Mechanical Testing and Evaluation of Braced Line Post Assemblies Composed of Non-Ceramic Insulators

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Abstract— This paper discusses the elastic buckling load of braced line post type assemblies comprised of non-ceramic insulators and the effects of the method of test on those values.

I. Introduction

Initially, the line post was the predominant use of an insulator as a tower component. The braced line post was a natural evolution for the insulated crossarm. It offers an advantage over the traditional line post by increasing the vertical load capabilities, allowing longer span length construction. Additionally, by sharing loads between two insulator units, some redundancy can be achieved.

The earliest braced line posts (pivoting horizontal-Vs) used porcelain components. To assure that only axial loads are applied to the porcelain strut and suspension insulators, pivoting hardware was employed.

Non-Ceramic insulators were first introduced to the braced line post design family in the late 1970s. The Non-ceramic insulators simplified the designs by using their inherent flexibility to eliminate the need for special pivoting joints. This offered a simpler assembly method and enabled the designs to better accommodate moderate load excursions (impulse loading).

Both the ceramic and non-ceramic braced line post assemblies offer improvements in strength, but there are limits imposed by the component members. Some of the member strength characteristics are straightforward. The ultimate strength capabilities of the suspension insulators are well defined, as is the strength of the hardware used to couple the insulators. The more difficult aspect involves the compressive strength capabilities of the strut or post member of the assembly.

For the porcelain assembly under extreme compressive loading, the post may undergo plastic buckling. In other words, the post strut member will withstand axial compression loading until it buckles in an unrecoverable manner.

But, the non-ceramic line post will sustain compressive load until it buckles elastically. Mild elastic buckling may be recoverable. As a result, an understanding of buckling characteristics of the non-ceramic insulator is essential.

While test procedures exist for the strengths of all of the sub-components used in braced line post assemblies, no standards exist for testing the design as a whole.

II. BUCKLING

Based upon Euler's buckling equations, the compressive characteristics of a column are a function of the end conditions of the column under test.

Buckling Load = $\pi^2 * E * I/(k*L)^2$

Where,

E = Young's modulus for the material, (lb/in^2)

I = Moment of Inertia (in^4)

L = Section length of the column (in)

k = Effective Buckling length based upon the end conditions of the column.

Traditionally, the "k"-factor ranges from ½ to 2. The final equation then ranges from:

Fixed – Free: k=2

$$\text{Buckling Load} = \pi^2 * E * I/(2*L)^2 = \pi^2 * E * I/(4*L^2)$$

Pinned – Pinned: k=1

$$\text{Buckling Load} = \pi^2 * E * I/(L^2)$$

Fixed-Fixed: k=½

$$\text{Buckling Load} = \pi^2 * E * I/(½*L)^2 = 4*\pi^2 * E * I/(L^2)$$

So the values available for a given post can differ by a factor of 16. The first issue involves determining what the "k"-factor is for the design under consideration. The second issue involves the method of testing.

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In determining the “k” – factor, it seems obvious that none of the braced line post assemblies exhibited the exact characteristics of Euler’s columns. The blunt force approach to determine these factors is to test.

Over the past 40 years, a great deal of testing has been performed. While the ground end characteristics of the line post (strut) insulator are reasonably definable, the line end fitting is more complicated. The vertical load applied by the conductor and the restraint applied by the suspension insulator form a vertical pivot axis, helping to restrain the post from buckling in a vertical plane.

The existence of that hinge simplifies data gathering. Originally, data was collected in all planes, but once the vertical pivot axis was recognized, data gathering could be focused in the horizontal plane.

The braced line post family is subdivided into three types of assemblies:

- Pivoting Horizontal V (see Figure 3) -
  - Ground end of post (strut) - Vertical hinge pin
  - Ground end suspension – tower vang
- Fixed Base Horizontal V (see Figure 4) –
  - Ground end of post – fixed base
  - Ground end suspension - tower vang
- Braced Line Post (see Figure 2) –
  - Ground end of post (strut) - fixed base
  - Ground end of suspension - tower face

Figure 1 - Pivoting Horizontal V
6,000 lb Vertical; 8,700 lb Longitudinal

Initially, it was believed that all three would perform equivalently. As it turned out, the assemblies offered different “k”-values. The vang at the ground end of the Horizontal V variants (fixed and pivoting) forces the line end of the assembly to move uphill to buckle, creating a degree of fixation and reducing the “k”-factor (see Figure 1). It does this by creating a hinge angle from the base of the post to the vang/suspension attachment point.

