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Checking Post Insulators with Interaction Curves

Introduction

When modelling post insulators in PLS-POLE or TOWER (hereafter only PLS-POLE will be referred to since post insulators are not normally used on lattice towers) software there are two different ways to define the post's strength.

The first approach has the strength expressed by three capacities defined in the directions of its local axes V, T and L as shown in Figure 1. (*This first approach is maintained for legacy purposes and is not directly used in v7.64 or later*).

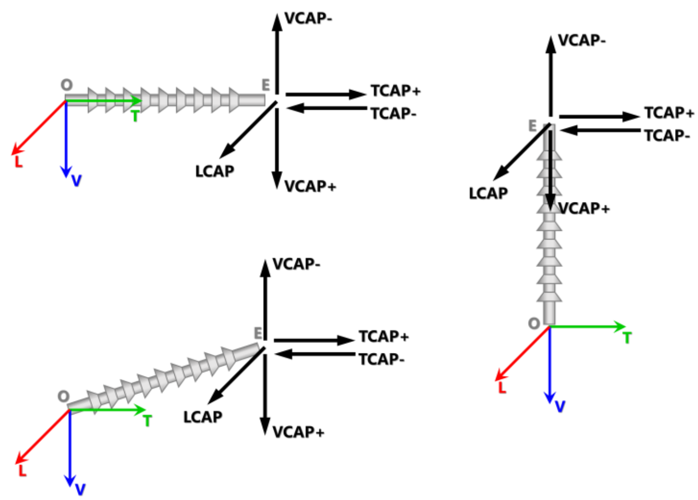


Figure 1: V-T-L Post Insulator Capacities

The transverse capacity is denoted **TCAP+** if it corresponds to a load that puts the post in tension or is denoted as **TCAP-** if the load puts the post in compression.

The vertical capacity is denoted **VCAP+** if the vertical load is down and **VCAP-** if the vertical load is up. The longitudinal capacity **LCAP** is assumed the same in both directions.

The second approach uses the axial and cantilever capacities. The axial capacity in Figure 2 is denoted as **TENCAP** if it corresponds to a load that puts the post in tension or is denoted as **COMCAP** if the load puts the post in compression. The cantilever capacity **CANCAP** is assumed the same in any direction perpendicular to the post.

Loads are applied in the global V, T and L directions but will be resolved into the respective components considering the post orientation, to compare against the stated axial or cantilever capacities when making use of this design check.

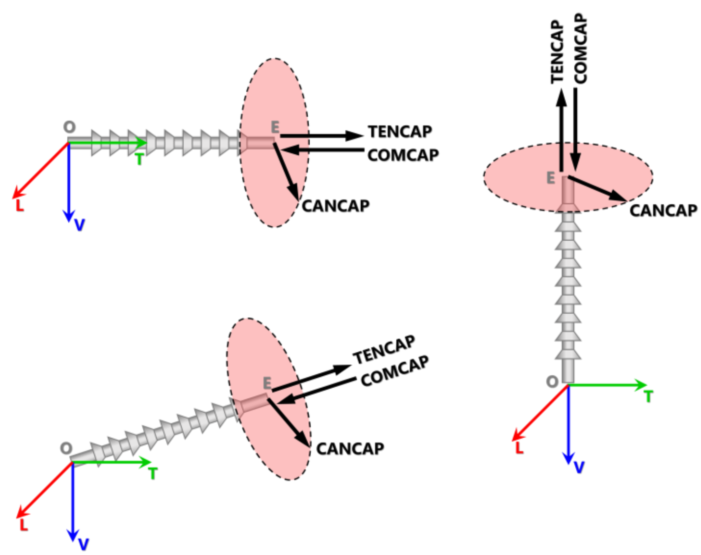


Figure 2: Axial and Cantilever Post Capacities

This document focusses on how to define and create an interaction curve to check post insulator strength, which uses the first approach shown in Figure 1.

Interaction Curves

In PLS-POLE, the V-T-L capacities can be independent of each other or, more realistically, can be related to each other through some kind of interaction surface.

In its earlier versions, PLS-POLE could only handle independent capacities. However, since Version 8, both the independent and dependent capacity cases are handled through the same interaction surface concept. An interaction curve can be thought of as a 2d slice of a 3d interaction capacity sphere or volume. A slice is defined by a given value of longitudinal capacity and consists of at least three or more transverse and vertical capacity pairs.

The capacity interaction surface is the boundary between an inside volume in which any combination of vertical, transverse and longitudinal loads can safely be handled by the post insulator and an outside volume where any combination of loads is unacceptable (usage more than 100%). In PLS-POLE, capacity interaction surfaces are symmetrical about the V-T plane, i.e., it is assumed that positive or negative longitudinal loads have identical effects on the capacities.

The intersection of an interaction surface by a plane perpendicular to the longitudinal axis (crossing that axis at the distance L from the origin) is a closed polygon which is the interaction between the vertical and transverse capacities for a given longitudinal load L. Such capacity polygons (or V - T interaction diagrams for given longitudinal load) are typically available as load charts from post manufacturers.

If you choose to work with independent vertical, transverse and longitudinal capacities you will generate an interaction surface as shown in Figure 3. The surface consists of the 6 outside faces of the cube shown.

