

## Longitudinal Loading: Fact vs. Myth

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Utilities have moved more towards compact line designs for tangent structures, using polymer line post and braced post insulators due to the demand for lower project costs and increased limitations on land and right of way. Line post and braced post insulators have been used for over 25 years and have served our industry well. The use of the braced post has taken off, and we are finding new applications (345kV) for Braced Post Insulators, as well as looking to push the mechanical limitations to new levels. The key to these new applications and capabilities is to understand the limitations and safe working loads for each braced post design, using Load Curves [Interaction Diagrams] to determine when the insulator is mechanically sound and when its limitations have been exceeded. Nothing complicates the design process more than Longitudinal Loads. This paper's focus is on the Facts and Myths pertaining to Longitudinal Loads.

**Myth:** By adding Longitudinal loads to the load curve, it covers all longitudinal load conditions.

This is False: the longitudinal loads added to the load curve are only applicable to the loads the post or braced post are exposed to in service conditions.

**Fact:** There are three different types of longitudinal loads; Stringing Longitudinal Load, Service Longitudinal Load, and Broken Conductor Longitudinal Load. Each is unique, and in each case, the expected longitudinal resistance of the line post is very different.

Stringing Longitudinal Loads – These are loads applied to the line post / braced post during the stringing of conductor through the stringing blocks suspended from each insulator. During the stringing process, the line post is most susceptible to side loads, which could damage the base connecting the post to the tower. The longer the post, the less force it takes to begin the onset of base deformation.

**Fact:** During Stringing, the line post can be deflected with minimal amount of force. There is nothing restraining the line end of the post.

**Fact:** The longer the post, the higher the deflection.

**Myth:** Increasing the core rod diameter of the post will fix the issue.

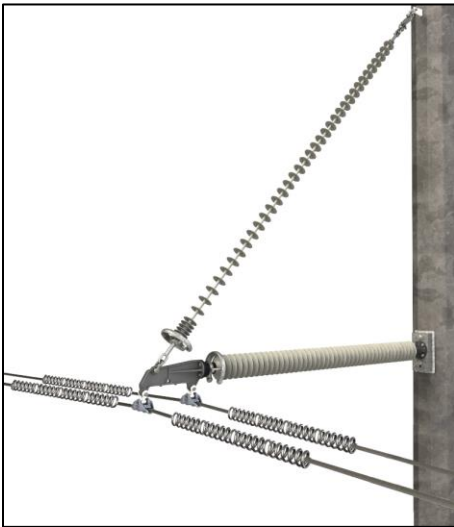
**Fact:** While an increase in the core improves post resistance to longitudinal loads, the base connecting the post to the tower is the first and more critical limitation. This will be covered in more detail later in this paper.



*Fig. 1 – Stringing of Braced Post*

Service Longitudinal Loads – After the conductor has been strung and tensioned, the line post / braced post now has longitudinal restraint or stiffness. In a tangent application, there typically is equal load on both sides of the post. Should there be any unbalance on either side, the post will deflect in that direction until it hits equal load on both ends. If this were to occur, the clamp would be unclipped from the conductor, allowing the post to return to normal, and then the clamp is clipped back in (Clipping Process).

The conductor, when in balance, acts like a spring, which gives strength to the post with respect to longitudinal resistance.



*Fig. 2 – Conductor under tension has similar properties to a spring*

Fact: when a spring is pulled open, it generates a recoil force to close it back to its original state.

On a BP application with balance loads on both side, temporary longitudinal load will cause the end of the post to deflect in the direction of that load, but the pulling force onto the conductor on the other side of the post will generate the recoil force to pull the system back into balance.

Fact: Service longitudinal loads should range from 100 to 1000 lbs. Any service load greater than 1000 lbs. may require using another design, like a deadend.

