CREATIVE COMPOSITES GROUP

5th Percentile Strength Values Development

In Support of the Creative Composites Group Composite Utility Poles Brochure

WHITE PAPER

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Introduction

Download the Composite Utility Poles Brochure:

https://www.creativecompositesgroup.com/resources/literature#utilities

In 2007, the National Electric Safety Code (NESC) Standards Committee adopted composite poles, crossarms and braces into the code. This action was a significant step in terms of mandating that the composite electrical structures manufacturing industry publish the design strength values to a 5% lower exclusion limit. This action forces all utilities that are designing with the NESC code to require manufactures to publish their design values based on 5th percentile strength factors. This paper describes the test, test set up, statistical calculations and relevant standards that were used to generate 5th percentile strength values as published in the Creative Composites Group Composite Utility Poles Product Brochure.

Investigation

The following physical characteristics were evaluated in order to obtain the 5th percentile strength values for design purposes:

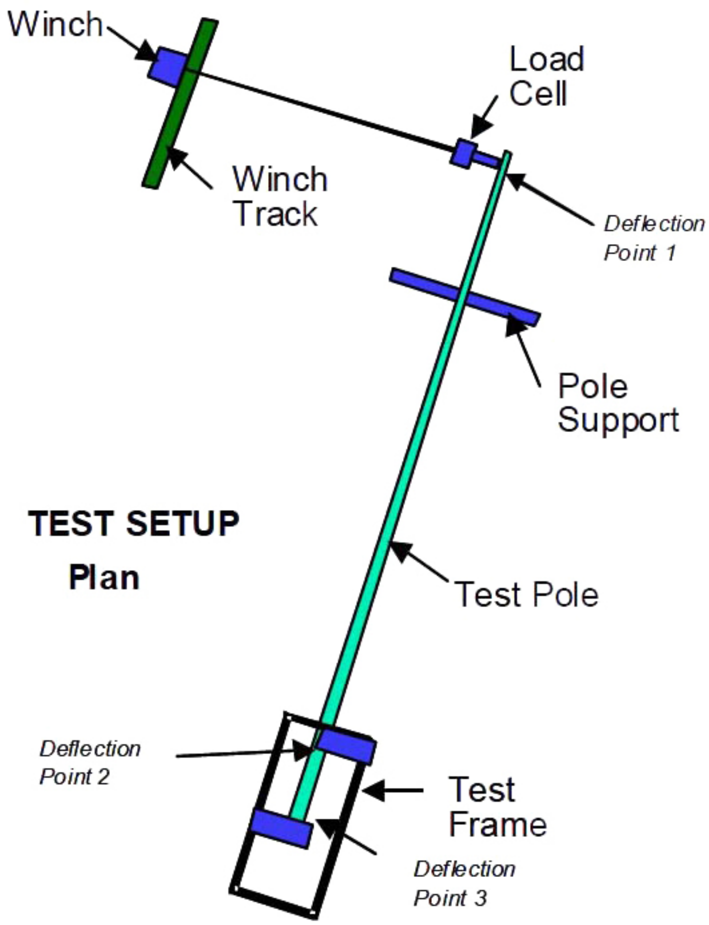
- Flexural and Compression Bending Strength per ASTM D1036
- Moment Capacity per ASTM D1036
- Modulus of Elasticity per ASTM D1036
- Axial Compression Strength
- Pole Torque Strength
- Pin Bearing Strength in the Lengthwise and Crosswise Direction of the Pole
- Washer Pull Through Strength
- Shear Strength
- In-plane Shear Strength per ASTM D5379

Experiment

Moment Capacity, Flexural and Compression Bending Strengths and Modulus of Elasticity

The moment capacity and flexural and compression bending strengths were calculated based on the 5th percentile strength of the poles when tested in full section to ASTM D1036 Standard Test Methods of Static Tests of Wood Poles. The cantilever method for determining bending strength and stiffness was utilized. Tests were conducted by EDM International, Fort Collins, CO., and by Creative Composites Group, Alum Bank, PA.

Figure 1: Pole Bending Test Setup



The test involved a horizontal cantilever arrangement with the butt end placed inside a rigid test frame and held in position by 12" wide nylon slings. Rigid horizontal support beams were used to support the dead weight of the pole. The load cable was attached approximately two feet from the pole tip using a nylon strap. Load was applied at a constant rate of deformation until failure using a winch. The winch was mounted on a trolley that moved along a track to keep the load perpendicular to the original pole axis. Creative's and EDM's test facilities are equipped with a pole holding fixture, loading system, electronic load and deflection measuring sensors, and a computerized data acquisition system. The calibrated S load cell has an accuracy of ± 6 lb., while the calibrated string pot has an accuracy of ± 1/16".