The braced line post demonstrated the highest “k”-factor (and the lowest buckling loads) due to the absence of any degree of fixation of the line end fitting in the horizontal plane (no hinge angle).

To perform these tests, free weights are attached to the line end of the insulator assembly (via a load bucket). The deflection of the assembly is monitored in the horizontal plane as a function of load. The data is then plotted and the inflection point of the deflection is determined. That inflection point becomes the buckling load (See Figure 7).

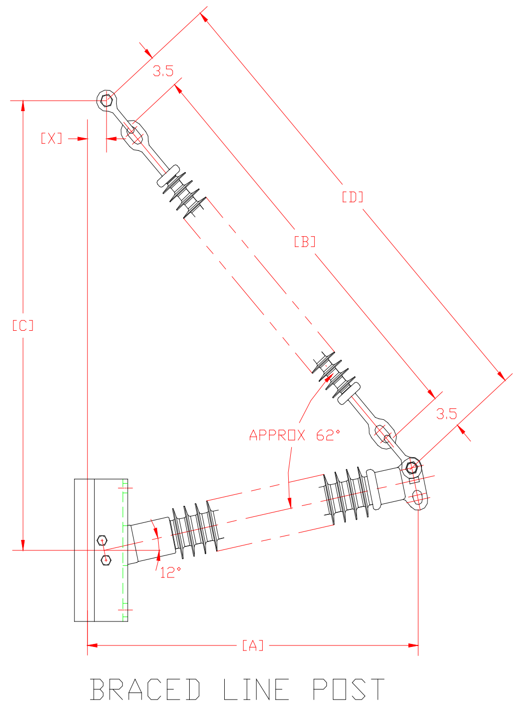

Figure 2

The data collected from a variety of different assemblies offered an empirical approach to determine the “k” factor for the denominator of the buckling equations. A graph of the data is shown as Figure 6. The buckling loads were calculated based upon equations (1) and (2) and the assembly design variables (see Figure 5) and represent the axial compression load applied to the post member.

$$\Sigma F_x = P_c*\cos(\alpha) - S_T*\cos(\beta) = 0 \quad (1)$$
$$\Sigma F_y = P_c*\sin(\alpha) + S_T*\sin(\beta) - V = 0 \quad (2)$$

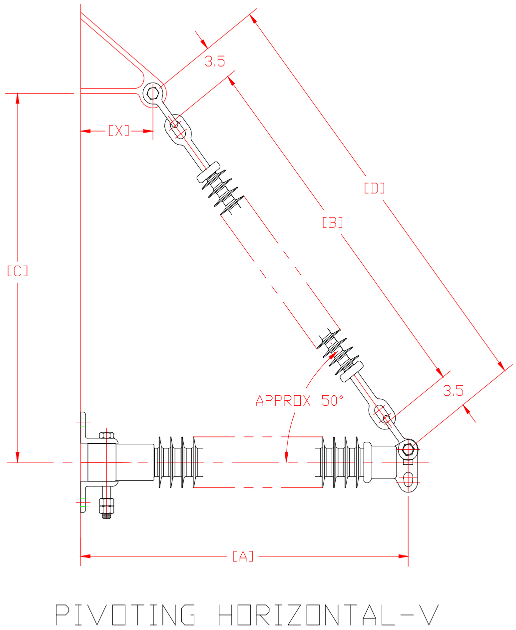

Figure 3

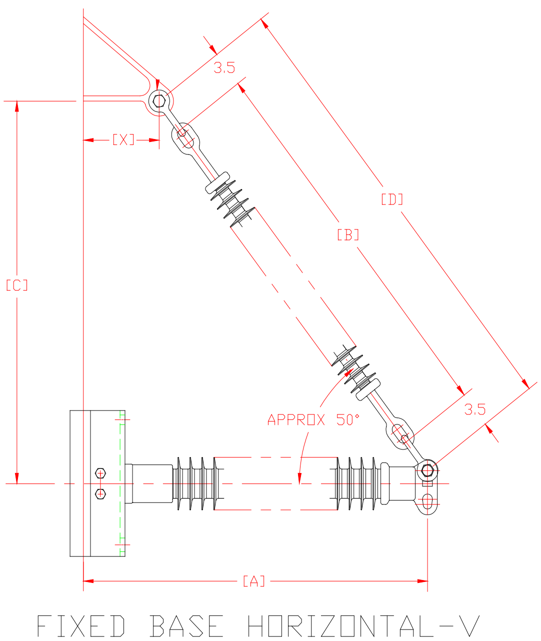

Figure 4

Based upon the empirical data, and with the convention that the k^2 value will be called k, the equations for the three types of assemblies tested would be as follows:

Pivoting Horizontal V:

Buckling Load = π^2*E*I/(1.03*L^2) (3)

Fixed Base Horizontal V:

Buckling Load = π^2*E*I/(1.02*L^2) (4)

Braced Line Post:

Buckling Load = π^2*E*I/(1.33*L^2) (5)

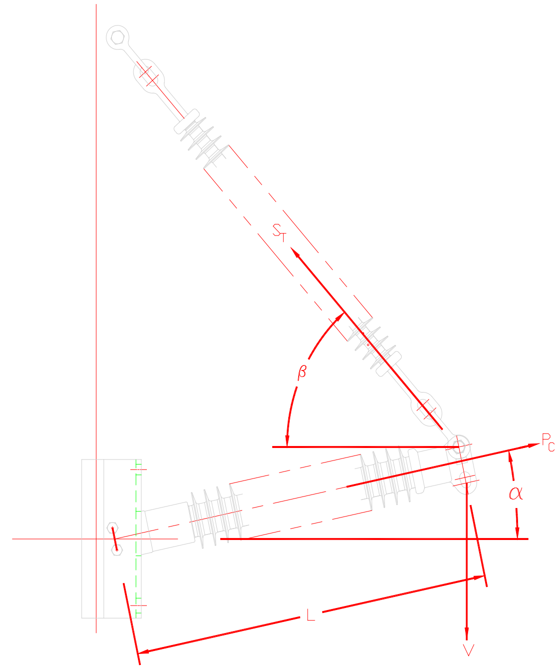

Figure 5

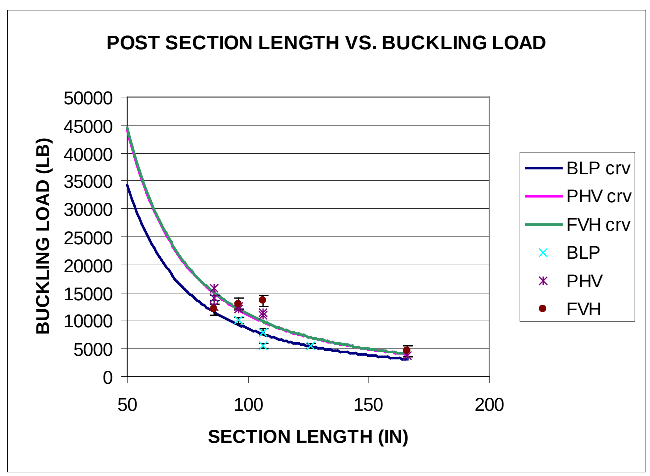

Figure 6 - Plot of buckling loads by assembly type

These equations were derived empirically using free weights for the testing. The method employed is detailed below.

Figure 7 depicts the results of testing a braced line post designed for a 345-kV application. The post length was 110 inches. Discrete loads were assembled in a load bucket and lifted off the ground using a hydraulic cylinder between the line end of the insulator assembly and the weights. The longitudinal offset of the line end of the braced line post was measured using a string potentiometer. The graph represents the deflection as a function of load from a static perspective. The inflection point of the curve has been estimated to be approximately 8,400 lb.

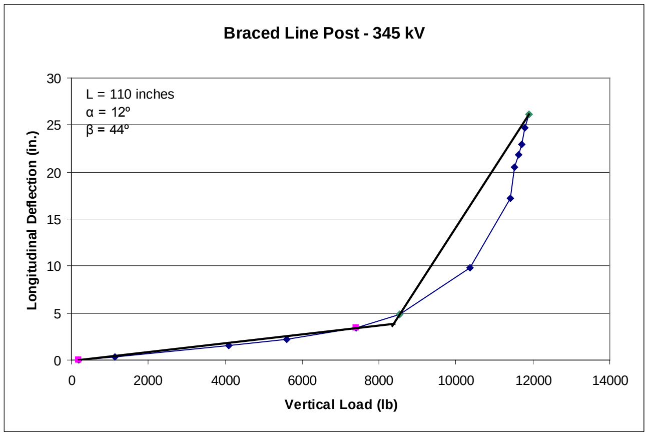

Figure 7 - BLP - 2.5" Diameter Rod

Applying equation (5) to the 110 inch long, 2.5 inch diameter post:

Buckling Load = $\pi^2 * E * I/(1.33 * L^2)$ = 7,054 lb.