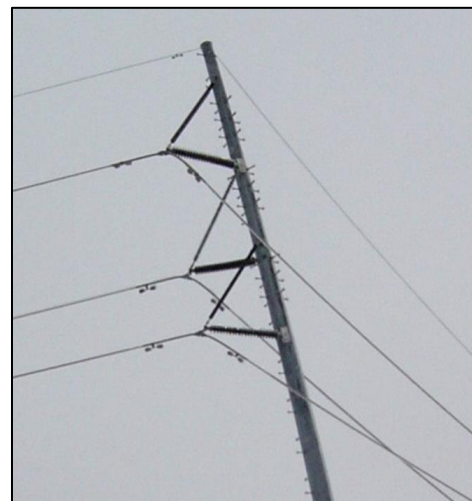
Broken Conductor Longitudinal Load – In the case of broken conductor(s), the job of the braced post insulator is to prevent a cascading failure and isolate the broken conductor to this one structure.

The line post absorbs the initial shock load of the broken conductor. This will most likely result in the entire assembly deforming 90 degrees, with the brace insulator holding the load of the conductor in tension.

Myth: The extreme loads for broken conductor condition should be part of the standard load curve.

This is False. The load curve should only include service load conditions. Broken Conductor ultimate loads should be separate from Service Loading and Stringing Loading.

Fact: The primary objective of the insulator in a broken conductor event is to prevent the cascading failure and hold the line at that structure.



*Fig. 3 – Broken Conductor – All 3 phases down, braced post stopped cascading failure.*

| LONGITUDINAL LOADS                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| STRINGING                                                                                                                                                                                                                                                                     | SERVICE                                                                                                                                                                                                                                                                                                              | BROKEN CONDUCTOR                                                                                                                                                                                                                                                                               |
| <ul style="list-style-type: none"> <li>• First Test of the Post</li> <li>• Base is 1<sup>st</sup> Limitation</li> </ul> <p><u>Test &amp; Validation Method</u></p> <ul style="list-style-type: none"> <li>• Side Load / Deflection</li> <li>• Slow Speed Pull Test</li> </ul> | <ul style="list-style-type: none"> <li>• Includes Conductor &amp; Tension</li> <li>• Loads = 0 to 1,500 lbs.</li> </ul> <p><u>Test &amp; Validation Method</u></p> <ul style="list-style-type: none"> <li>• Multi-axis testing (w/ Vertical &amp; Transverse Loads)</li> <li>• Controlled Speed Pull Test</li> </ul> | <ul style="list-style-type: none"> <li>• Prevent Cascading Failure</li> <li>• Hold the Conductor</li> </ul> <p><u>Test &amp; Validation Method</u></p> <ul style="list-style-type: none"> <li>• Sudden Load Release Event (Shock Load Withstand)</li> <li>• One Time Load Withstand</li> </ul> |

Broken Conductor – This is a onetime ultimate load event, where the line post absorbs the shock load of the suddenly release conductor tension. The rod being flexible offers dampening of that sudden load release, and if the hardware holding the conductor remains intact after the shock load, the insulator will hold the conductor restrained. Once again, the base connecting the line post to the tower is a critical to the ultimate results, but only as a function of initial resistance to the shock load. In most cases, the base will be permanently deformed and potentially broken. There is a need to differentiate between line post and braced post base performance.

Line Post Application Fact: The base used to connect the post to the tower must not break during a broken conductor event, or it will have failed to prevent the cascading failure. [Typically the loads for line post applications would be much lower than those on a braced post.]

Braced Post Application Fact: The base used to connect the post to the tower can permanently deform and break off entirely from the tower and still withstand the broken conductor event. If the brace insulator remains connected to the conductor hardware, the braced post insulator will have withstood the broken conductor event.

Service Loads - Rating cantilever load capacity of a line post and braced post is a “Complex” process, as the strength and weakness of the insulator depends on the various combinations of Vertical, Transverse, and Longitudinal Loads. The post’s strength is limited and defined by; section length, rod OD, upsweep angle, and base connection to the tower.