Pin Bearing Strength

Transverse Pin Bearing Strength

Lengthwise Pin Bearing Strength

Two holes were drilled through short sections of both the round and octagonal poles. Either a 1” diameter or ¾” diameter pin was placed through the pole. A load was applied at a steady rate through the pin until a pin bearing failure occurred. The failure load is defined as the first decrease in load when observing the load/deflection graphs. The test was conducted in both the lengthwise and transverse directions of the pole. The Transverse Pin Bearing Strength and Lengthwise Pin Bearing Strength photos depict the test set up. The instrument utilized to test the poles is a calibrated 50 kip flexural test machine located at Creative’s facility.

Washer Pull Through Strength

Washer Push Through Test Set Up

Washer pull through strengths were determined for both the octagonal and round pultruded poles. The test set up involved a three-foot section of pole, cradled on each end, resulting in a free spanning section of pole with a length of two feet. A hole was drilled through the pole. A bolt was placed through the washer and into the hole. The top of the bolt head was loaded at a steady rate until failure occurred. The data acquisition system logged the load and displacement until failure. The failure load is defined as the first drop in load when observing the load/deflection plots.

In-plane Shear Strength per ASTM D5379

In-plane Shear Strength

The in-plane shear strength was determined by ASTM D5379 Standard Test Method for Shear Properties of Composite Materials by the V-Notched Beam Method 1. The coupons were extracted from the octagonal and round poles and prepared per the requirement of ASTM D5379. Tests were conducted on the calibrated Instron 250 kN tensile test machine at Creative's facility.

Observations and Results

Moment Capacity

Local Compression Buckling Failure

The Octagonal and round poles were tested per ASTM D1036 to failure via the cantilever method. The failure mode was local compression buckling at a position equivalent to several feet above the ground line.

The full section failure load was multiplied by the moment arm of the pole, determined by subtracting the pole length by the sum of 10% of the pole length plus two feet plus an additional two feet, which takes into account the location of the load applied at the top of the pole. The resultant of the failure load times the moment arm equates to the moment at failure.

The moment capacity, derived from full section testing, was then used to predict the strength capacity of the poles at various lengths and loads. The pole load charts were developed based on the failure moments of tested poles. The failure moments of the tested poles were used to develop the pole load charts. The following charts summarize the octagonal and round pole test data.

Table 1: *Octagonal Pole Full Section Testing*

		Octagonal Pole CP076 8″	Octagonal Pole CP074 10″	Octagonal Pole CP210 10″
Pole Moment Capacity and Modulus of Elasticity per ASTM D1036	# of Specimens	3	5	12
	Mean Value lb	1,949	2,741	3,371
	Standard Deviation	52	93	85
	COV	2.7%	3.4%	2.5%
	5% LEL	1,863	2,587	3,232
	Average Bending Moment lb-ft	62,368	100,047	123,048
	5% LEL Bending Momment lb-ft	59,611	94,437	117,953
	Modulus of Elasticity psi	4.30E+06	4.00E+06	3.70E+06

Table 2: Round Pole Full Section Testing

		Round Pole TU440 10"x3/8"	Round Pole TU455 12"x3/8"	Round Pole TU450 12"x1/2"	Round Pole TU460 16"x1/2"
Pole Moment Capacity and Modulus of Elasticity per ASTM D1036	# of Specimens	6	5	3	3
	Average Bending Moment lb-ft	144,052	178,909	262,009	400,369
	Standard Deviation	8,177	7,486	13,315	8,648
	COV	6%	4%	5%	2%
	5% LEL Bending Moment lb-ft	130,601	166,593	240,104	386,144
	Modulus of Elasticity psi	4.98E+06	5.10E+06	5.84E+06	5.52E+06

The data detailed in Tables 1 and 2 describe the number of tests conducted, the average failure load, the standard deviation, coefficient of variation, the average bending moment, the 5t% lower exclusion limit, and the modulus of elasticity.

The 5th percentile strength limits, derived for all of the design values throughout the pole brochure, were derived with the following equation:

5th percentile strength limit = mean - 1.645 (mean x COV) in which the COV is the coefficient of variation within the test results.

Flexural and Compression Bending Strength and Axial Compression

The flexural and compression bending strengths were derived by establishing the compression and flexural stress at failure. The values were realized by dividing the moment by the section modulus of the pole sections.

Because the poles fail in compression, the bending strength is limited to the compression stress at failure. The compression bending strength is conservatively assumed to be the axial compression strength as well. The conservative axial compression strength is used to predict the short column axial compression capacity of the poles.

