Dampers were qualified for 795-kcmil 3M Composite Conductor by testing according to IEEE 664. The standing wave ratio method was used, with a span tension of 25% RBS (7783 pounds).

The 795-kcmil 3M Brand Composite Conductor is adequately dampened with the 1706-10 damper, which is the same one that would be used for ACSR conductor of similar construction. Damping efficiencies for 1706-10 dampers were measured and compared to the 26% acceptance curves, as shown in Figure 22, showing they meet or exceed the requirement and will provide adequate protection on 795-kcmil conductor.

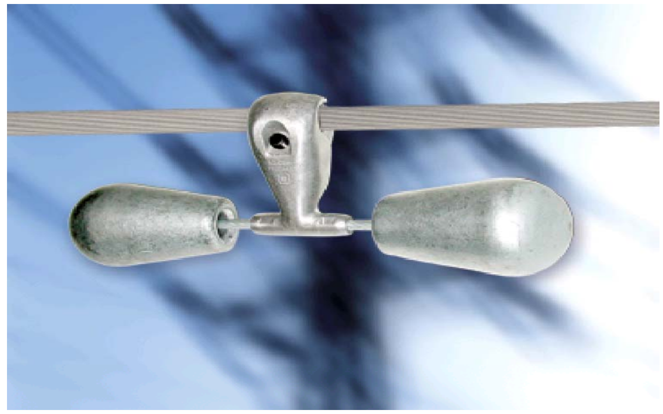


***Figure 20: Damper from Alcoa-Fujikura.***

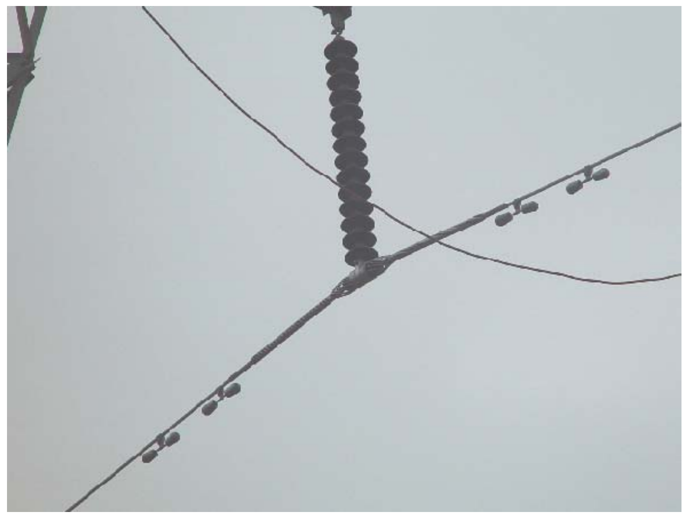


***Figure 21: Dampers were installed on the 795-kcmil 3M Composite Conductor in the WAPA 230-kV network.***

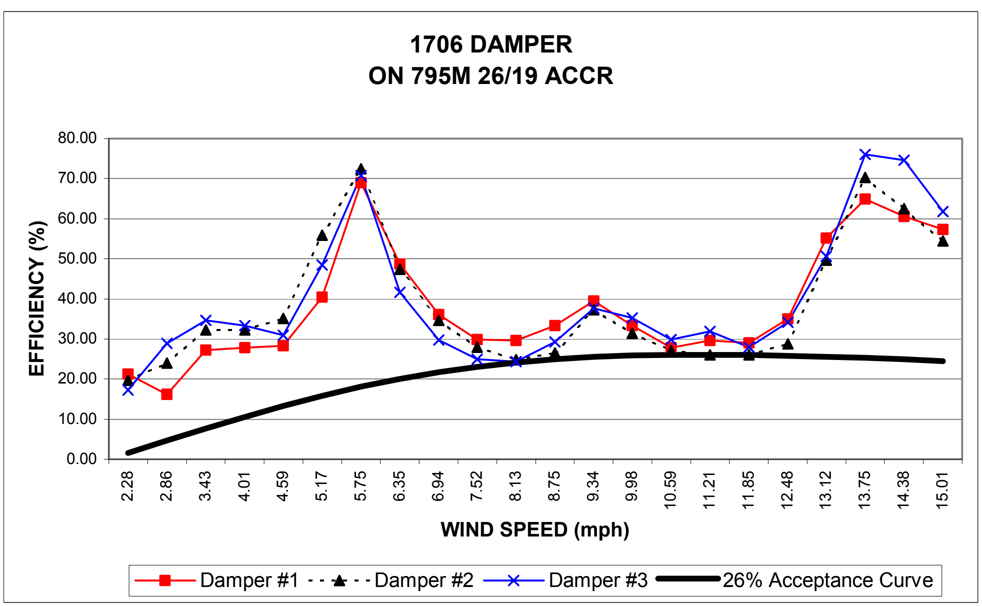



***Figure 22: Efficiency vs. wind-speed showing performance of the 1706-10 damper on a 795-kcmil 3M Composite Conductor***

## Stringing Blocks (Sheaves)

Large diameter stringing blocks (or sheaves) should be used during installation to minimize bending strains. 3M recommends using lined blocks with a minimum diameter of 28 in (71 cm)

*Figure 23: 795-kcmil 3M Composite Conductor passing over a 28 inch block during the sheave test*

### Sheave Test

To verify the suitability of using a 28" diameter block for installation of 795-kcmil 3M Brand Composite Conductor, a simple sheave test was performed. A 100 ft (30 m) length of conductor was strung through a 28" diameter sheave with a contact angle of 120° (Figure 23). The conductor was tensioned to 15% RBS (4670 lbs), and pulled through the block for a length of 30 ft (9 m). From this section, a tensile test sample was subsequently prepared, to measure the residual strength. A 10 ft (3 m) long test sample broke at 31,480 lbs (101% RBS), suggesting no damage from the block and that a 28" diameter block would be suitable for installation.