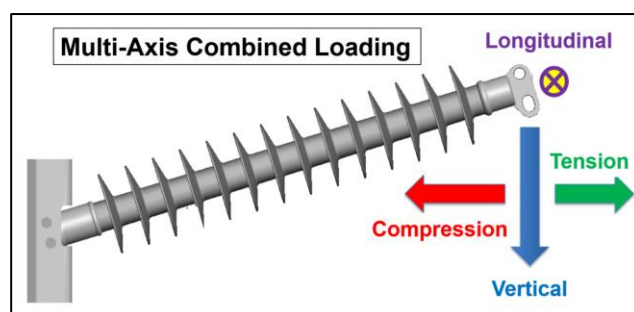


Fig. 4 – Multi-Axis Loading

Fact: Combined Loads including Compression & Longitudinal loads will cause the post to the buckle sooner than on combined loads with tension.

Stringing Loads – during stringing, the objective is to successfully pull through the conductor and properly sag and tension the conductor without causing damage to the line post / braced post. The primary concern would be deformation of the base connecting the post to the tower. Should the base or mounting hardware be deformed, stretched, or damaged during stringing, those components would need to be replaced prior to energizing the line. The base therefore is very critical to the longitudinal resistance of the line post.

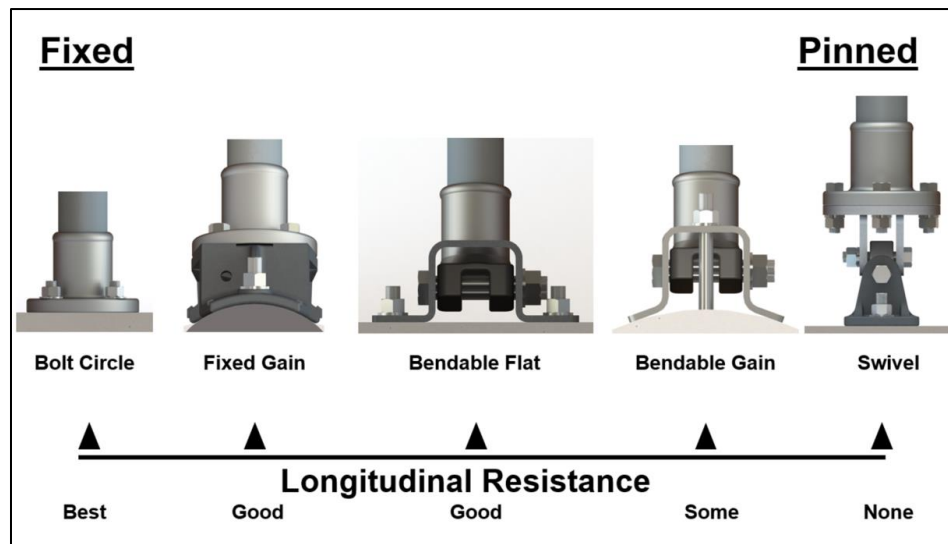
The base is the single most critical part of any line post or braced post application, as it is the base that transfers the combined loads of the conductor through the post into the tower. The Euler Buckling equation requires that the base be defined as Fixed or Pinned.

#### Pinned Connection

- Free to Rotate in the direction of the longitudinal load
- Can restrain Vertical and Transverse loads (potentially limited depending on base type)
- Offers no resistance to a longitudinal load

#### Fixed Connection

- Limited / No rotation in the direction of the longitudinal load (depending on the base type)
- Can restrain vertical & transverse loads, as well as bending moment from longitudinal
- Resists longitudinal loads