Modulus of Elasticity

The average modulus of elasticity for each pole profile was derived by back calculating the modulus from a mechanics of materials beam equation. The constant cross section of the pole simplifies the computations necessary to both predict the deflection of a pultruded pole and to derive the full section modulus of elasticity. The load vs. deflection data, developed during the ASTM D1036 pole tests, was utilized to back calculate the modulus of elasticity.

The modulus of elasticity was derived by the following equation:

$E = PL^3/3\Delta I$

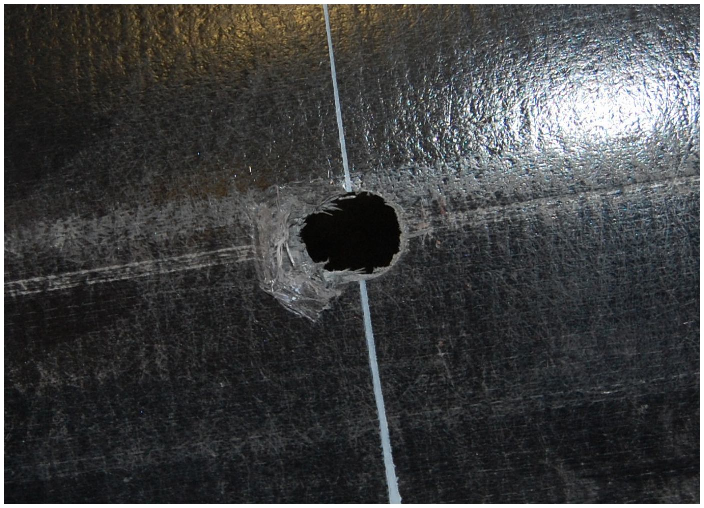
In which:

E = Modulus of Elasticity (psi)
P = Load (lb)
L = Test Length of Pole (in)
Δ= Deflection (in)
I = Moment of Inertia (in^4)

The modulus can be used to predict the serviceability deflection due to P-delta effects, guy loads and wind loading.

Pin Bearing Strength

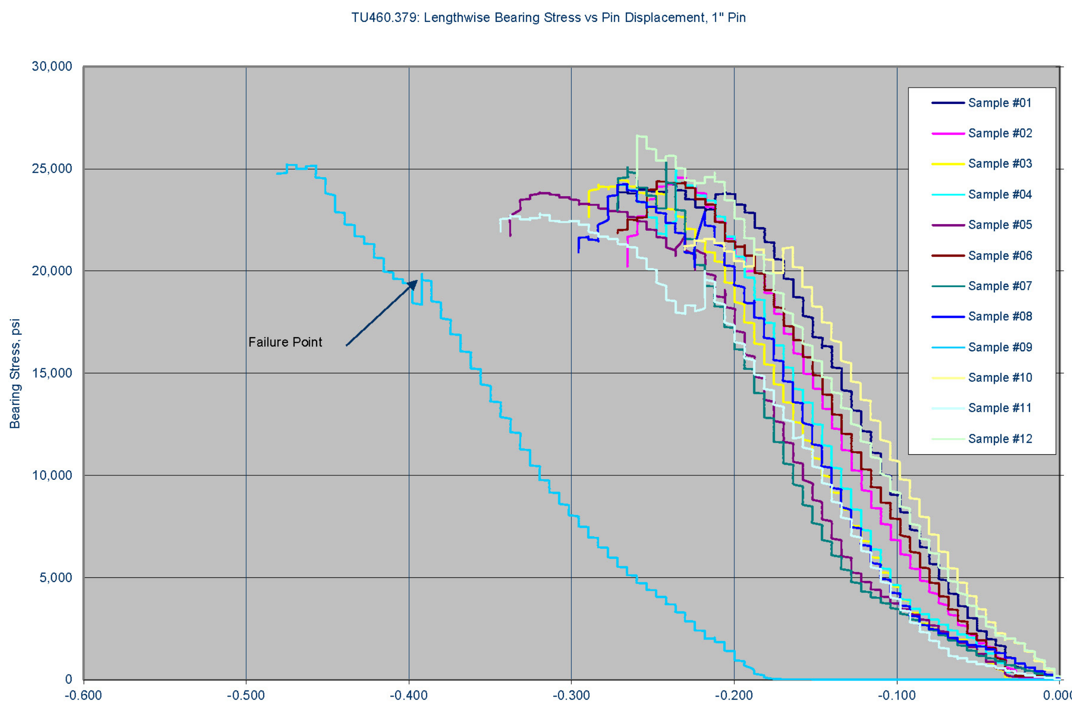
Typical Pin Bearing Failure



The pin bearing strength was calculated based on the data generated from the full section pin bearing tests. The strength was calculated by dividing the load at failure by the number of through holes, the diameter of the pin, and the nominal wall thickness of the pole. The failure load is the point in the load/ displacement graph that depicts the first yield, or drop in load.

