

Maximizing & Validating Ultimate Capacity in High Strength Applications

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The notion of High Strength applications is intriguing in many ways. A project with “High Strength” in the scope will garner extra attention for the project, potentially making it higher visibility. High strength insulators can improve efficiency of a project which can be measured in shorter project duration or more important, lower total cost of the project. Gaining this efficiency is a function of going above and beyond the status quo (how we always did it) and finding new solutions to old and new problems. The challenge to these new solutions is to prove that they will work, and that the risk is worth the effort.

This paper will discuss how current insulator applications can be improved for higher capabilities, and how those capabilities could be tested and validated.

Suspension & Tension Insulators: Mechanical loading of suspension insulators in most cases is simple. The definitions of SML (Specified Mechanical Load) and RTL (Rated Tensile Load) are understood and easily quantifiable. Regardless of the application, the primary load applied to the insulator is tensile, and for the specified SML rating, the insulator is not limited by section length. Testing can be completed at the factory (as part of the manufacturing process), or it can be done at a 3rd party test lab. Setting up a test at a lab is not difficult, the testing process is standard.

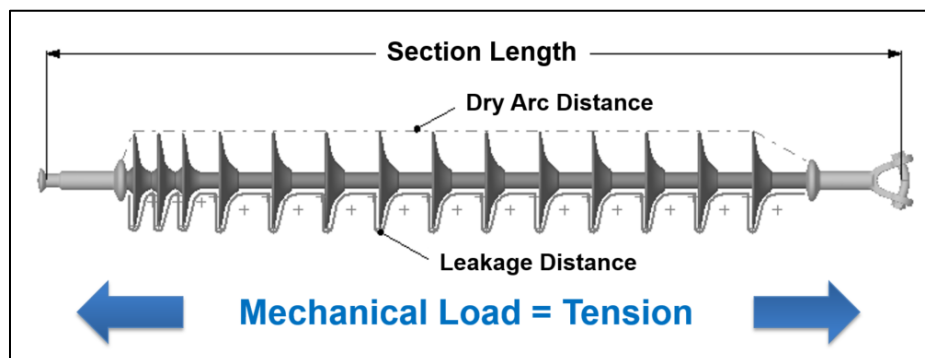


Fig. 1 – Tensile loading = Simple

Maximizing tensile performance of a suspension is a function of increasing the rod diameter, upgrading the end fittings, and getting the most out of the crimp (compression of the end fitting onto the core rod). The key to the crimp is to get the most tensile output, without cracking or overstressing the rod.

Where 30klb and 50klb SML have predominantly been the most used ultimate strength for polymer, suspension applications can go up to 120klb SML and beyond if required.

20%	36,000 lbs	160 kN
Average Tensile Failure Load		
10%	33,000 lbs	147 kN
Lower Control Limit		
SML	30,000 lbs	133 kN
Ultimate Rated Tensile Load		
Damage Limit		
RTL	15,000 lbs	67 kN
Working Tensile Load		

Fig. 2 – Tensile Rating of 30klb. suspension insulator. [Average failure and lower control limits are assumed values as reference for this paper]

Tensile Ratings

SML = Specified Mechanical Load = ultimate rated tensile load for the insulator.

RTL = Rated Tensile Load = working tensile load the insulator can used for in service. (service conditions should include safety factors for Ice and Wind loading).

Tensile Failure Load = TFL = this would be the load the insulator actually fails in tensile loading in one of 3 failure modes...

1. End fitting pull off – this is the most common failure mode, and the one that can be controlled and predicted as a function of the manufactures crimp process.
2. End fitting break – this would be the next common failure mode, with ball type end fittings potentially having the lowest breaking loads. The end fitting limit is directly tied to what specific end fitting type is being used, and by the standards that govern that design (ANSI, IEC, CSA, etc).
3. Rod shatter – this is the least common failure mode, which is the failure of the core rod in tension. The limit of the rod is a function of the rod diameter.

Damage Limit = the load at which the insulator begins to stretch, elongate, or deform. This includes stretching or breaking of individual fiberglass strands within the core rod, and elongation and deformation of the end fittings.

Lower Control Limit = a design limitation imposed by the manufacturer as part the process of validating the insulators tensile rating. This is typically supported and defined by some form of SPC (Statistical Process Control).

When validating the SML for a suspension, the resulting data from the tensile tests should provide a range of failure loads. The wider the range, the less in control the manufacturing process is. The goal for the manufacturer would be to have a tighter range of failure, which is evidence of a process in control. Once the average failure load is defined, SPC can be used to determine the lower control limit for that insulator and manufacturing process.

This is where we should ask a few critical questions.