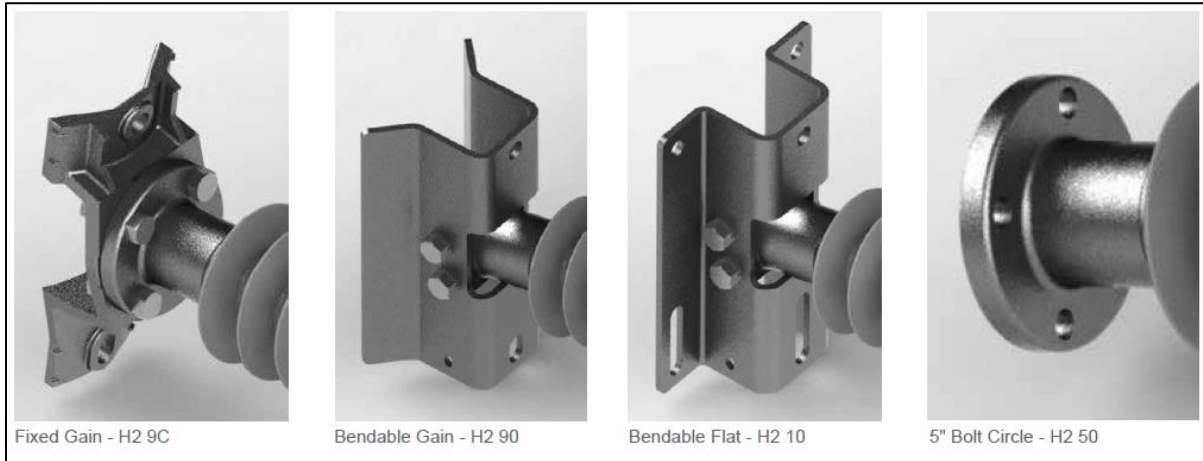
*Fig. 5 – Fixed / Pinned Line Post Base Types. Pinned connections offer no resistance to longitudinal loads. A true Fixed connection offer the best resistance to longitudinal loads.*

Figure 5 shows the various standard base types used for line post and braced post insulators. The most common base type is the gain base, which is used to mount the post to a round pole. The Flat base and Bolt Circle are used to mount onto large flat surfaces. With respect to longitudinal loading, the bolt circle connection provides the most longitudinal resistance, and the swivel base offers none.

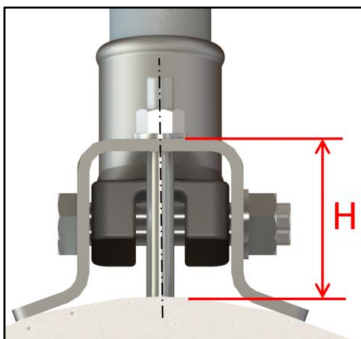
Fact: Swivel base applications are used in braced post applications only. Using a swivel or hinged connection to the tower makes the braced post a Pinned / Pinned condition, with no resistance to longitudinal loads (and potentially limited Vertical and Transverse loads).

Gain base applications are by far the most used tower connection for both line post and braced post applications. There are 2 styles of gain bases that are most common; Bendable Gain and Fixed Gain. Both would be considered fixed connections, but they have different longitudinal loading capacity.

## Typical Base Connections



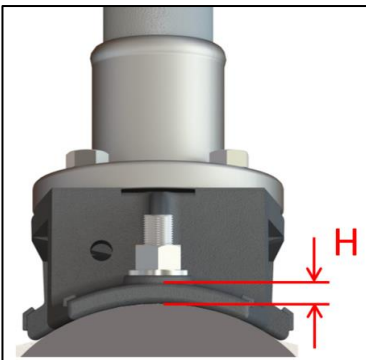
*Fig. 6 – Standard Base Types*



*Fig. 7 – Gain Base [H = 9"] The long mount bolt offset makes the bolt susceptible to bending.*

**Bendable Gain** – This base is connected to the post via an anchor end fitting and two mount bolts. The term “bendable” refers to the manufacturing process where a flat steel plate is bent and formed into the gain shape. This style base is typically made from formed steel, but is also available made from aluminum and cast iron.

The bendable gain design works well for Vertical and Transverse loads, but is very limited with respect to Longitudinal Loading. This is due to the long offset of the center mount bolt. The height “H” is approx. 9” from the tangent of the tower.



