995.0 kcmil ACCS/TW/C7® Overhead Conductor Tensile Tests

NEETRAC Project: 24-151

Final

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NEETRAC
National Electric Energy Testing, Research, and Applications Center

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NOTICE

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1.0 BACKGROUND

This project covers the tensile testing of the complete conductor, complete core, and individual strands from 995.0 kcmil ACCS/TW/C7 conductor provided by the Lower Colorado River Authority (LCRA).

An overhead conductor is an assembly of conductive strands, typically aluminum or aluminum alloy. Most designs incorporate a high strength core, which is typically steel but composite materials are gaining popularity. Regardless of steel or composite, a core can be a single strand or multi-strand. Conductor specifications are computed based on a weighted average of the properties of each component, modified by "stranding factors" to account for stranding effects.

This report provides test data and examines conductor strength from three (3) complimentary perspectives:

1. Nominal strength, which according to the governing Standards, is the sum of nominal required strength of the components with de-rating factors to account for manufacturing and stranding effects.

2. Expected strength based on the tensile test results for the core strands and the aluminum strands, and applying the same derating factors used to compute the nominal strength

3. Direct tensile test of the complete conductor and complete core, using laboratory end fittings.

Caveat: conductor standards require manufacturer agreement to apply the component acceptance criteria to strands removed from a finished conductor. There is an additional stipulation that if the manufacturer agrees to testing after stranding, the acceptance criteria are reduced to 95% of the pre-stranding requirement. This restriction is reasonable because properties change during manufacturing. Strand tests were performed after manufacturing and without manufacturer agreement. Accordingly, the individual strand tests should be considered "for information only".

2.0 TEST SAMPLES

Test samples were removed from a reel provided by INL circa January 2025. The designation on the reel identified the conductor as 995.0 kcmil ACCS/TW/C7.

3.0 PROCEDURE AND TEST APPARATUS

Conductor samples were cut from the reel. A bolted clamp was applied to each end of the sample before the sample was cut. This practice ensures the manufacturing pre-stress is preserved in the test sample. For the strand tests, the samples were disassembled to individual aluminum and core strands. Each strand was labeled to preserve the sample number and location in the conductor.

3.1 Aluminum Single-Strand Tensile/Elongation Tests

The individual strand samples were cut to 14-inch length to provide a gripping section and a 10-inch gage section. The gage section was marked using an indelible black marker, with a fine scratch mark placed 10.000 inches apart. The Standards define the elongation as the percent change in the distance between the gage marks when the fractured ends are joined. Figure 1 shows a C7 strand under test.

In addition to the breaking strength (in lb), the normalized tensile strength (in psi) was computed using the strand area measurement.

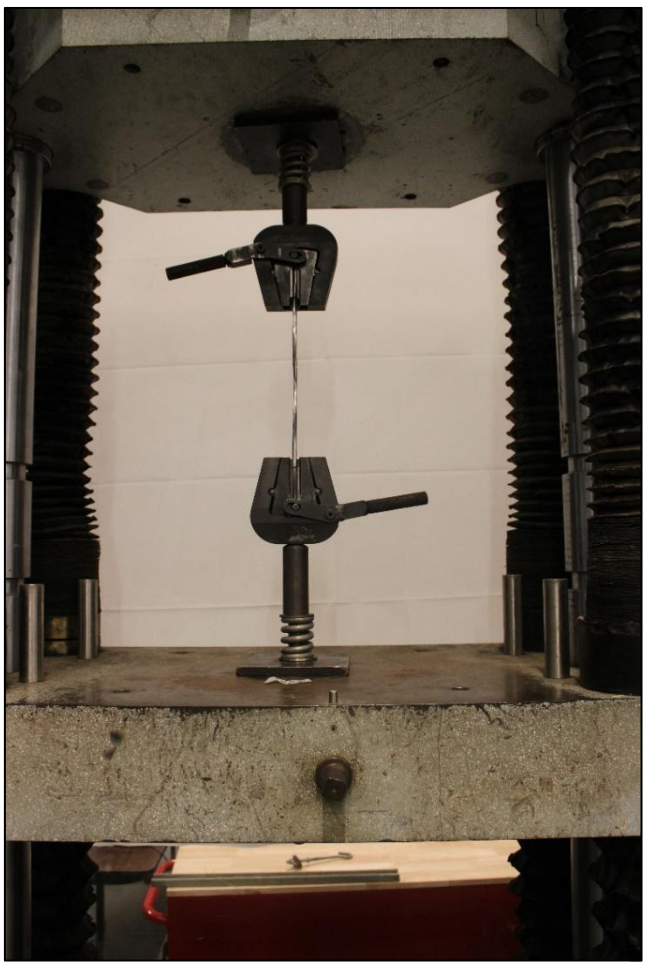

Figure 1: Single-Strand Tensile Test

<u>3.2</u> <u>Aluminum Strand Area</u>

The C7 conductor uses trapezoidal wire (TW) shaped aluminum strands to increase the aluminum packing factor. Direct area measurement is not practical due to the shapes used for TW strands. Accordingly, the strand areas and the total area were determined using the mass method of ASTM B263. Individual strands were straightened and cut to 24-inch length. A wide-range caliper micrometer (Figure 2) was used to obtain the precise length. The strand is then weighed on a gram balance (Figure 3). The mass, the length, and the density are used to impute the aluminum area and the equivalent round-wire diameter.