NOTE: *The relationship between the dimensions of this surface and the capacities from Figure 1 are shown in the bottom right-hand corner.*

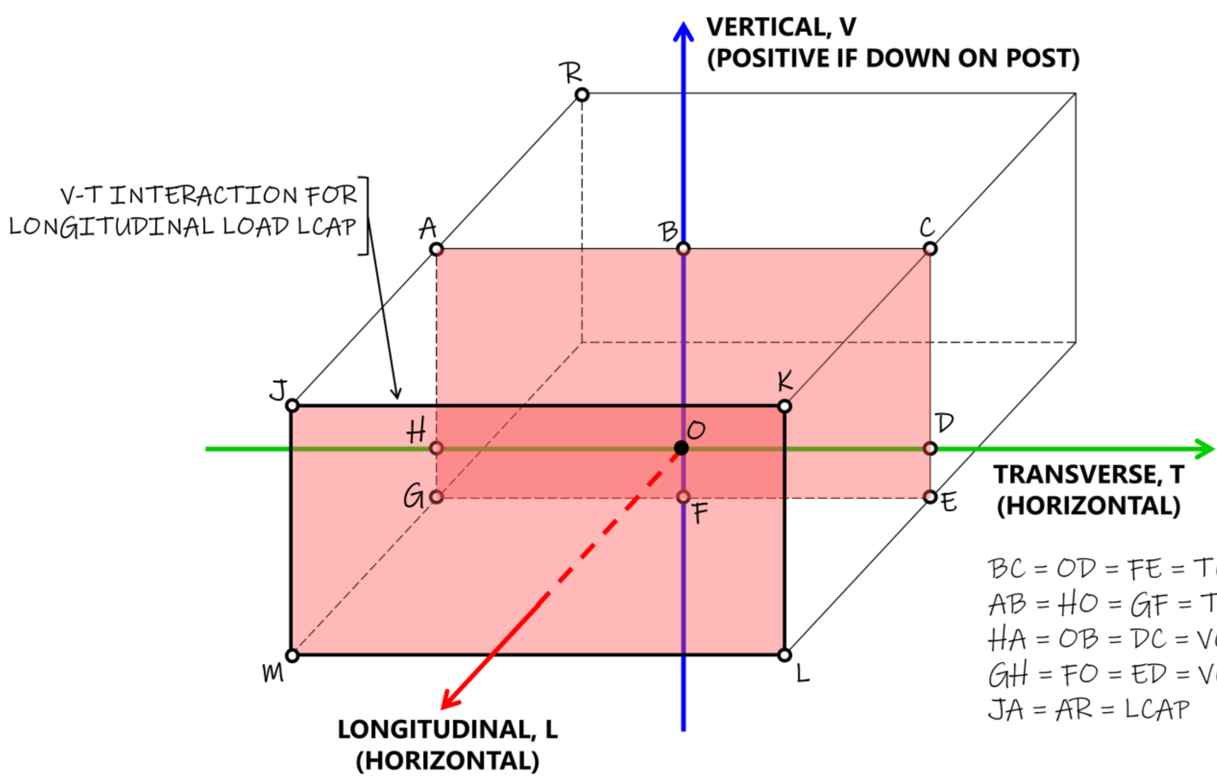


Figure 3: No Interaction between Capacities

When there is dependency between the capacities in the three directions you will rather work with a "stepped" interaction surface, such as that shown in Figure 4 by an arbitrary surface. The surface is defined from two V – T interaction diagrams (load charts) assumed given by a post manufacturer for longitudinal loads **L1** and **L2**. The "stepped" nature of the interaction surfaces is a consequence of PLS-POLE conservatively assuming that the V - T interaction for any longitudinal load is the same as that provided for the next larger longitudinal load. In the chart below, the V - T interaction polygon for the longitudinal load **L1** is defined by *7 points* (vertices) and that for load **L2** is defined by *5 points*.

There should be at least 3 points to define such polygons.