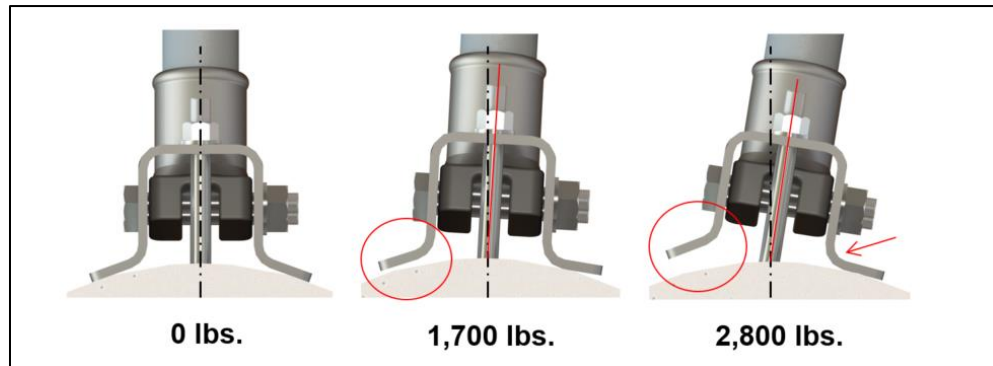
*Fig. 8 – Fixed / Cast Base; the shorter bolt is more resistant to bending loads.*

**Fixed Gain** – This base is connected to the post with a 5” bolt circle and four mount bolts. The term “Fixed” refers to it being more rigid than the bendable, and is typically a cast / ductile iron material.

The fixed gain base works equally well for vertical and transverse loads, and offers good longitudinal resistance, because the bolt height “H” is just the thickness of the base, so the mounting bolts are much closer to the tower in better position to withstand longitudinal loads.

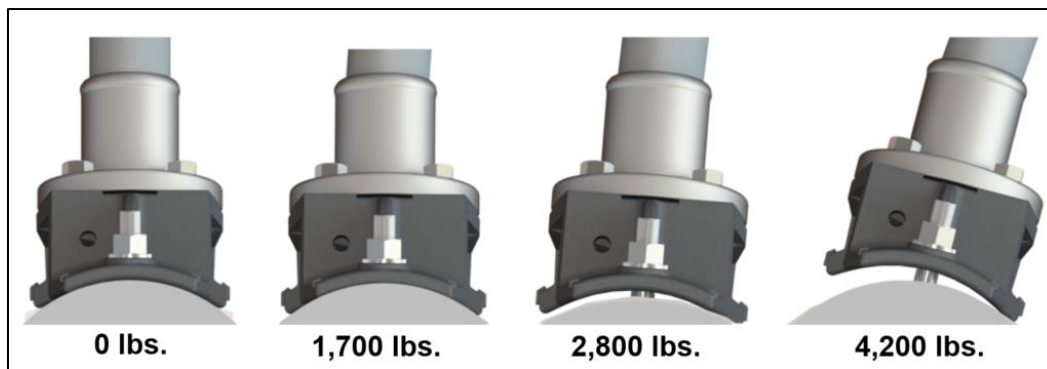
## Gain Base Comparison: Bendable vs Fixed

To show the difference in performance of the gain bases, longitudinal loads were applied to identical 2.5" diameter line posts, both approx. 47" long, one with a bendable gain base, the other with a fixed gain base. Tests were also completed with longer posts, 72" and 97" to cover the range of application for the 2.5" line post.



*Fig. 9 - 2.5" Line Post 47" Length w/ Bendable Gain Base.*

The bendable gain offers some longitudinal resistance early in the tests, but because this base was not designed to withstand side loads, the base lifts off the tower on one side, and deforms (compresses) in the direction of the longitudinal load. At 1,400 lbs. the bendable gain base starts to lift off and deform, and the moment on the center bolt causes it to start bending. At 2,800 lbs. the base continues to deform, with most of the load being absorbed by the base, more like a pinned connection than a fixed.



*Fig. 10 - 2.5" Line Post 47" Length w/ Fixed Gain Base*

The fixed gain offered much more longitudinal resistance than the bendable gain. This is due to the base being more compact and mount bolt is closer to the tower (less bending moment). At 1,700 lbs. the base was still firmly in contact with the tower, and first lift off the tower was not until 2,800 lbs. This is 2 times the resistance of the bendable gain. Due to the more rigid base connection to the tower, the core rod of the line post is able to withstand much more of the longitudinal loads.

Deformation of the base and mount bolts during stringing longitudinal loading are potentially dangerous to the long-term performance of the insulator. The damaged base and bolts would need to be replaced before the line is energized. The fixed gain allowed for the line post (core rod) to absorb the load, which it can recover from without concern.

Fact: as the length of the post increases, it takes less load to deflect the line post.