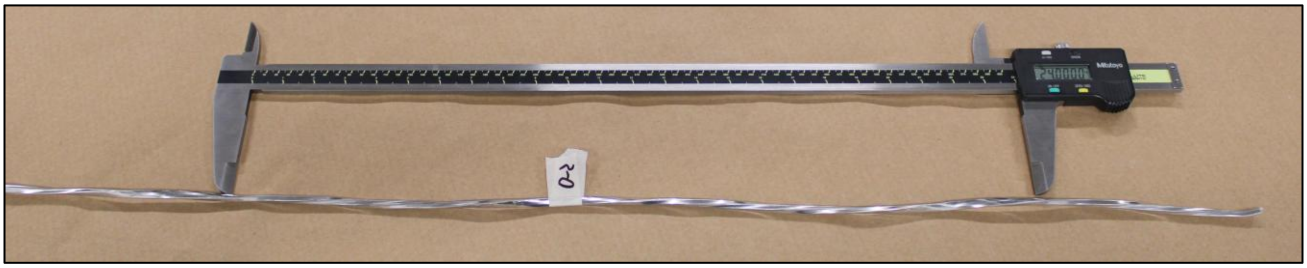

Figure 2: Length Measurement

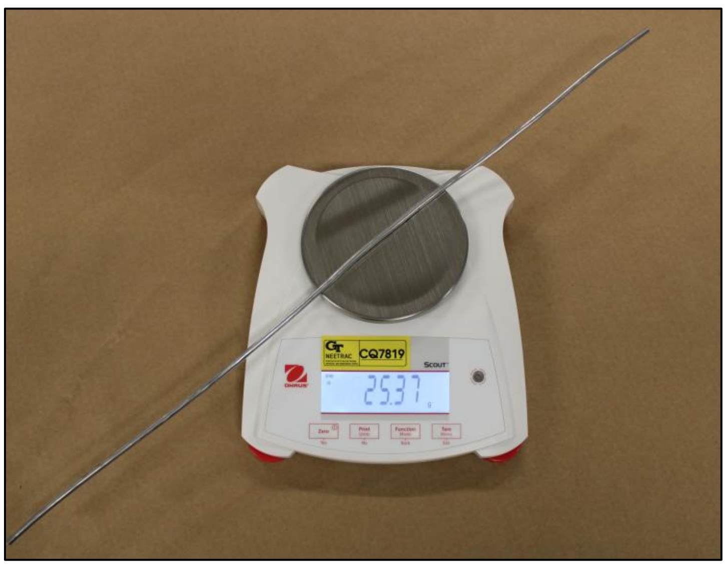

Figure 3: Mass Measurement

The mass method was repeated for a nominal 2-ft section of complete conductor. A "stranding factor" provided by the manufacturer is used to account for the extra length of the helix shaped strands.

<u>CFC Core Strands</u>: core strands were previously tested for residual strength following crush testing. One reference sample (no prior testing) was included in the crush test. Those results are repeated here.

Tensile testing of the CFC core strands was problematic because vee-wedge grips typically used for strand tests crushed the soft matrix resulting in low tensile values. As an alternative, the maximum fiber stress was determined by measuring the bending radius at rupture. This is not a tensile failure mode because CFC strands in bending fail on the compression side of the bend, and at a lower stress than the tensile failure load. Nonetheless, rupture in bending provides a representative estimate for the tensile strength.

A template with circles was drafted to provide a reference for the bending radius. A video of each bending test was taken to capture the moment of rupture. Freeze-frame editing software was used to capture the final frame before the strand ruptured. The image was then used to determine the minimum bending radius (maximum fiber stress) before rupture. This method proved quite robust as the bent shape was circular until the moment of rupture, and the number of pixels in the image was scaled and used to determine the radius of curvature of the C7 strand. Figure 4 shows the video frame immediately prior to rupture, and the frame immediately following the rupture.