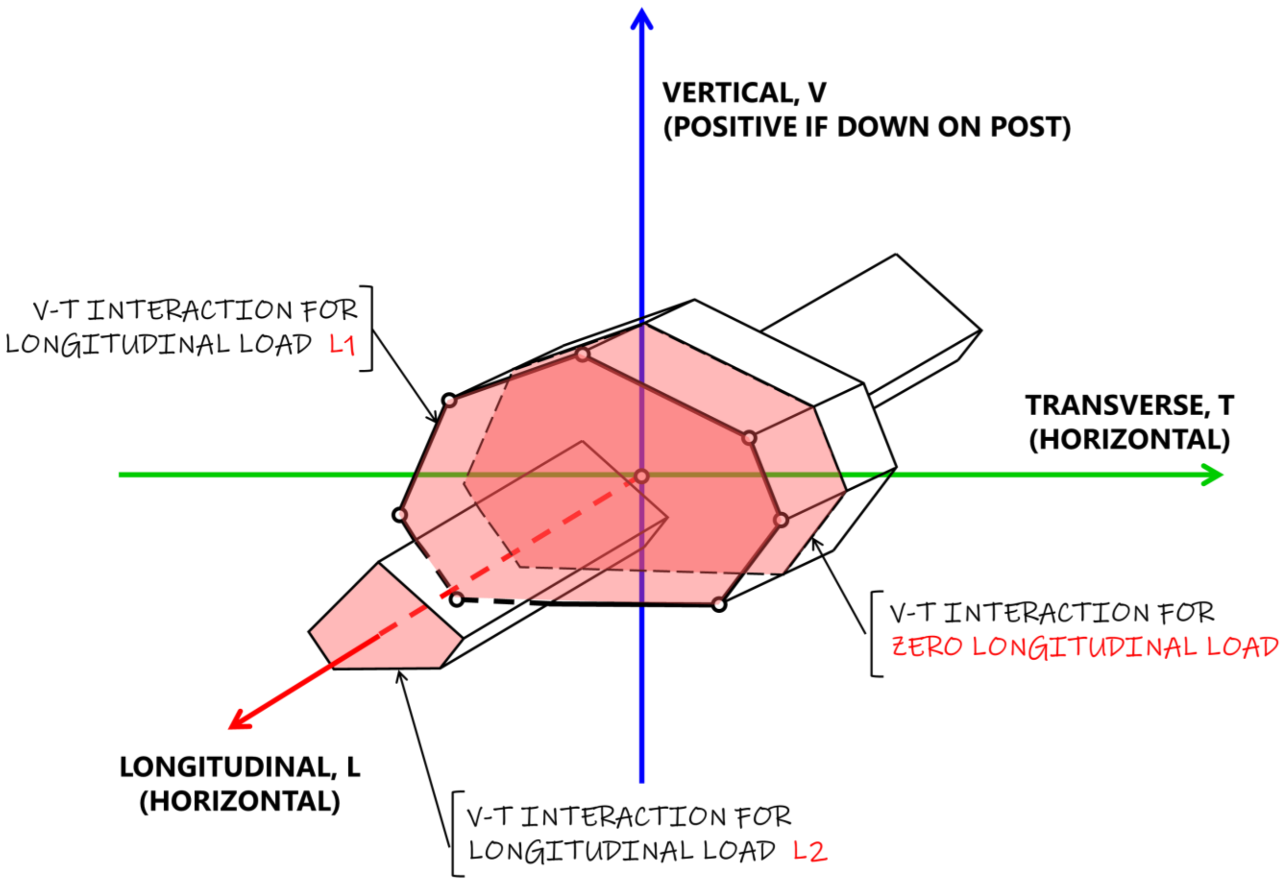


Figure 4: "Stepped" Interaction Surface

Creating the Post Insulator Component Library

The post insulator strength capacities are entered in the library found at ***Components/ Insulators/ Post Properties…*** shown in transposed form in Figure 5.

This is where you make the choice of whether to use the interaction capacity curves OR the axial and cantilever capacity checks. If you leave any of this information blank, the corresponding strength check will not be performed. However, if you enter BOTH an interaction capacity curve AND the axial and cantilever capacities, then both of these strength checks will be performed.