| *Block Diameter (ins)* | *Residual Strength (%RBS)* | *Safety Factor at 2000 lbs tension* | *Safety Factor at 5000 lbs tension* |
|---|---|---|---|
| 28 | 101 | 2 | 1.8 |
| 22 | 97 | 1.5 | 1.4 |
| 14 | 100 | 1.05 | 1 |

*Table 9. Decreasing the block diameter does not reduce the residual tensile strength but does reduce the available safety factor.*

Similar experiments performed using smaller block diameters are shown in Table 9. This shows that the residual tensile strength remains unaffected after passing over a small diameter block. However the safety factor for using smaller blocks quickly reduces until at a 14" diameter there is no safety margin. The conductor is stressed to the breaking point under combined bending over a 14" block and 5000 lbs of tension.

Thus the recommendation of using a 28" diameter block preserves a safety factor of approximately 2, so long as the stringing tension is < 20% RBS, and the turning angle is < 120°.

# Installation Guidelines

## General

The installation of composite conductors basically follows IEEE 524, "Installation Guidelines for Overhead Transmission Conductors". However there are some additional requirements such as the use of DG-Grips (Distribution Grips). Departures from the traditional equipment and procedures used for ACSR are summarized in Tables 10 and 11.

| Installation Equipment | ACSR | ACCR |
|---|---|---|
| Stringing Blocks | Yes | Yes (28") |
| Bull Wheel | Yes | Yes (36") |
| Drum Puller | Yes | Yes |
| Sock Splice | Yes | Yes |
| Conductor Grips | Any | DG-Grips |
| Cable Spools | Yes | Yes (40" Drum) |
| Cable Cutter | Yes | Yes |
| Reel Stands | Yes | Yes |
| Grounding Clamps | Yes | Yes |
| Running Ground | Yes | Yes |

***Table 10: Comparison of installation equipment needs between ACSR and the 3M Composite Conductor (ACCR)***

| Installation Procedure | ACSR | ACCR |
|---|---|---|
| Cable Stringing | Tension / Slack | Tension |
| Sag Tensioning | Any | Line of sight, Dynometer |
| Dead Ending | Any | Use DG-Grip with chain hoists |
| Clipping | Any | Any |