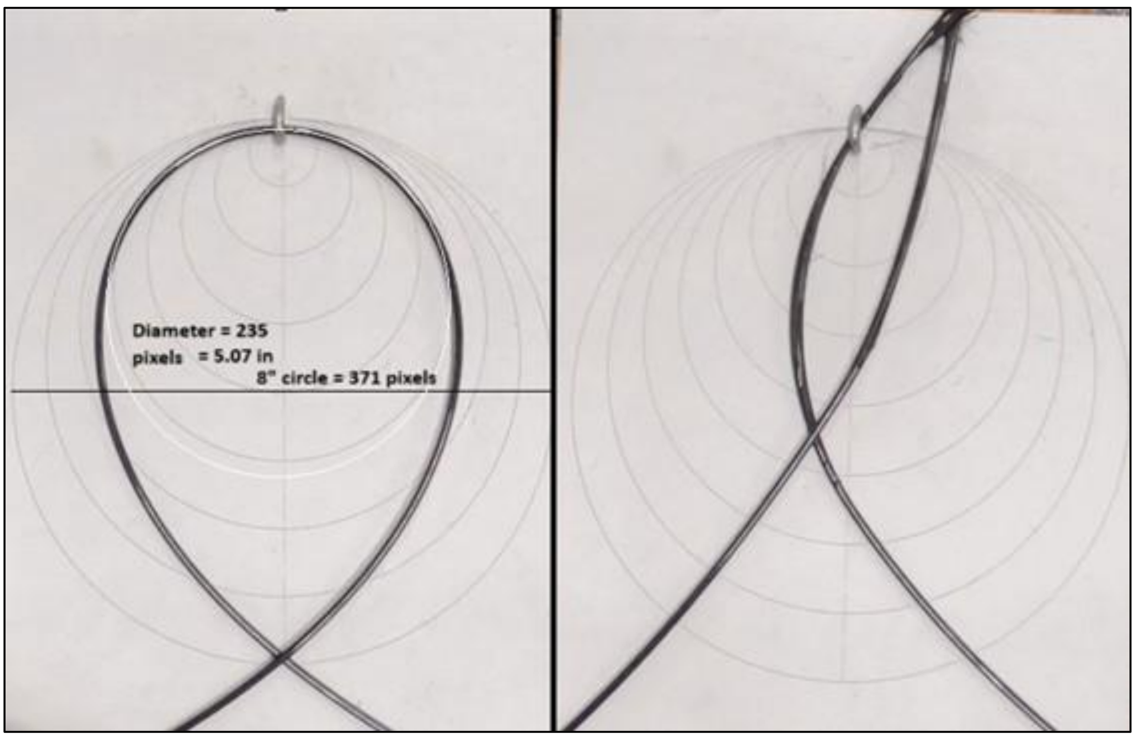

Figure 4 Image at Rupture (Left) and Immediately After (Right)

The white circle visible in the right image of Figure 4 was superimposed on the strand image using graphics software. The straight black line represents the diameter of the 8-in circle. Based on the pixel resolution, the resolution of the bending radius measurement is 0.02 in (0.4% of the 5-inch measured circle).

An elegant beam formula is available to compute the maximum fiber stress based on the bending radius, elastic modulus and the distance of the fiber from the neutral axis:

$$\sigma = Ey/R$$

Where σ: stress (psi)

E: elastic modulus (psi)

y: distance from the neutral axis of bending (in)

R: radius of curvature (in)

3.3 Tensile Tests of Complete Conductor and Complete Core

NEETRAC did not test the complete conductor, because EPRI already provided results from their stress-strain test. The C7 core was tested by preparing a complete conductor sample, and removing the aluminum strands while the sample was under a low initial tension in the tensile test machine. The EPRI data on the complete conductor test is provided to have all tensile test results in this report.

4.0 RESULTS

4.1 Aluminum TW Strands

Dimensions: Figure 5 shows the area data for straightened strands from each layer.

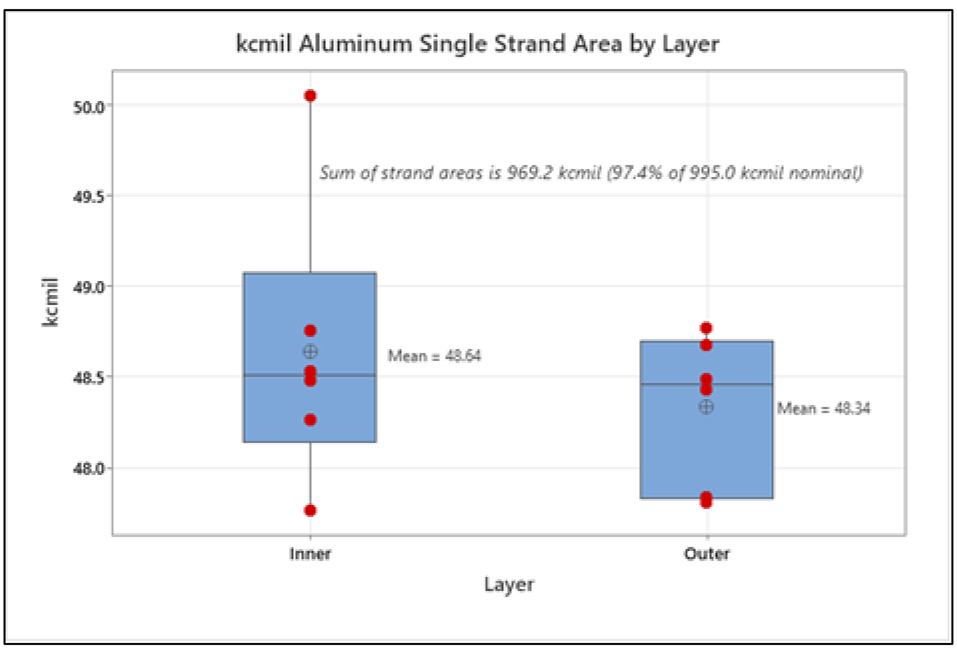

Figure 5: Area Data for C7 Aluminum Strands

Figure 5 is missing limit lines because the size and shape of TW strands are treated as trade secret and values are not published. The total conductor kcmil area can be determined since we know the inner layer contains eight (8) strands, and the outer layer contains twelve (12) strands. Using the mean value by layer, the total conducting area is 969.2 kcmil, which is 97.4% of the 995.0 kcmil nominal conductor size.

As a cross-check, the mass method measurement was performed for strands in the helix shape as removed from a specified length of conductor. The difference is that the length measurement is made on the intact conductor cut with square ends. The manufacturer's stranding factor (see Appendix) was used to correct for the extra length in the helix shape (as opposed to a straightened strand). This method provides the area directly, but cannot distinguish differences between the two layers.