Then, applying equations (1) and (2) with the conventions detailed in Figure 5, the vertical load required to be applied to the assembly that would initiate buckling would be 8,130 lb. Within the experimental error for the test method employed, that was the load determined.

But, you could test in a different manner to determine the buckling characteristics of the assembly. You could load the assembly using a fixed anchor point and a hydraulic cylinder. Because the load will always pull the line end of the assembly back toward the anchor point, the line end of the braced line post now has a degree of fixation not available to the assembly loaded with free weights. Loading the same 345 kV assembly from a fixed anchor point yielded the plot of Figure 8. Note that the deflection is less than 20% of that for the assembly with free weights. No indications of buckling were observed up to 16,000 lb (greater than the maximum load applied with free weights).

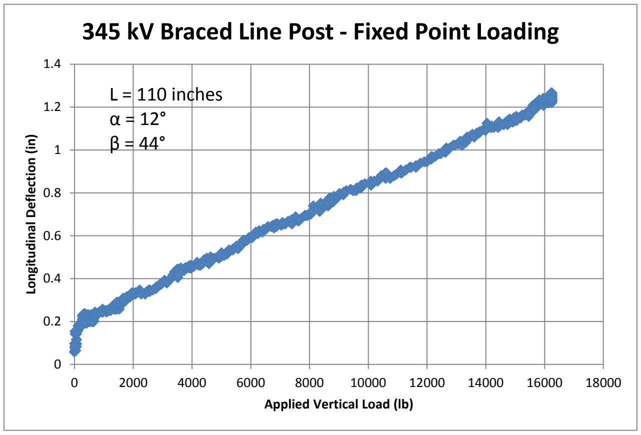

Figure 8 - BLP - 2.5" Diameter Rod

The two test methods would lead to markedly different interpretations of the capabilities of the same assembly.

Going back to the use of free weights in a load bucket, the bucket should act as an anchor point, until such time as it clears the ground. A second series of tests were performed on a 230 kV braced line post assembly. Initially, a series of static loads were applied and the deflection of the assembly with the full load measured. The results are shown in Figure 9.

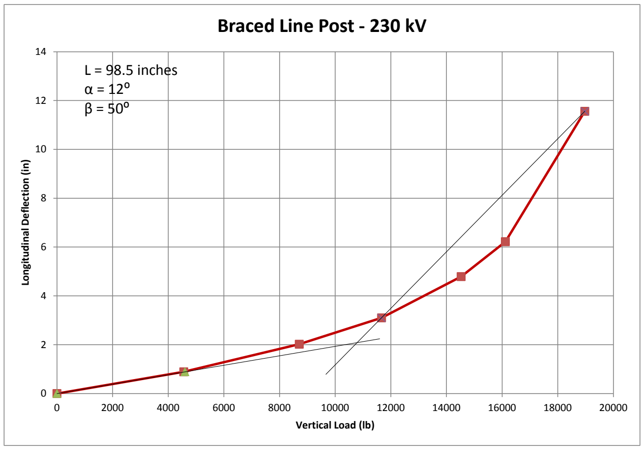

Figure 9 - BLP - 2.5" Diameter Rod

The inflection point in this case occurs at approximately 10,800 lb. The calculated buckling load for a 98.5 inch post in a braced line post would be approximately 8,800 lb (8,797 calculated). Using equations 1 and 2, the vertical load required to apply that compressive load would be 10,433 lb, within the anticipated experimental error.

In this instance, load and deflection were measured during the application of each of the loading cases. The position of the free weights below the structure may not be precisely aligned with the line end fitting, allowing some relative shift in the loading position when compared with the fixed point loading of Figure 8. However, comparison of some of the loadings provides insight.

A vertical load of 8,700 lb is below the anticipated buckling load of the assembly. Figure 10 plots the load/deflection data collected for the 8,700 lb static load.