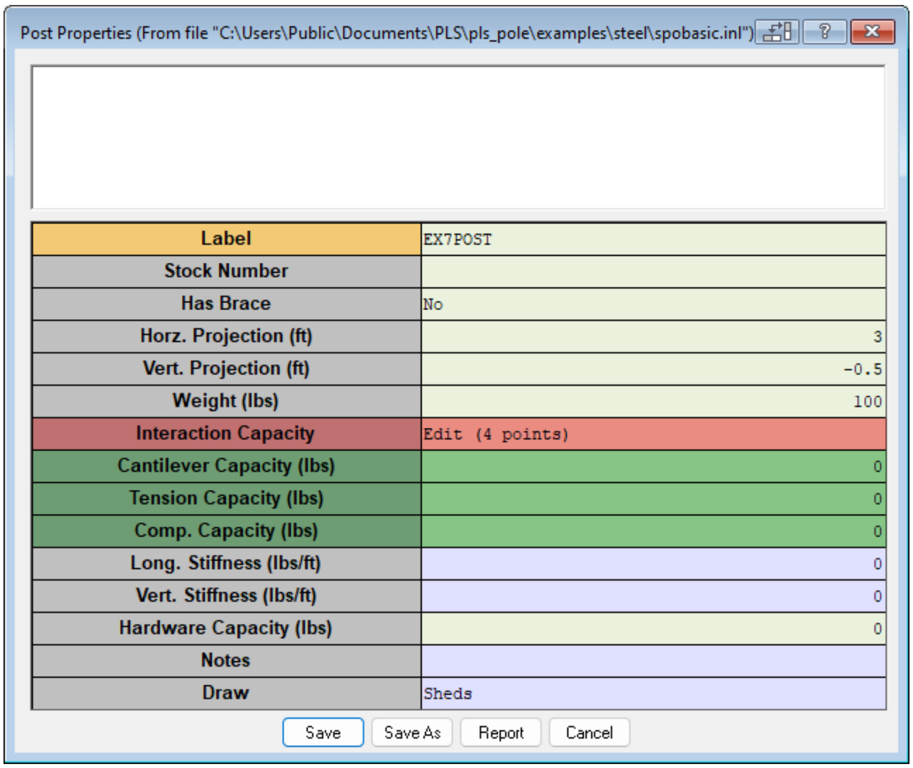


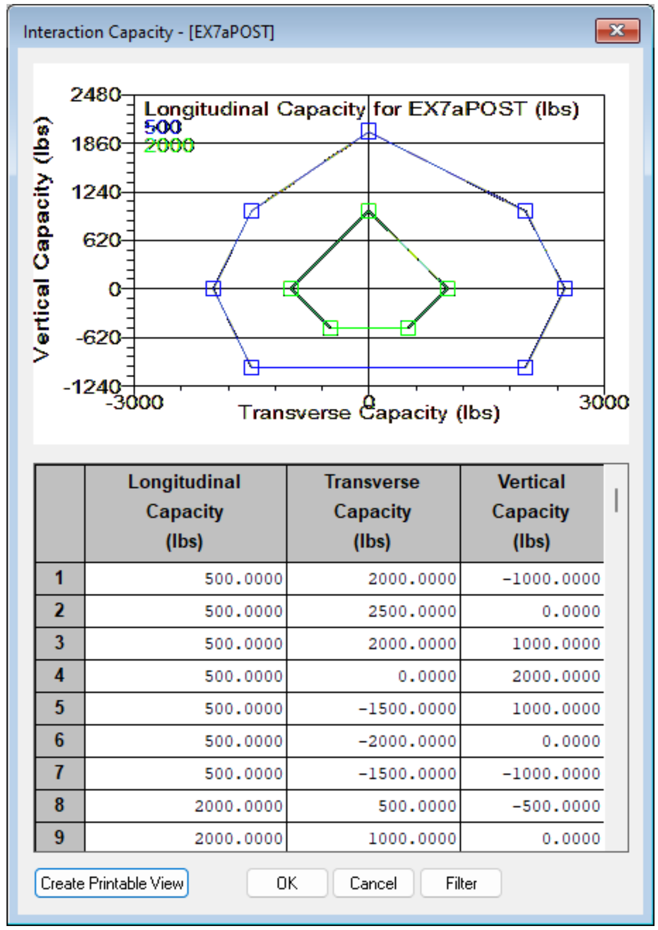
Figure 5: Post Properties

<u>NOTE</u>:

- You may need to contact your post insulator representative or manufacturer to obtain their interaction curves.
- Manufacturers frequently supply curves that include strength factors. *When inputting them in PLS-POLE you will need to reconcile any manufacturer applied strength factor with the S.F. For Insulators found in **Loads/ Vector Loads (LCA File)…** and in **Criteria/ Structure Loads (methods 3,4)…** in PLS-CADD.*
- Some manufacturers even supply curves that use factors other than those specified in the NESC.
- In all cases, it is important that you sort out what strength factor will be used before inputting the curve. You may want to review our NESC Insulator Requirements technical note at https://www.powline.com/technotes/NESC_Insulators.pdf

As mentioned above the interaction curves are defined by three sets of numbers which are input by clicking on the button in the *Interaction Capacity* column found in the table shown in Figure 5.

This takes you to the *Interaction Capacity* dialog shown in Figure 6 in which you define the geometry of each V - T interaction diagram (load chart). Starting with the diagram corresponding with the smallest longitudinal load, you enter the coordinates (Longitudinal, Transverse and Vertical Capacities, in that order) of each point defining that closed polygon. Then you enter the coordinates of the points defining the diagram for the next higher longitudinal load. This is illustrated in Figure 6 for an arbitrary situation similar to that depicted in Figure 4.



	Longitudinal Capacity (lbs)	Transverse Capacity (lbs)	Vertical Capacity (lbs)
1	500.0000	2000.0000	-1000.0000
2	500.0000	2500.0000	0.0000
3	500.0000	2000.0000	1000.0000
4	500.0000	0.0000	2000.0000
5	500.0000	-1500.0000	1000.0000
6	500.0000	-2000.0000	0.0000
7	500.0000	-1500.0000	-1000.0000
8	2000.0000	500.0000	-500.0000
9	2000.0000	1000.0000	0.0000

Figure 6: Interaction Capacity Data

Note:

These coordinates should be entered such that they appear in a counterclockwise order in the graph.

Also, no concave polygons are permitted for the graph. If a concave polygon is given by a manufacturer, then the engineer should make the appropriate judgment to enter the most conservative convex polygon for the strength check.

An error will be given if a concave polygon is created by the entered coordinates.

After entering all points for the interaction capacity diagram, you can use the *Filter* button to remove any redundant collinear points. This button also makes any clockwise convex curve become counterclockwise.

The definitions of these capacities are defined below:

Longitudinal Capacity:

Longitudinal is defined as being perpendicular to the post and in the horizontal plane. A curve is both identified and defined by its longitudinal capacity. A change in the longitudinal capacity input in the Interaction Capacity table indicates the start of a new curve. The Longitudinal Capacity is assumed symmetric and must be input as a positive number (program will assume the capacity in the negative direction is the same).

Transverse Capacity:

Transverse is defined as being in the direction of the post and in the horizontal plane. Positive values of transverse capacity correspond to tension capacity and negative values correspond to compression capacity (for non-vertical posts).