The total conductor area for the mass method is 971.9 kcmil, which matches the straightened strand result within 0.28%.

Breaking Strength: the original breaking strength data showed the outer layer strands measured 12.5% stronger than the inner layer strands. This was considered anomalous because the area measurement shows both layers have the same area. Since it is nominally the identical material, the expectation was that the strength would measure the same. Both the tensile test and the area measurement were repeated independently to resolve the apparent discrepancy. All results were repeatable with no statistically significant differences between the two sets of data. The difference in the tensile strength among strands from the different layers is therefore a real difference.

Figure 6 shows the two data sets by layer and by technician.

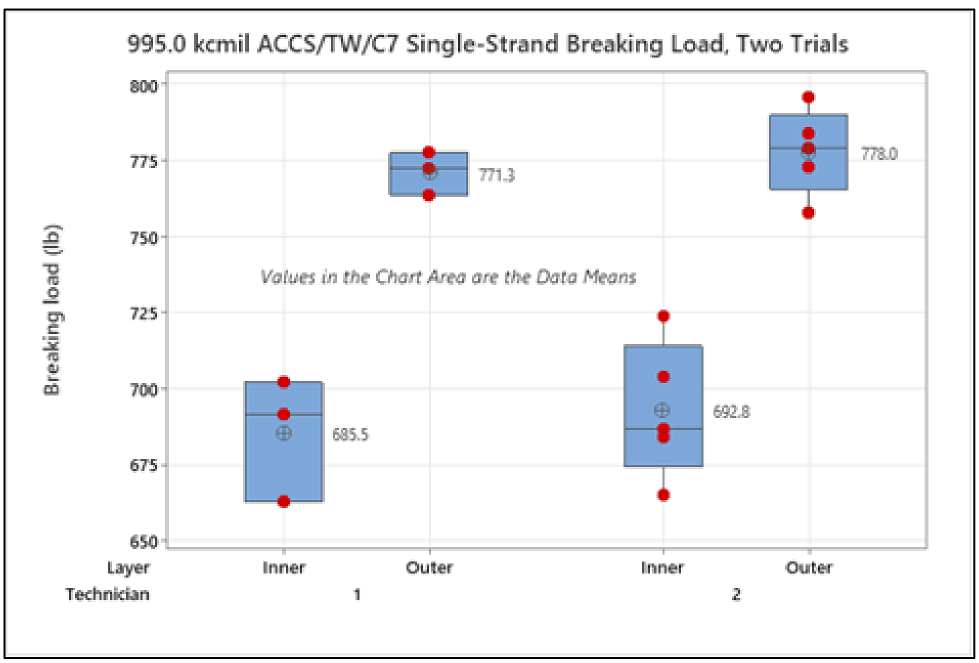

Figure 6: Breaking Strength for C7 Aluminum Strands

Normalized tensile strength: requirements for O-temper aluminum strands for overhead conductors are governed by ASTM B609, "Aluminum 1350 Round Wire, Annealed and Intermediate Tempers, for Electrical Purposes". Requirements for TW strands reference the round-wire standard, using a round-wire equivalent for the TW strand. Using the mean area from Figure 5, the equivalent round wire diameter for the inner layer TW strands is the square root of the cmil area, or 0.2195 in. The round-wire equivalent for the outer layer strands is 0.2198 in. Regardless of the strand size, the allowable tensile strength for O-temper aluminum is 8.5 kpsi to 14.0 kpsi. These values apply only before stranding. The tensile strength data from Figure 6 was normalized by dividing breaking load by the strand area. Since the technician is not a significant factor, the results are merged to best compute the average tensile strength.