- *What percentage above the SML should the lower control limit load be?*
- *Is this defined or addressed in a standard?*

20%	60,000 lbs	267 kN
Average Tensile Failure Load		
10%	55,000 lbs	245 kN
Lower Control Limit		
SML	50,000 lbs	222 kN
Ultimate Rated Tensile Load		
Damage Limit		
RTL	25,000 lbs	111 kN
Working Tensile Load		

Fig. 3 – Tensile Rating of 50klb. suspension insulator.

Technically speaking, a tensile validation test would be considered “passed” if the failure load is just 1lb. over the SML rating. This would not be ideal, as it leaves very little room for error with respect to manufacturing. There should be some design safety factor included in the process. The table shown in figure 3., the average failure load is assumed to be 20% above the 50k SML, and the lower control limit as 10% above the 50k SML. These values were selected at random for reference and discussion in this paper.

The damage limit for the insulator is a function of the tensile failure load, usually ranging from 75% to 85% of the lowest TFL. It is not a function of the SML rating. Ideally, the damage limit should be near the SML rating, and a safe distance from the RTL rating.

Example: the damage limit for the 60,000 lb. TFL

- Assume lowest tensile failure load = 57,000 lbs.
- 75% of lowest TFL = 43,000 lbs.
- 85% of lowest TFL = 49,000 lbs.

We could then safely conclude that this 50k SML insulator can withstand an extreme load event up to 40,000 lbs. without causing damage to the insulator. Maybe we consider adding a new load rating between SML and RTL, calling it the TWL = Tensile Withstand Load.

Cantilever Loading of Post Insulators: Where Tensile loading is considered easy or simple, Cantilever loading is very complex, with many layers of complication. We again have ultimate and working ratings expressed as SCL (Specified Cantilever Load) and MDCL (Maximum Design Cantilever Load) respectively. This is where the similarity to suspension mechanical loading stops, and where cantilever loading gets complicated.

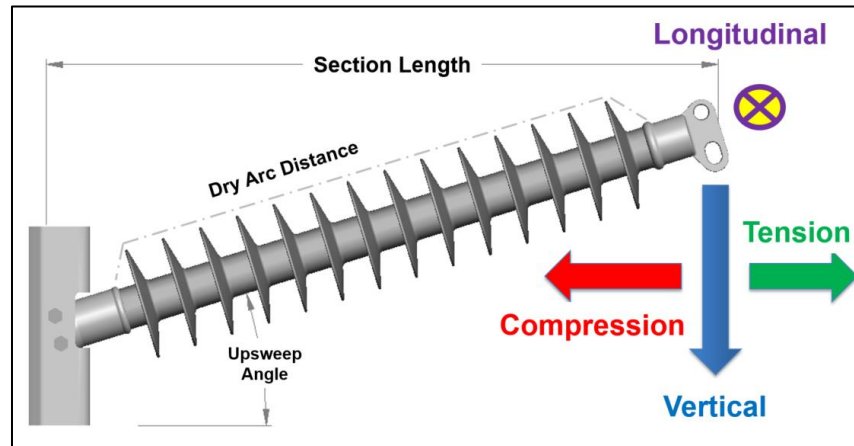


Fig. 4 – Cantilever loading = Complex

Post (line post and braced post) insulators are not selected by the SCL rating or working load. The mechanical rating of the post is limited by the section length. As the post increases in length (voltage), its ultimate cantilever rating is reduced. Conversely, as the post is shortened, it gains mechanical strength, but then loses electrical capability. When selecting a post insulator, there needs to be balance between mechanical and electrical performance.

The mechanical rating of the post is impacted by the type of end fittings and connection base, both of which are part of standards, but not as well defined as the Go/No Go criteria used for tension insulators.

These variables aside, the “Load Curve” or interaction diagram is by far the most complicated part of post application. Unlike a tension insulator that no matter the application, it withstands a single tensile load. The line post and braced post are subject to a variety of combined loads, comprised of vertical, transverse (compression and tension), and longitudinal loads. The purpose of the load curve is to take these various load conditions and provide some Go / No Go criteria for that post insulator. All the required loading conditions must fall on or below the MDCL (working) curve. Any load above the MDCL has a potential to cause issues and should be reviewed closer before proceeding.

There is no single cantilever test that validates the ultimate and working ratings of the post. A combined vertical and compression load will have a lower buckling limit than will a combined load of vertical and tension. Each of these load cases will have different results with respect to SCL and MDCL. Testing can be completed for most line post applications at the factory, along with some of the braced post applications, but cantilever testing cannot be completed as part of the manufacturing process.

There are 3rd party test labs that can perform cantilever testing, some may be limited to single vector load testing (traditional test method), while others may have the capability to test multi-axis loading. Multi-axis testing provides a better representation of service load conditions the insulator may be exposed to in the field.

Load Curves / Ratings / Validation

The SCL and MDCL ratings on the line post drawings are single load conditions on the load curve. See Figure 6, where each curve crosses the Y-Axis of the chart is the rating provided on the drawing. These ratings are vertical loads with zero transverse load and no longitudinal load.