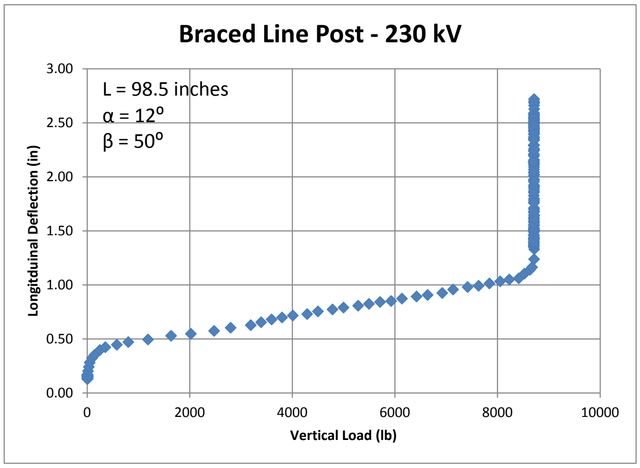

Figure 10 - BLP - 2.5" Rod Diameter

The first 0.5 inches of deflection represent a longitudinal shift of the line end fitting with the load. After that, the longitudinal shift increased to approximately 1 inch up to 8,000 lb. That represents approximately 50% of the deflection with free weights from Figure 9. Once the free weights cleared the ground, another inch of deflection resulted. But, it is important to note that the deflection increased as the load cleared the ground. While immediately before the load left the ground, the deflection was 1 inch, once the weights were free, the deflection increased to 2 inches (average).

It should be noted that the oscillation of the line end fitting once the load bucket has cleared the ground is an indication of the freedom of motion available to the assembly when tested with free weights. A quick review of the data prior to the load bucket being lifted indicates the effect of the degree of fixation on the data.

The same 230 kV assembly was installed in a load frame to simulate a vertical load from a fixed loading point. The longitudinal deflection of the line end of the assembly was monitored with a string potentiometer (precision ±0.050"). The anchor point for the load was visually aligned. The initial deflection (see Figure 11) of 0.4 inches appears to represent misalignment of the anchor point. When the simulated vertical load exceeded 4,000 lb, no additional deflection was measured with loads up to 10000 lb. The overall deflection was less than 20% of that registered with free weights and no indications of instability were observed.

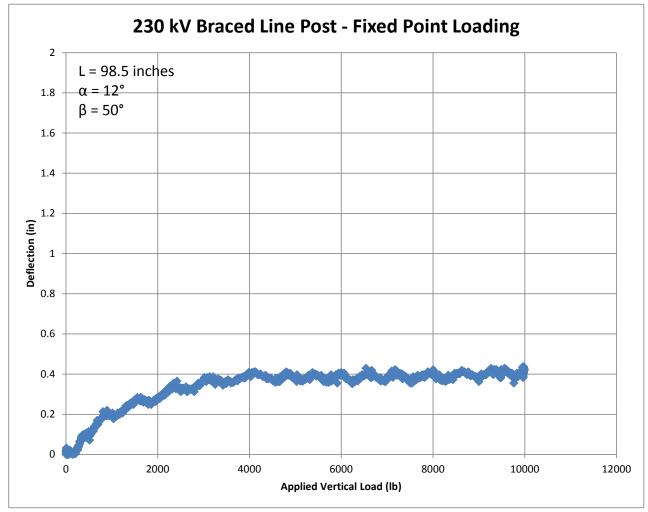

Figure 11 - BLP - 2.5" Rod Diameter

III CONCLUSIONS:

While standards do not define a test method for determining the vertical load capability of non-ceramic braced line post insulators, the testing method employed may suggest markedly different results.

Testing with a fixed anchor point assumes that the tension in the conductors supported by the assembly will be sufficient to limit the ability of the assembly to move in a longitudinal direction. This imparts an additional restraint on the buckling characteristics of the line post (strut) and subsequently offers higher elastic buckling onset values.

Testing with free weights assumes that the attachment point for the conductors can move longitudinally under appropriate conditions. Testing with free weights offers greater deflection for the post (strut) member of the assembly, and results in significantly lower elastic buckling onset loads.

The Vertical load rating of a braced assembly will be based on one of these test methods. When presented with load ratings for a given design, the user should inquire regarding the method of testing used to develop the vertical load rating of the braced line post or horizontal V insulator assembly. That response, when compared to the utility's understanding of longitudinal conductor motion and real-world application, should help determine the effectiveness of the assembly to meet the requirements of the installation.

IV REFERENCES

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