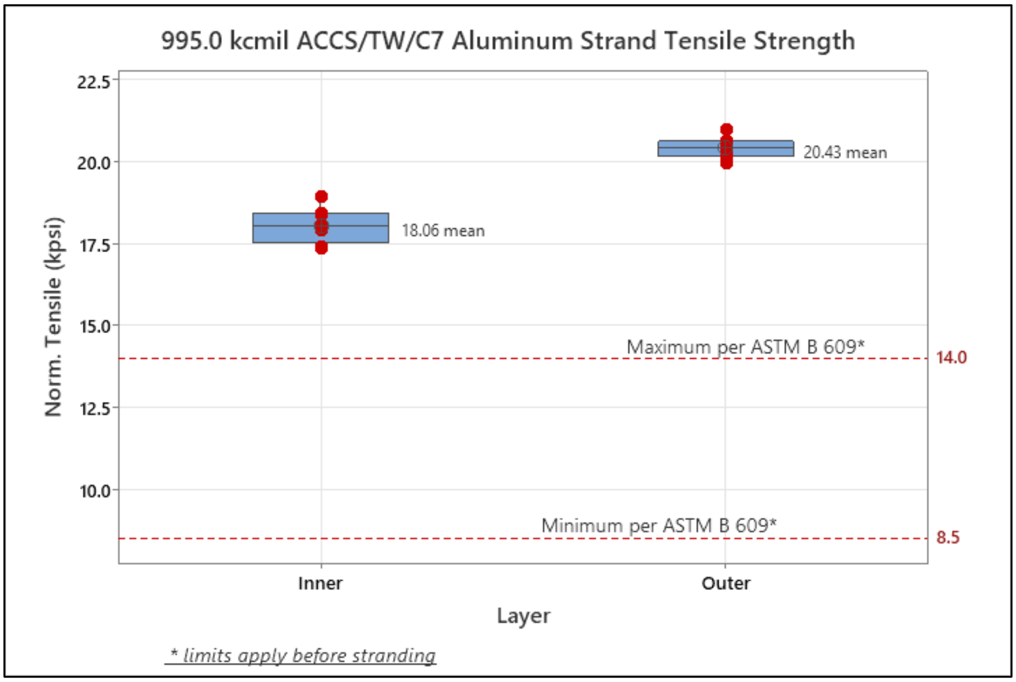

Figure 7: Normalized Tensile Strength Data

Elongation: Figure 8 shows the elongation data for the aluminum strands. There are currently no consensus standards for C7 conductor. The closest reference is ASTM B857, which has requirements for ACSS/TW conductor. Both designs have similar TW aluminum strands and strand counts. The difference is ACSS/TW has a stranded steel core whereas C7 has a stranded CFC core.

ASTM B857 requires that the annealed aluminum strands exceed 20% elongation after stranding. For ductile metals such as aluminum, elongation and tensile strength are inversely related. The low elongation measurements (Figure 8) are consistent with the high tensile strength shown in Figure 7.

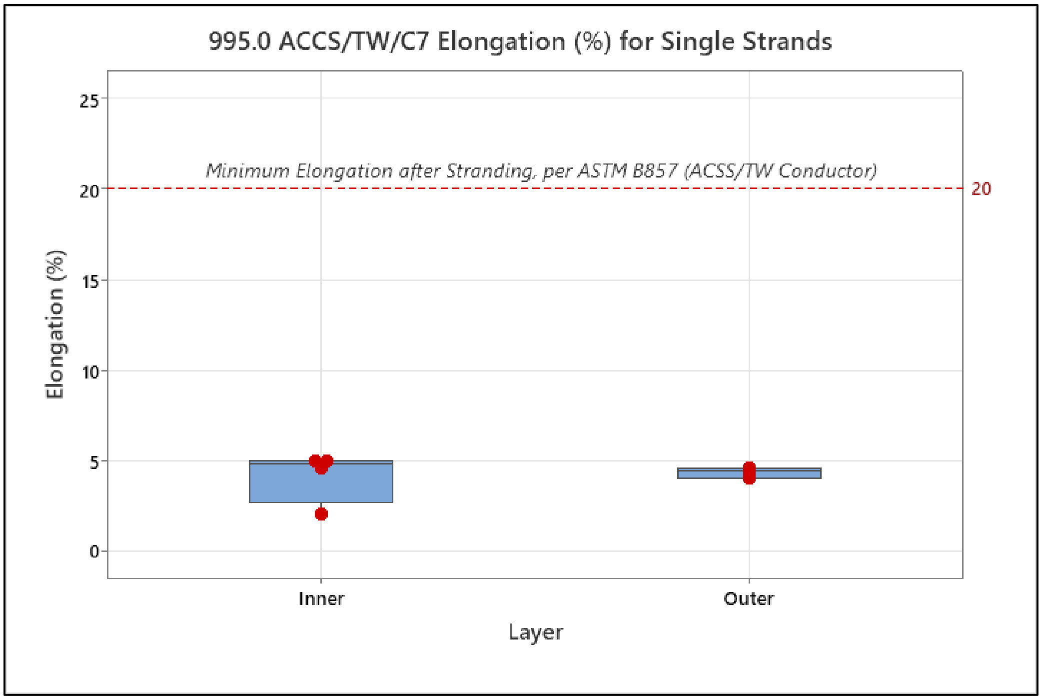

Figure 8: C7 Aluminum Strand Elongation Data

4.2 CFC Core Strands

Figure 9 shows the fiber stress computed from the bending radius test.