Vertical Capacity:

Vertical is the same as the global Z axis except a positive value indicates downward capacity and a negative value indicates uplift capacity. One special case to be aware of is the input of a negative Vert. Up Capacity which in previous versions signified a required minimum vertical load. This is translated into a positive Vertical Capacity and will result in an interaction curve that is entirely above the vertical axis.

To elaborate on the creation of interaction curves here is simple summary of what to remember when creating them:

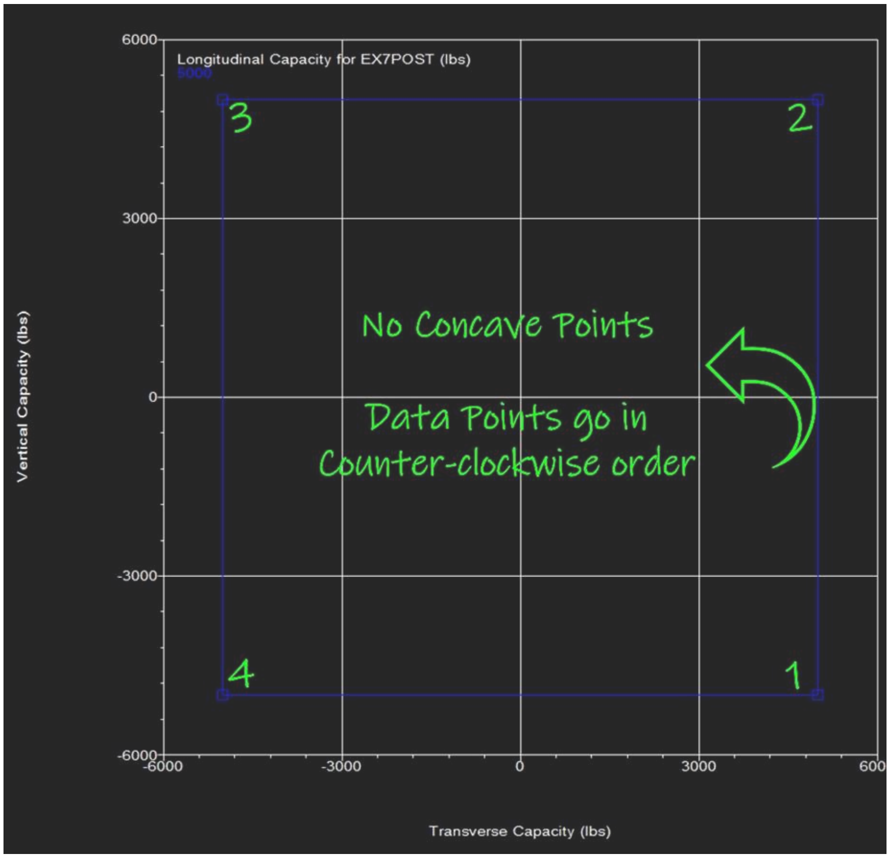


Figure 7: Good Interaction Curve

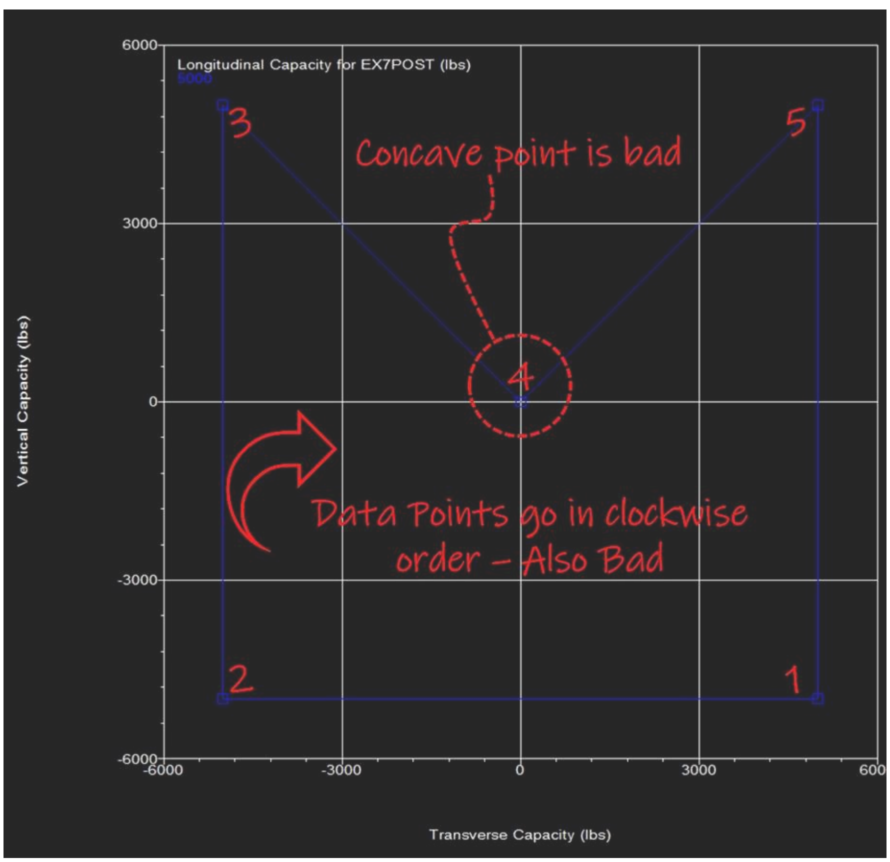
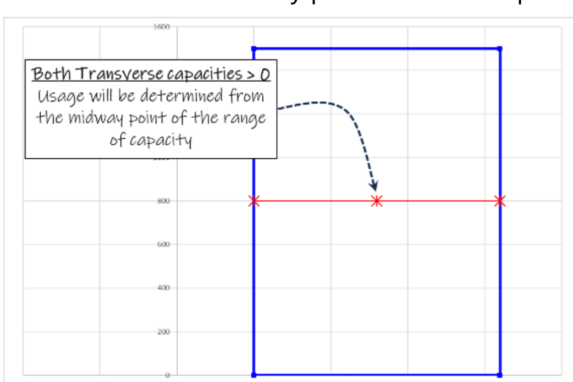
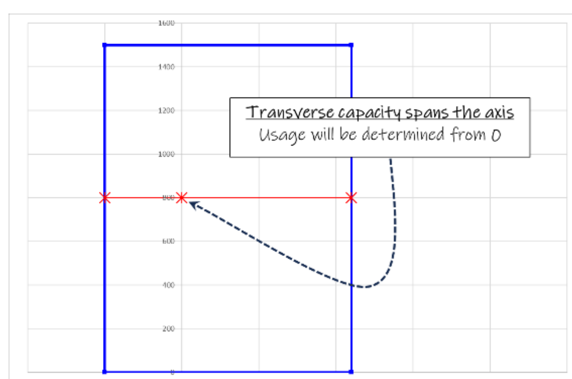