***Table 11: Comparison of installation procedures between ACSR and the 3M Composite Conductor (ACCR)***

The installation of 795-kcmil 3M Brand Composite Conductor at Fargo, North Dakota on the 230-kV network of WAPA provides an excellent study of the required installation practices for this type of conductor. As seen in the Tables above, the major departure from ACSR installation revolves around the care of bend radii. Bending of the composite conductor must be carefully monitored during installation to avoid damage to the composite core. The combination of bending and tensile loads can damage the core if they exceed the allowable core strength. Thus specific recommendations on the use of conductor grips and block diameters are necessary.

## Installation Equipment

Standard bull wheel and puller equipment were used, but with the added requirement that the bull wheel diameters

***Figure 24: A 36 inch bull wheel with reel stand (left) and standard drum puller (right), used to install 3M Composite Conductor***

were at least 36 inches (91 cm) (Figure 24).

During pulling through blocks, a swivel should be used to minimize twisting of the conductor. A *sock splice*, also known as a basket grip, Kellem grip, or wire mesh, can be used to pull composite conductors (Figure 25). An example of a sock splice can be found in the GREENLEE® product catalog. A running ground was used with a rotation marker, although very little rotation (one revolution per 100 ft) was observed.

***Figure 25: A sock splice with swivel used to pull 3M Composite Conductor in behind ACSR (left) and a 28 inch stringing blocs (right), used to install 3M Composite Conductor***

### Stringing Block (Sheaves)

According to IEEE Std. 524, as sheave diameters are increased, several advantages are gained. First, the radius of bending of the conductor is increased, so the amount of strain in the wires is reduced. Second, the bearing pressures between conductor strand layers are reduced, thus reducing potential conductor internal strand damage. (This is commonly known as strand notching). Lined blocks are recommended for use with composite conductors. The recommended diameter for the 795-kcmil 3M Composite Conductor is 28 inches (Figure 25). Also, for the 3M Composite Conductor as well as AAC and

ACSR, the maximum tensile stresses are obtained by superposition of tensile (pulling tension during stringing) and bending stresses (bending around stringing blocks). If the addition of all stresses exceeds the Rated Breaking Strength (RBS), the conductor will be damaged. The relationship between RBS, bend diameter, and superimposed tension is illustrated in Figure 26. It shows that a 28 inch (71 cm) block can safely be used (safety factor of 2) with the 795-kcmil conductor if the tension is less than 2000 lbs. Additionally, 36 inch (91 cm) diameter wheels should be used for the bull wheel-tensioner, for pulling tensions up to 5000 lbs, for the same reason of minimizing bending strains in the conductor.

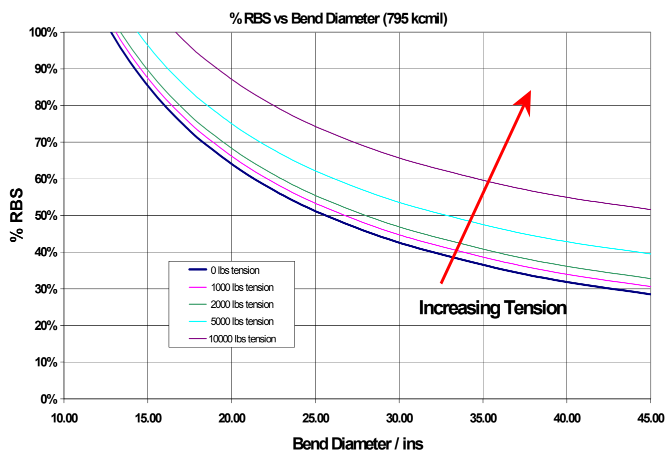



***Figure 26: %RBS vs. bend diameter for 795-kcmil 3M Composite Conductor. Contours show how increasing applied tensions combined with bend diameters, increase the effective conductor loading (%RBS)***

### Hardware Installation

After pulling in over the blocks, dead-ends, suspension assemblies and mid-span splices were installed. For this particular installation, a combination of hardware types was used, namely compression dead-ends and splices from Alcoa-Fujikura and helical–rod dead-ends and splices from Preformed Line Products. All the suspension assemblies were of the helical rod type, marketed under the trademark THERMOLIGN™, from Preformed Line Products (Figure 27).