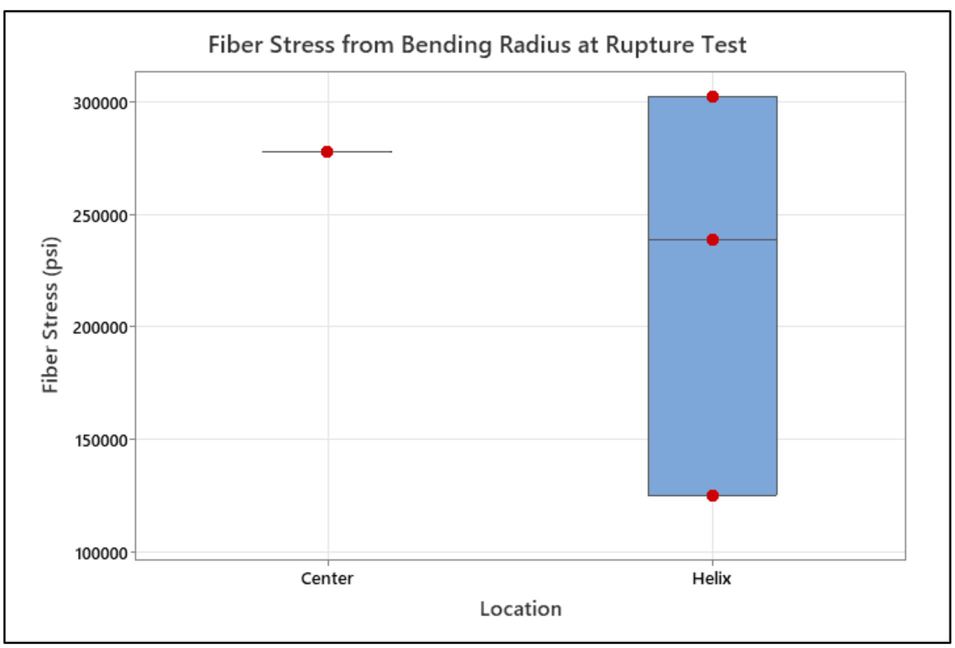

Figure 9: C7 Core Strand Maximum Fiber Stress from Bending Test

Figure 10 shows the estimated breaking strength based on the fiber stress. Actual tensile values are expected to be higher.

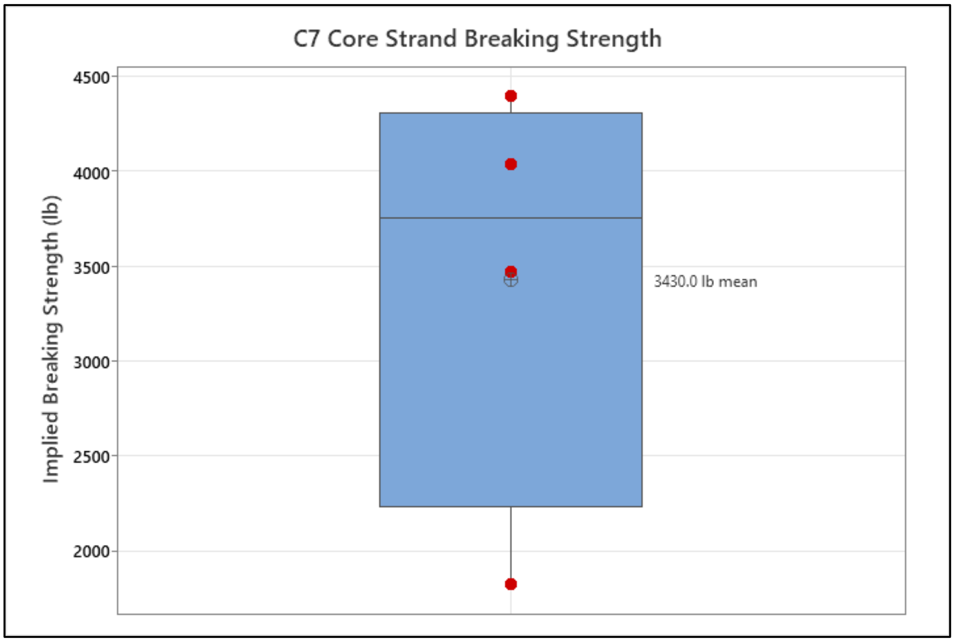

Figure 10: C7 Core Strand Breaking Strength Estimated from Bending Test

4.3 Conductor Breaking Strength

The manufacturer's specification sheet lists the rated breaking strength (RBS) of the complete conductor as 33,500 lb. Ratings for conductor strength are computed using the required minimum strength and the nominal dimensions of the constituent materials. The rated breaking strength (RBS) is a weighted average of the strength of the individual strands multiplied by rating factors designed to account for degradation from stranding. Rating factors are not available for the C7 conductor but were estimated based on the manufacturer's published RBS.

4.3.1 Strand Strength Method

Nominal Rating: A consensus Standard for ACCS/TW/C7 conductor is not available. The manufacturer publishes a rated breaking strength, but does not provide the calculation. ASTM B857 (ACSS/TW conductor) defines the rated strength of the conductor as:

Annealed Aluminum: minimum tensile strength x nominal wire area x number of strands x derating factor. The aluminum derating factor for all ACSS/TW conductors is 0.96.

Core: strength of the core strand x number of strands. For all ACSS/TW conductors, the core derating factor is 1 (no derating).

Accordingly, the nominal rated strength is:

Aluminum inner layer: 8,500 psi x 0.03783 sq in x 8 strands x 0.96 =	2,470 lb
Aluminum outer layer: 8,500 psi x 0.03794 sq in x 12 strands x 0.96 =	3,715 lb
Core: 262,600 psi* x 0.01474 sq in x 7 strands =	27,095 lb
Total: (ratings are rounded to the nearest 100 lb) =	**33,300 lb**

*value is not published, but was inferred from the manufacturer's 33,500 lb nominal RBS.

Expected strength computed using single-strand test data from this report:

Aluminum inner layer: 689.2 lb per strand x 8 strands x 0.96 =	5,293 lb
Aluminum outer layer: 774.7 lb per strand x 12 strands x 0.96 =	8,925 lb
Core: 3,430 lb per strand x 7 strands =	24,010 lb
Total: (ratings are rounded to the nearest 100 lb) =	**38,200 lb**

4.3.2 Strength by Direct Test of a Complete Conductor

Core: the core was tested by making a complete conductor sample, and removing the aluminum layer after the potting resin cured. The sample ruptured at 28,382 lb (105% of nominal rating). Figure 11 shows the data recorded during the test.