Fact: The Fixed Gain Base provides more Longitudinal Resistance than a Bendable Gain.

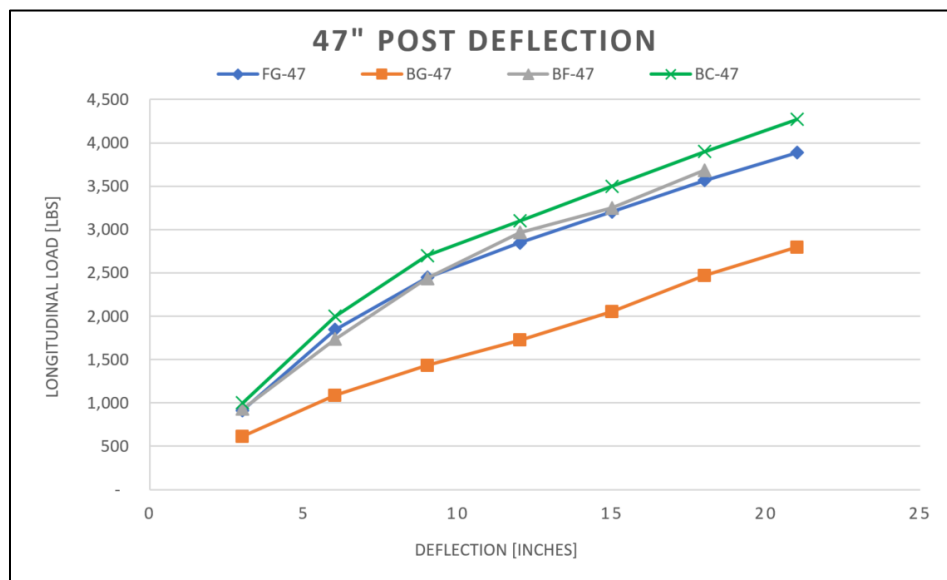
Table 1 shows the point of deformation for each length post for both gain base types. MacLean H2 Series line posts were used for this testing. [H290 = Bendable / H29C = Fixed]

The deflection curves (see figures 11 – 13) are

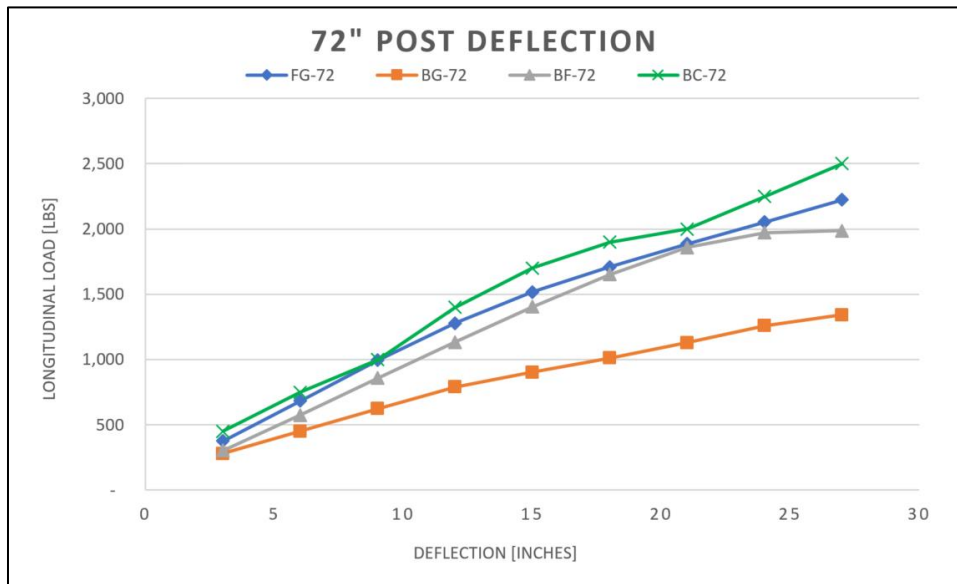
| Table 1: 2.5" Gain Base Test Results |               |                  |
|--------------------------------------|---------------|------------------|
| Section Length                       | Base Type     | Base Deformation |
| 47"                                  | Bendable Gain | 1,400 lbs.       |
|                                      | Fixed Gain    | 2,800 lbs.       |
| 72"                                  | Bendable Gain | 800 lbs.         |
|                                      | Fixed Gain    | 1,700 lbs.       |
| 97"                                  | Bendable Gain | 500 lbs.         |
|                                      | Fixed Gain    | 1,100 lbs.       |