Figure 8: Bad Interaction Curve

Interaction Strength Check Explanation

Once you have defined the interaction curves then PLS-POLE can use them to check your post insulator. This check involves finding curves with a longitudinal capacity greater than the longitudinal load and seeing if the point defined by the transverse and vertical load falls within that curve while accounting for the insulator strength factor.

The percent usage concept for this check is somewhat arbitrary and is designed to meet two goals: first, to produce the same results as previous versions did and second, to give you some intuition as to how close to the limit (how close to the edge of the curve or how far beyond the curve) your load is. To do this, separate longitudinal, transverse and vertical usages are calculated for every curve. Then the maximum of these three usages is compared with that of all other curves. Finally, the curve producing the highest maximum usage is selected.

<table>
<tr><td>Step 1:</td><td colspan="2">Find applied load point VTL values.
Divide load point VTL's by the insulator strength factor.
Plot on interaction diagram.</td></tr>
<tr><td>Step 2:</td><td colspan="2">Disregard any curves for which your longitudinal load is greater than.
PLS-POLE starts by looking at the longitudinal capacity.
It is possible for PLS-POLE to base usage from any other remaining longitudinal curves your load point falls underneath.
So, if the load point falls into a longitudinal capacity curve it divides the longitudinal load by the largest longitudinal capacity curve it falls in.</td></tr>
<tr><td>Step 3:</td><td colspan="2">If the capacity of the post in the longitudinal direction is adequate, you'll need to calculate the higher of the usages in the transverse and vertical capacities.</td></tr>
<tr><td>Step 4:</td><td colspan="2">At the given load point (after dividing by SF), extend lines vertically and horizontally to the bounds of the limiting curve to establish the transverse and vertical capacities in the positive and negative directions.</td></tr>
<tr><td rowspan="2">Step 5:</td><td colspan="2">Determine the usage by using the measured capacities and the load point values.
This can be done in one of two ways, depending on the actual values for these capacities:</td></tr>
<tr><td><u>1. If VCAP+ and VCAP- are both > or < 0</u>
<u>(or TCAP+ and TCAP- are both > or < 0):</u>
Find the midway point of the range. The usage is then determined from the midway point to the load point.

</td><td><u>2. If the VCAP± (or TCAP±) range crosses the axis (i.e., one capacity is positive and the other is negative).</u>
In this case the usage is determined as the magnitude of usage measured from 0.

</td></tr>
<tr><td>Step 6:</td><td colspan="2">The reported usage will be the highest of the V or T usage</td></tr>
</table>

- * If your load point doesn't fall beneath any longitudinal curve PLS-POLE reports **200% NG**
- * If your interaction capacity diagrams have no negative vertical load capacities and your point load has negative vertical load PLS-POLE reports **200% NG**

Sample calculation:

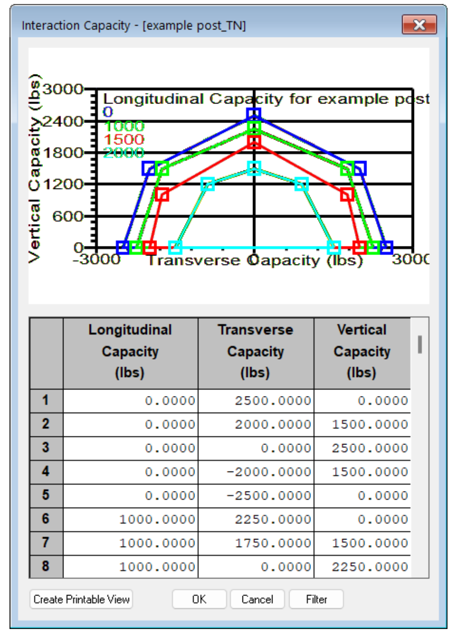
Consider the following two load cases with the post insulator curves shown in Figure 9.