***Figure 27 : Helical-rod suspension assembly being installed (left) and complete with dampers (right)***

Dampers were installed on either side of the suspension assemblies. Compression hardware requires the use of a 100 Ton press using standard production dies from Alcoa-Fujikura. This ensured long dies bites that helped to minimize any potential for bowing in the accessory.

### Conductor Grips

The preferred method for introducing tension into the conductor is to tension the conductor with a helical-rod DG Grip (Distribution Grip) as seen in Figure 28, that is removed after the sag procedure is completed. Rigid grips, such as Chicago Grips should never be used with this conductor because they cause damage. DG Grips are rated to 60% of the conductor RBS, and can only be used three times during installation for the purpose of gripping the conductor. For cases where high tensions or high safety factors are required, Helical-rod dead-end assemblies may be used. These are specifically designed to carry the full load of the conductor without any potential damage to the conductor, as shown in Figure 28. To facilitate removal, the structural rods should not be snapped together at the end, when using the helical-rod assemblies as a conductor grip. A helical-rod dead-end should only be used once as a conductor grip and can then still be re-used as a permanent dead-end. Final sag is set using dynameters.

***Figure 28 : Helical-rod DG-Grip (top) and dead-end assemblies (bottom) may be used as a conductor grip***

# Quick Reference

## Properties

A brief summary of 26/19, 795-kcmil 3M Composite Conductor behavior is shown in the following table.

***Table of Properties***

| Property | Summary |
|---|---|
| Construction (for 26/19) | 26 wires of temperature resistant Al-Zr alloy, 19 wires of aluminum matrix composite |
| Tensile Strength | Conductor meets the rated breaking strength. |
| Stress-Strain curves | Design coefficients derived |
| Aeolian Vibration | Excellent resistance. No damage |
| Electrical Resistance | Meets prediction. |
| Axial Impact Resistance | Excellent. Exceeds RBS under shock loads. Helical rod dead-end supports load. |
| Torsional Ductility | High ductility. Aluminum strands fail before core > 88 degrees/ft (289 degrees/m) |
| Crush Strength | Meets IEEE 1138 requirement – no damage, full strength retention |
| Short-circuit response | Runs cooler than equivalent ACSR conductor. Good Performance |
| Lightning Resistance | Damage levels equivalent to ACSR |
| Terminations & Joints | Alcoa-Fujikura compression style, and helical-rod assemblies from PLP. Hardware runs much cooler than conductor at high temperature, excellent mechanical properties |
| Suspension Assemblies | Helical-rod assemblies from PLP. Runs cool at high conductor temperatures, excellent mechanical properties. |
| Galloping | Excellent resistance. No damage |
| Dampers | Alcoa-Fujikura style. Use dampers at all times. |
| Stringing Blocks | Important to oversize blocks-28 inch (71cm) diameter. Full strength retention after sheave test. |
| Installation Guidelines | Follow IEEE 524. Only use tension method, large blocks, swivels, sock splice, and only use preformed conductor DG-grips to tension. Avoid tight radius requirements. |

## Accessories

A summary of accessories and their suppliers is shown in the following table.

***Table of Accessories and Suppliers***

| Accessory | Alcoa-Fujikura | Preformed Line Products | Other |
|---|---|---|---|
| Dead-end | X | X | |
| Joint/Splice | X | X | |
| Jumper Terminal | X | | |
| Jumper Connectors | X | | |
| Tee Tabs | X | | |
| Repair Sleeves | X | X | |
| Parallel Groove Clamps | X | | |
| Dampers | X | | |
| Spacers | | X | |
| Sock Splice | | | X |
| Swivels | | | X |
| Grips | | X | |
| Sheaves - Blocks | | | X |

## Questions/Contacts

For more information, design help, price quotes, and other information you can contact 3M directly.

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