The pin bearing mode of failure is not without warning. The glass fibers begin to buckle as the hole elongates and the load begins to decline during the pin bearing failure process.

Table 3: *Chart Load vs Displacement Pin Bearing*



The following charts display the number of test performed, the mean value, standard deviation, coefficient of variation and the 5th percentile strength values both in terms of the force and resulting stress for both the lengthwise and crosswise pin bearing tests:

Table 4: *Pin Bearing Results*

		Octagonal Pole CP076 8"	Octagonal Pole CP074 10"	Octagonal Pole CP210 10"
Bearing Load Lengthwise (lb)	# of Specimens	12	15	30
	Mean Value	10,224	10,584	11,192
	Standard Deviation	1,440	1,111	2,805
	COV	0.160	0.105	0.258
	5% LEL	7,541	8,756	6,434
Bearing Strength Lengthwise (psi)	# of Specimens	12	15	30
	Mean Value	27,263	28,223	27,132
	Standard Deviation	3,839	2,963	6,799
	COV	16%	10%	26%
	5% LEL	20,110	23,348	15,598

Table 5: *Pin Bearing Results*

		Octagonal Pole CP076 8"	Octagonal Pole CP074 10"	Octagonal Pole CP210 10"
Bearing Load Crosswise (lb)	# of Specimens	12	12	11
	Mean Value	5,759	4,336	4,653
	Standard Deviation	1,005	924	1,088
	COV	0.201	0.216	0.224
	5% LEL	3,856	2,798	2,938
Bearing Strength Crosswise (psi)	# of Specimens	12	12	11
	Mean Value	15,357	11,562	11,280
	Standard Deviation	2,680	2,46	2,638
	COV	0.201	0.216	0.224
	5% LEL	10,283	7,458	7,123

Table 6: *Pin Bearing Results*

		Round TU440 10"x3/8"	Round TU455 12"x3/8"	Round TU450 12"x1/2"	Round TU460 16"x1/2"
Bearing Load Lengthwise (lb)	# of Specimens	12	12	12	12
	Mean Value	17,901	20,869	29,300	23,065
	Standard Deviation	946	3,783	2,889	2,035
	COV	0.048	0.159	0.098	0.078
	5% LEL	16,492	15,415	24,591	20,088
Bearing Strength Lengthwise (psi)	# of Specimens	12	12	12	12
	Mean Value	31,824	27,826	29,300	23,065
	Standard Deviation	1,681	5,043	2,889	2,035
	COV	5%	16%	10%	8%
	5% LEL	29,319	20,553	24,585	20,088
Testing of the TU440 was performed with a 3/4" pin. Testing of TU455, TU450, and TU460 was performed with a 1" pin					

Table 7: Pin Bearing Results

		Round TU440 10″x3/8″	Round TU455 12x3/8″	Round TU450 12″x1/2″	Round TU460 16″x1/2″
Bearing Load Crosswise (lb)	# of Specimens	12	12	12	12
	Mean Value	17,377	11,954	17,251	15,393
	St. Dev.	957	1,127	2,114	2,152
	COV	6%	10%	11%	12%
	5% LEL	15,778	10,059	14,063	12,399
Bearing Strength Crosswise (psi)	# of Specimens	12	12	12	12
	Mean Value	10,774	15,938	17,251	15,393
	St. Dev.	654	1,503	2,114	2,152
	COV	5%	10%	11%	12%
	5% LEL	9,878	13,412	14,063	12,399
Testing of the TU440 was performed with a 3/4″ pin. Testing of TU455, TU450, and TU460 was performed with a 1″ pin					

Washer Pull Through Strength

The washer pull through results, as depicted in Tables 8 and 9, feature the number of specimens tested, the mean value, the standard deviation, coefficient of variation, and the 5th percentile value in terms of load at failure. The failure load is the point in the load/displacement graph that depicts the first yield or drop in load.