Both load cases have an insulator strength factor of 1.

Note that the interaction capacity curves in Figure 9 do not include any points with negative vertical capacity which indicates that there is no uplift capacity.

Load Cases:

Longitudinal (lbs.)	Transverse (lbs.)	Vertical (lbs.)
0	2050	1200
1100	2050	1200



	Longitudinal Capacity (lbs)	Transverse Capacity (lbs)	Vertical Capacity (lbs)
1	0.0000	2500.0000	0.0000
2	0.0000	2000.0000	1500.0000
3	0.0000	0.0000	2500.0000
4	0.0000	-2000.0000	1500.0000
5	0.0000	-2500.0000	0.0000
6	1000.0000	2250.0000	0.0000
7	1000.0000	1750.0000	1500.0000
8	1000.0000	0.0000	2250.0000

Figure 9: Example Interaction Capacity

When checking this insulator under these two load cases the output is:

```
Summary of Post Capacities and Usages for Load Case "example":

 Post Vertical Tran. Long. Cant. Axial    Vert.    Vert.   Trans.   Trans.    Long.    Cant.    Comp.    Tens. Insul.  Usage    Input Factored Hardware   Max.
Label    Force Force Force Force Force     Down       Up     Neg.     Pos. Capacity Capacity Capacity Capacity   S.F.         Hardware Hardware    Usage  Usage
                                       Capacity Capacity Capacity Capacity                                                    Capacity Capacity
        (kips) (kips) (kips) (kips) (kips)  (kips)   (kips)   (kips)   (kips)   (kips)   (kips)   (kips)   (kips)                %   (kips)   (kips)        %      %
-----------------------------------------------------------------------------------------------------------------------------------------------------------------
   P1     1.20  2.05  0.00  1.20  2.05     1.35    -0.00     2.10     2.10     0.00     0.00     0.00     0.00   1.00  97.62     0.00     0.00     0.00  97.62
   P2     1.20  2.05 -1.10  1.63  2.05     2.00    -0.00     1.40     1.40     1.50     0.00     0.00     0.00   1.00 146.43     0.00     0.00     0.00 146.43 NG  Out of
 bounds: arbitrary vertical capacity
```

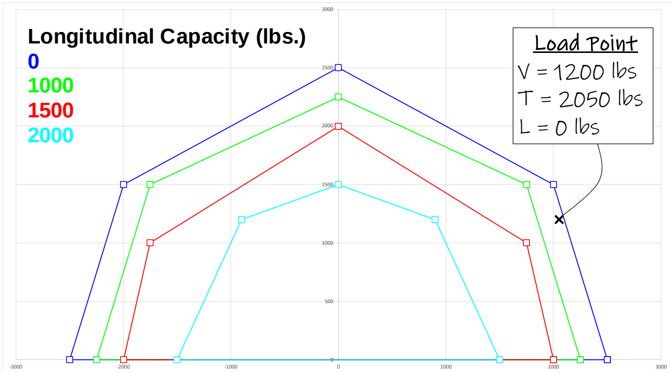
For the 0 lb. longitudinal load case the program picks the 0 lb. longitudinal curve (as indicated by the 0.00 Long Capacity) which has a 2100 lbs. of Transverse Capacity resulting in 97.62 % usage. The program will also calculate the vertical usage, but since it doesn't control the insulator usage it is not reported.

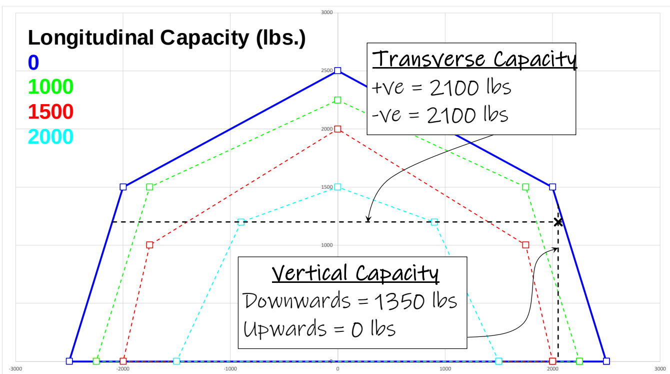
For the longitudinal load of 1100 lbs., the program picks the 1500 lbs. curve which only has 1400 lbs. of transverse capacity resulting in the 146% usage. *Note that in this case the printed vertical capacity is arbitrary since the load cannot be projected on the interaction curve*.