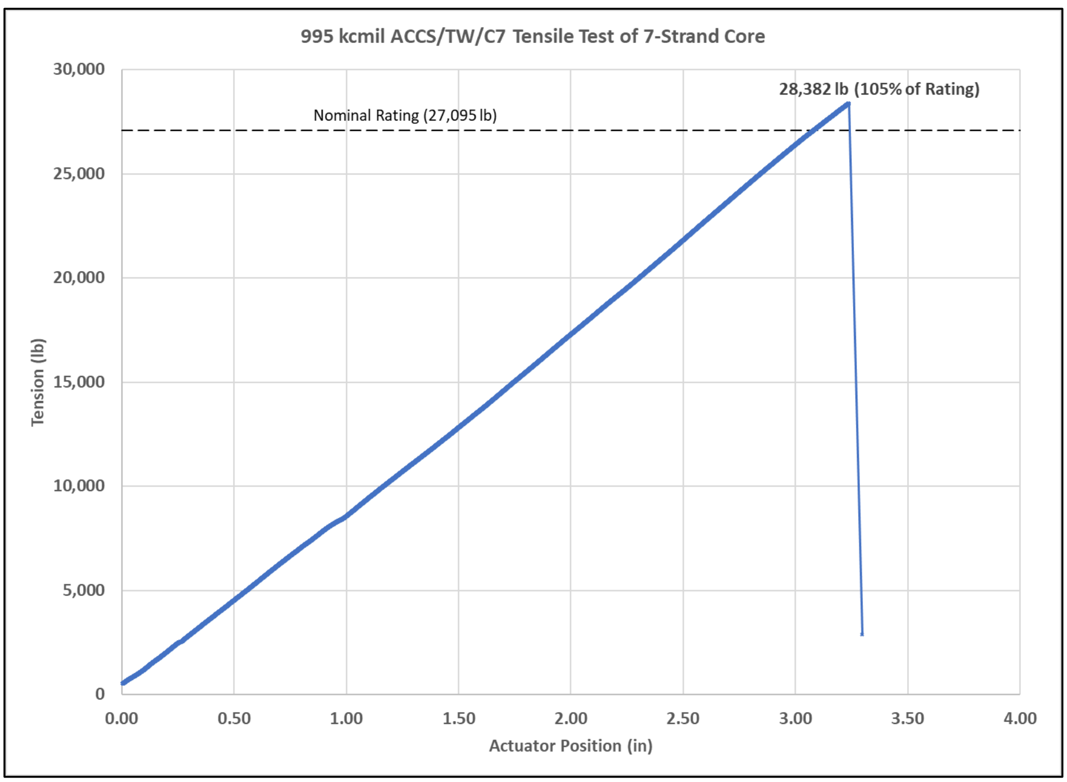

Figure 11: Test Data for 7-Strand Core Test

Complete Conductor: the complete conductor was tested by the Electric Power Research Institute (EPRI) as part of their stress-strain test. Data provided to NEETRAC shows the sample ruptured at 34,894 lb, or 104% of the nominal rating. Figure 12 shows the data recorded during the test.