Transverse loads on the negative side of the chart are Compression loads. Combined compressive loads take away from the post cantilever capacity. Transverse loads on the positive side of the chart are Tension loads. On the tension side of the chart the post has more combined load capacity. When designing a transmission line with posts, relative to transverse loading, it is best to have the posts aligned so that the conductor pulls away from the tower (in tension) vs the conductor pulling into the tower (in compression).

10%	4,400 lbs	19.6 kN
CBL - Cantilever Breaking Load		
SCL	4,000 lbs	17.8 kN
Ultimate Cantilever Load		
Damage Limit		
MDCL	2,000 lbs	8.9 kN
Working Cantilever Load		

Fig. 5 – Cantilever data table

[this is table & curve are for reference only, to show the relationship between CBL – SCL – MDCL. The CBL percentage is assumed for this paper.]

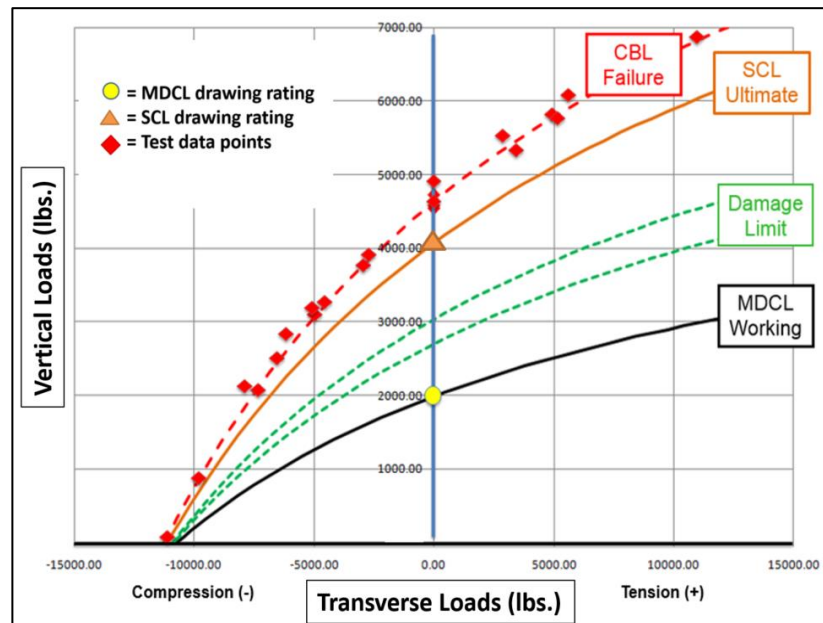


Fig. 6 – Cantilever load curve demo

The MDCL or working cantilever curve is 50% of the ultimate curve or SCL. However, there are cases where the customer requires the MDCL be 40% of the SCL, which is a more conservative value for the working curve. Adding this safety factor to the MDCL rating could be because there is no defined relationship between the CBL and SCL. The CBL loads (cantilever failures) should be some % above the SCL, and not right on the edge (1 lb. above) of the SCL. If the CBL were to be defined and required to be 10% greater than the SCL rating, then there would be no need to put that 10% safety factor on the working curve.

The damage limit for the post is also a function of the CBL, and ideally would be closer to the SCL than to the MDCL. The post may be subject to more peak load events due to ice and wind, which if the applied loads are already at boundary limit, those spikes above the MDCL could diminish the original integrity of the post, and if the events are frequent enough, this could lead to fatigue of the post.

Maximizing Cantilever Applications

The line post insulator is limited by section length, the longer the post, the bigger the core rod diameter needs to be to withstand the cantilever loads. While it is feasible to use larger diameter posts (3" and 3.5") for these longer post applications, the rate at which the MDCL increases is not proportional to the rate at which the costs increase. It is at this point that the transition from line post to braced post makes sense, where adding a brace to the original 2.5" post can provide up to 7 times more cantilever capacity, with minimal increase in cost for the assembly.

Moving from a line post to a braced post is one way of maximizing cantilever applications. But a braced post assembled using traditional line post hardware (base and end fittings) may be limited by that same hardware. These fittings and bases were design for the lower line post ultimate loads, not for the much higher requirements of the braced post. Maximizing the braced post cantilever capacity requires upgrades to the base connection and to the line end fitting strength. In a maximized braced post design, all the potential limitations are in line to one another, and the resulting limitation of the assembly should be the buckling limit of the post. Too often, we get hung up on technical terms like modulus of elasticity and K-Factor of the rod. The reality is that the hardware used by the various suppliers drives more of the variability in load ratings and load curves than does the rod.