Table 8: Washer Pull Through Results

		Octagonal Pole CP076 8″	Octagonal Pole CP074 10″	Octagonal Pole CP210 10″
Washer Push Through (lb) 4″x4″x3/8″ washer	# of Specimens	12	10	12
	Mean Value	13,697	14,698	14,571
	St. Dev.	1,187	1,035	1,190
	COV	0.085	0.070	0.074
	5% LEL	11,786	13,014	12,802

Table 9: Washer Pull Through Results

		Round TU440 10″x3/8″	Round TU455 12x3/8″	Round TU450 12″x1/2″	Round TU460 16″x1/2″
Washer Push Through (lb) 6″x6″ washer	# of Specimens	12	12	12	12
	Mean Value	17,377	17,232	24,663	22,620
	St. Dev.	957	935	3,602	1,803
	COV	6%	6%	14%	0.064
	5% LEL	15,778	15,528	18,944	20,223
TU440 testing was performed with a 3/8″ thick washer. Testing of TU455, TU450, and TU460 was performed with a 1/2″ thick washer					

Yielded Steel Washers, Elongated Thimble Eye Nut and Typical Washer Pull Through Failure Mode

The Three failure modes were observed during the washer pull through tests. The 50 ksi steel washers, measuring 6"x6"x1/2", were observed to yield, which resulted in the hollow pole section cracking due to the high stress concentration. The threaded eye nut utility hardware elongated prior to the ultimate load being obtained. This spurred a change in the test set up in which the force was changed from a tension to compression. The applied load was induced into the pole through the hardware bolt head and washer as detailed in the washer pull through test set up photograph.

In-plane Shear Strength per ASTM D5379

The In-plane shear results, as demonstrated in Table 10 for the 12"x1/2" round pole, contains the mean, standard deviation, coefficient of variation, and the 5th percentile shear strength values.

Table 10: *In Plane Shear Results*

TU450.379 IPS by ASTM D5379	
Sample #	Ultimate IPS Stress, psi
1	10,501
2	11,870
3	11,629
4	8,684
5	12,087
6	11,455
7	10,850
8	11,901
9	12,286
10	9,306
11	11,754
12	12,825
# of Specimens	12
Mean Value	11,262
St. Dev.	1,228
COV	9.2%
5% LEL	9,550

Pole Torque Strength

The pole torque strength was determined utilizing the 5th percentile in-plane shear strength determined via ASTM D5379. Referencing P.K. Mallick Fiber Reinforced Composites Materials, Manufacturing and Design, second edition, Design of Torsional Members, the following relationship exists between the in-plane shear strength, torque, geometry and thickness of the part:

Torque = $t_{xy} * 2 * \pi * r^2 * t$

Where: t_{xy} = in-plane shear strength (psi)
r = mean radius (in)
t = wall thickness (in)

Example calculation of the 12"x1/2" pole 5th percentile torque strength:

Torque = 9,550 psi $*2 * \pi * (5.75)^2 * .5$ = 991,948 lb-in or 82,662 lb-ft

Shear Strength

The ultimate design shear capacity of the pole was calculated utilizing the 5th percentile in-plane shear strength. The shear capacity of the 12" x1/2" round pole was calculated using the following equation:

V = $(t_{xy} * \text{Area}) /2$

Where: t_{xy} = 9,550 psi
A = Area (in^2) = 18.1 in^2
V = Shear Strength (lb)

Therefore, the ultimate 5th percentile design shear strength equates to: 86,428 lbs.

Conclusions

The design values, detailed in the Creative Composites Group Composite Utility Poles Electrical Distribution & Transmission brochure, have been derived based on the requirement of the 2007 NESC. The code requires that 5th percentile strengths be published for design purposes. CCG has undertaken the task of determining the 5th percentile characteristic strengths for each of the design properties below.

- Flexural and Compression Bending Strength per ASTM D1036
- Moment Capacity per ASTM D1036
- Modulus of Elasticity per ASTM D1036
- Axial Compression Strength
- Pole Torque Strength
- Pin Bearing Strength in the Lengthwise and
- Crosswise Direction of the Pole
- Washer Pull Through Strength
- Shear Strength
- In-plane Shear Strength per ASTM D5379

Concluding Points

- 5th Percentile design values have been determined and documented in the Creative Composites Group Composite Utility Poles Electrical Distribution & Transmission brochure.
- The design values are NESC 2007 up through the current compliant.
- The design values should be utilized in conjunction with the load factors detailed in the NESC code.

ABOUT THE COMPANY

Creative Composites Group is a custom design, engineering and Fiber Reinforced Polymer (FRP) fabrication provider. We offer comprehensive engineering, design and consultation for unique fabrication projects. Our manufacturing capabilities include the broadest range of engineered FRP solutions to build your ideal projects. That's possible only with our proven engineering processes, end-to-end collaboration, service and support resources. Since FRP composites last longer than conventional materials they often have a lower lifetime cost when you consider longer service life and low to no maintenance costs.

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