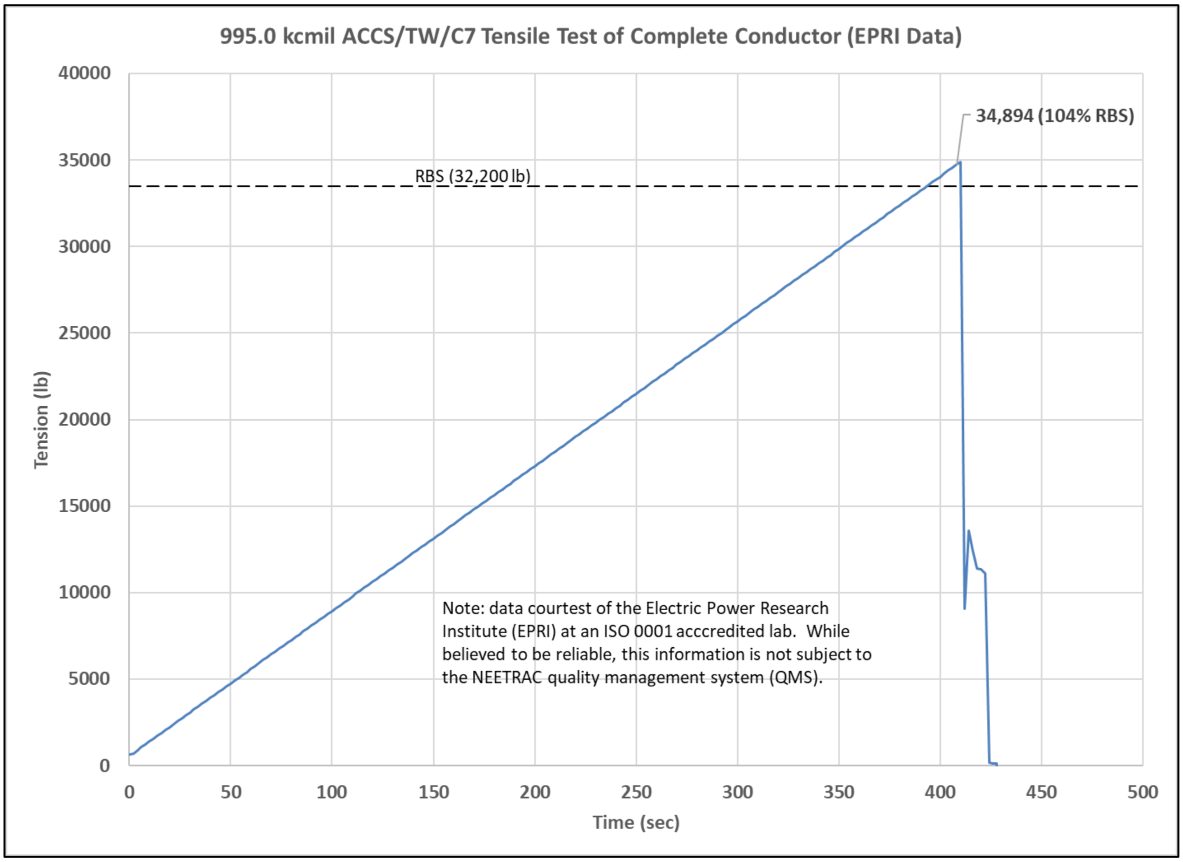

Figure 12 Tensile Test Data for Complete Conductor

5.0 SUMMARY AND CONCLUSIONS

The 995.0 kcmil ACCS/TW/C7 conductor exceeded all manufacturer strength requirements and is therefore suitable for service in an overhead line.

The aluminum strands are subject to requirements of ASTM B609 before stranding. Measured after stranding, the aluminum temper is above the before-stranding limits. That can be accounted for by strain hardening during the stranding process.

No Standard exists for the complete conductor, but all TW conductors using annealed aluminum are consistent with ASTM B857 (ACSS/TW conductor). That standard requires that the aluminum strand elongation exceed 20% after stranding. The aluminum area tolerance is ±2% of the nominal requirement. Two discrepancies were found:

1. As-found aluminum area is 2.7% below the 995.0 kcmil nominal. The maximum allowable is 2.0%.

2. As-found elongation was below 5%, versus a requirement of 20% or higher.

6.0 EQUIPMENT

Tinius Olsen universal testing machine (UTM), calibration control # CQ 0013

MTS long-bed tensile test machine, calibration control # CQ 0194

Gram scale (for mass method), calibration control # CQ7819

2-ft caliper micrometer (strand length for mass method), calibration control # CQ6733

7.0 REFERENCES

- ASTM B609 Aluminum 1350 Round Wire, Annealed and Intermediate Tempers, for Electrical Purposes

- ASTM B857 (ACSS/TW conductor)

- Southwire LLC data sheet for 995 kcmil ACCS/TW/C7, dated January 10, 2020

APPENDIX: MANUFACTURER'S DATA SHEET

Southwire®
One Southwire Drive
Carrollton, Ga. 30119 USA
(770)832-4242

OverAmp Version 6.1
Run Date: 1/10/2020

Overhead Conductor Ampacity

995.0 kcmil Type 13 ACCS/TW/C7-TP

Construction Information:

Construction:	Single
Overall Diameter:	1.108 in
Rated Breaking Strength:	33500 lb
Weight:	1001 lb/1000 ft
Surface Condition:	Average
Insulation Thickness:	N/A
Trap Wire Type:	13

Aluminum Info:

Material:	1350-O Temper Al 63%
Conductivity:	63.0% IACS
Number of Strands:	20
Strand Diameter:	N/A
Strand Factor:	1.0215
Number of Layers of Aluminum:	2
Diameter over Aluminum:	1.108 in

Core Information:

Material:	C7
Conductivity:	.1% IACS
Number of Strands:	7
Strand Diameter:	0.1370 in
Core Diameter:	0.4110 in
Strand Factor:	1.0000

Calculation Conditions:

Ambient:	40°C
Wind:	2 ft/s
Wind Angle:	90 Deg
Sun:	95.97 Watt/sq ft
Coef of Emissivity:	0.5
Coef of Absorption:	0.5
Atmosphere:	Clear
Local Time:	12 - Noon
Date for Local Time:	Jun. 10
North Latitude:	30°
Azimuth of the Sun:	0° (N-S)
Altitude (Above Sea Level):	0 ft
Frequency:	60 Hz AC

Reactance Information:

GMR:	0.0377 ft
Ind. Reactance, Xa @ 1ft:	0.3978 ohm/mi
Cap. Reactance,X'a @ 1ft:	0.0912 MOhm-mi

Conductor Temperature °C	°F	RESISTANCE (ohm/mi) DC	60 Hz AC	AMPACITY Sun No Wind	No Sun No Wind	Sun Wind	No Sun Wind
20	68	0.0892	0.0910				
25	77	0.0911	0.0928	****	****	****	****
50	122	0.1003	0.1019	****	354	199	517
75	167	0.1096	0.1111	543	710	818	937
90	194	0.1152	0.1166	735	860	1007	1101
100	212	0.1189	0.1202	838	946	1110	1194
125	257	0.1282	0.1294	1051	1133	1322	1388
150	302	0.1374	0.1386	1225	1291	1493	1548
175	347	0.1467	0.1478	1375	1431	1639	1686
180	356	0.1486	0.1497	1403	1457	1666	1712
200	392	0.1560	0.1570	1509	1557	1769	1811
225	437	0.1653	0.1662	1632	1675	1888	1925