The deflection curves shown in figures 11 – 13 compare the performance of the different base types with respect to longitudinal deflection & section length. As the post increases in length, it takes less load to deform each base. The best performing connection in all cases is the bolt circle end fitting.

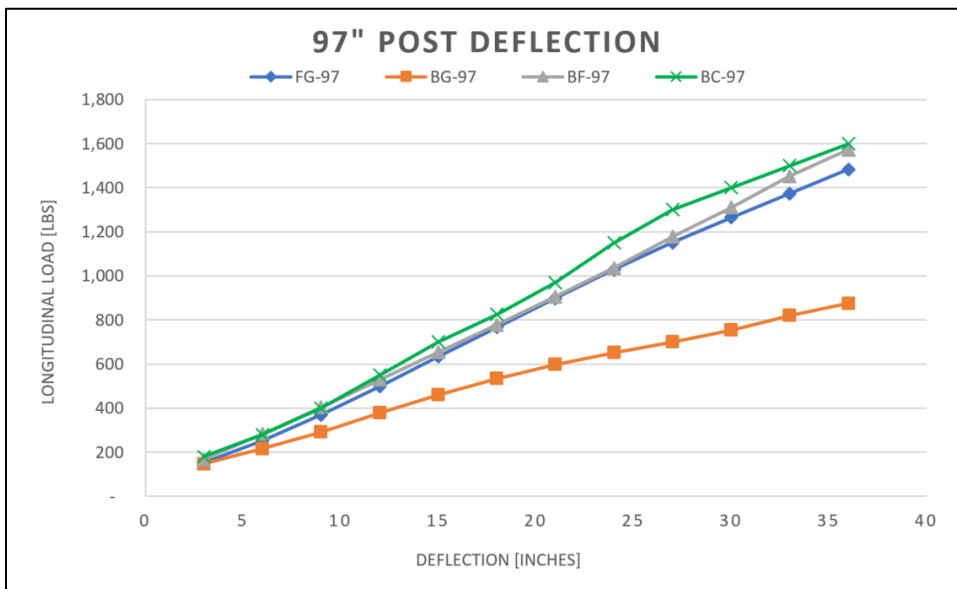
This data is applicable to the MacLean H2 (2.5") line post insulators.



*Fig. 11 – 47" Line Post Base Deflection Comparison*



*Fig. 12 – 72" Line Post Base Deflection Comparison*



*Fig. 13 – 97" Line Post Base Deflection Comparison*

Myth: All bases provide the same or comparable mechanical strength.

This is false. Not only is there a major performance difference using fixed vs bendable, but each design is not governed by a detailed ANSI Standard. There is no minimum strength requirement, and the base design and strength is left up to each insulator manufacturer to define. ANSI C29.17 only defines that the base must have center mount hole spacing 12" and that the base should have a 12-degree upsweep.

Fact: The ANSI C29.17 standard needs more dimensional requirements and minimum performance criteria for all base connections for line post and braced post applications.

Fact: The Bolt Circle end fitting is the most reliable line post connection to the tower.

Conclusion

The key to rating the working cantilever loads of line post and braced post applications is understanding the limitations and knowing how to properly define those limits with respect to the various combined loads the insulators may be exposed to. Longitudinal loads make this already complex equation more complicated, but by properly breaking down the different forms of longitudinal loads and how the post is strong or weak in each case, we can move forward with engineered solutions that are stronger and capable of higher loads.

Line Post and Braced Post insulators in service today have performed well, but times are changing and expectations are increasing. Many utilities are looking to further harden their existing lines, adding higher levels of safety factor. Now is the time to review existing design limitations and look to drive standards to higher levels.



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