Fig. 7 – line post gain base, deformed due to longitudinal load

The base is the single most critical part of any braced post application, as it is the base that transfers the combined loads of the conductor through the post into the tower. Traditional bases were not designed for these higher braced post loads, and are much more susceptible to deformation from stringing and longitudinal loads. (for more detail on base design and longitudinal loads, see INMR paper "Longitudinal Loading: Fact vs. Myth".

To get maximum load capacity from the braced post insulator, the base connection to the tower should be Fixed, as close to rigid as possible.

The base should be low profile and made from stronger materials (higher grade of steel or thicker cross section) to match the loading expectation of the braced post application. The bolt circle is an ideal tower end fitting for these more robust applications.



Fig. 8 – line post drop tongue fitting limiting this braced post assembly.

The line post end fitting, in this case a standard line post drop tongue, is the weak link of the traditional braced post assembly. The fitting does not have the proper tensile strength to withstand the higher braced post combined loads. This deficiency is compounded by the fact that the pulling angle changes the breaking limit of the fitting. The fitting has the most strength when both ears are pulled straight apart. But with both ears being pulled at angles, that breaking strength drops as the angle increases.

Maximized performance of any braced post can only be realized if the limitation of the line end fitting is overcome. This is completed by using a higher strength adaptor bracket (best if mounted to a bolt circle end fitting on the post).

The brace insulator primarily holds vertical load and some of the transverse loads. The brace capacity can be maximized by increasing the SML rating of the suspension insulator. The brace insulator will rarely, if ever, be the limitation for a braced post. It is unlikely to ever be loaded to the point of breaking, the rod or end fitting will most likely fail long before the brace.

Now that we have a new base, line end connection, and increased SML brace, the final component to upgrade is the rod. As previously mentioned, when the limits for all individual braced post elements are equal, the assembly will be limited by rod buckling.

- The post within a braced post application primarily withstands compression and longitudinal loads.
- The post is most resistant to compression when applied at zero-degree upsweep.
- The buckling limit is a function of rod diameter and post section length. As the post length increases, so must its rod diameter.

Testing & Validation for the Braced Post

Testing of each individual component is essential; the following are individual tests for the brace post.

- Base – Longitudinal load resistance [stringing, service, broken conductor]
- Brace Insulator – SML tensile testing
- Brace Hardware – tensile test
- Bracket – fixtured cantilever test to validate the tensile strength at various angles pulls
- Post – deflection and compression tests, for a range of lengths and rod diameters.

The values from the individual component testing need to be part of the combined load curve, to establish the boundary limits. All these values go into a buckling equation which drives the formation of the curve, which also considers the variable geometry of the braced post (section length, assembly height, upsweep angle, etc.).

Validating the load curve requires full scale testing of the braced post assembly, testing a range of combined load cases that cover the extreme loads on the ends of the curve, and several load cases along the curve between those extreme loads.

Testing of the optimized braced post

- The braced post assembly should be set up to match the field application, matching the pole geometry as close as possible with respect to bolt mount patterns and pole OD at the base connection.
- The same bolts (type and grade) that will be used in service should be used in testing.
- Multi-axis testing – the test should have at least 3 axis testing to simulate vertical, transverse, and longitudinal loads as they would be applied to the braced post in service.
- Testing should include longitudinal restraint, to simulate the stiffness provided to the post tip by the conductor. An unrestrained braced post will be free to walk in whatever direction the combined load dictates. But in service, the end of the post is not free to move at random, the conductor adds to the equation.
- Each test case would take 3 individual loads to a service load condition, and then add additional compression to simulate wind loads, or additional vertical to simulate ice loads.
- Each test would be pulled to failure.
- During testing, as the post bows and ultimately buckles, the resulting stress will have impact on the base and mounting bolt performance as the braced post approaches its CBL.

Ultimately, the objective of the testing is to collect data points that confirm the that the SCL rating of the assembly is accurate, giving some additional credibility to the calculated load curve. The deflection data will help define when the loads are approaching a damage limit. The line post rod will remain essentially rigid throughout most of the test sequence, and as the rod approaches its buckling limit, the post transitions from rigid to flexible, quickly driving the assembly to a failure of the rod, the base, or the bolts.

The CBL for a High Strength braced post is when something physically breaks in the assembly. Often, this will be the bolts mounting the post to the tower.

The SCL rating for that same High Strength braced post should be at the point before the post transitioned from rigid to flexible.

Conclusion – Whether considering suspension, line post, or braced post insulator for higher strength applications, the keys to success are the same.

1. Know and understand the current limitations of the application at hand. We cannot make something stronger if we first cannot determine what makes it weak.
2. When a limitation is reached, determine what upgrade is needed to overcome that limit.
3. Never stop asking what else something should be or can do!
4. Don't let “this is how we always did it” get in the way of progress.

The opportunities for improvement are out there, and High Strength applications could be the solution to reducing project duration, savings costs, or improving reliability of a T-line.



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