In all cases, you should not be overly concerned with the actual numeric value of the usage **as all that matters is whether or not you are inside the curve (i.e. have a usage under 100%).**

The working steps to show how these usages are calculated are shown on the following page:

Load Case 1:





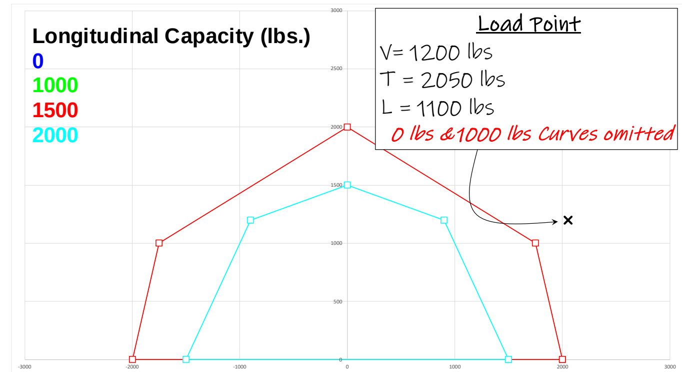
Transverse Usage:

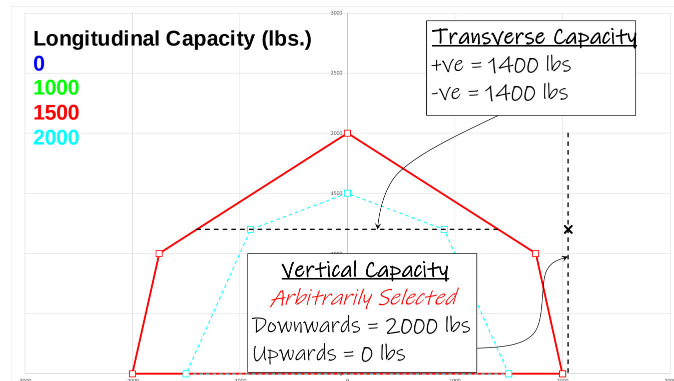
$$T_{usage} = \frac{T_{Load}}{T_{Capacity}} = \frac{2.05\ kips}{2.1\ kips} = 97.62\%$$

Vertical Usage:

$$V_{usage} = \frac{V_{Load}}{V_{Capacity}} = \frac{1.2\ kips}{1.35\ kips} = 88.89\%$$

Load Case 2:





Transverse Usage:

$$T_{usage} = \frac{T_{Load}}{T_{Capacity}} = \frac{2.05\ kips}{1.4\ kips} = 146.43\%$$

Vertical Usage:

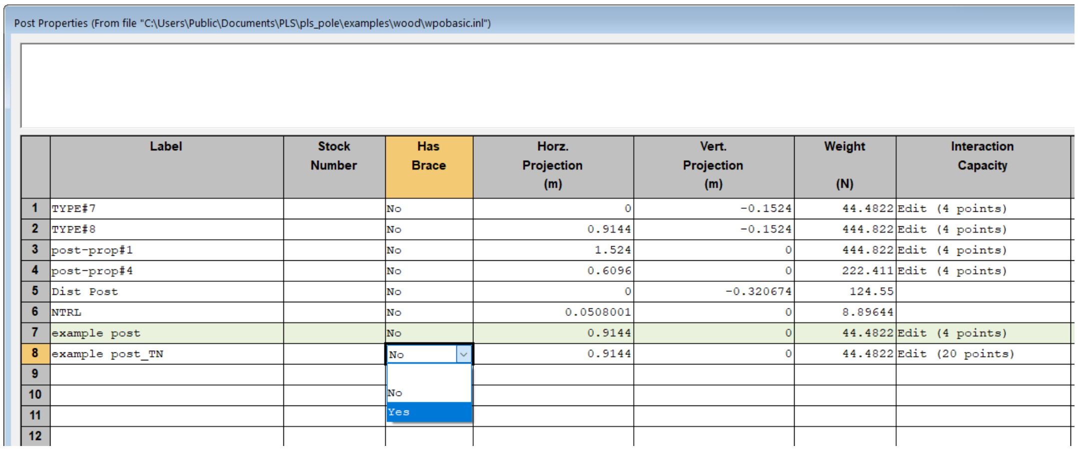
$$V_{usage} = \frac{V_{Load}}{V_{Capacity}} = \frac{1.2\ kips}{2.00\ kips} = 60\%$$

Notes and Frequently Asked Questions

1. How does PLS-POLE handle Braced Post Insulators:

Adding a Braced Post Insulator to a model is a very straightforward process.

The first step is to denote that the post insulator has a Brace. This is done in the third column titled "**Has Brace**" in the Insulator Component Library (***Components/ Insulators/ Post Properties…***), by changing the designation form "*No*" to "*Yes*".



	Label	Stock Number	Has Brace	Horz. Projection (m)	Vert. Projection (m)	Weight (N)	Interaction Capacity
1	TYPE#7		No	0	-0.1524	44.4822	Edit (4 points)
2	TYPE#8		No	0.9144	-0.1524	444.822	Edit (4 points)
3	post-prop#1		No	1.524	0	444.822	Edit (4 points)
4	post-prop#4		No	0.6096	0	222.411	Edit (4 points)
5	Dist Post		No	0	-0.320674	124.55	
6	NTRL		No	0.0508001	0	8.89644	
7	example post		No	0.9144	0	44.4822	Edit (4 points)
8	example post_TN		No	0.9144	0	44.4822	Edit (20 points)
9							
10			No				
11			Yes				
12							

Figure 10: Post Property component library indicating if an insulator has a brace or not

After that you need to provide PLS-POLE a joint to attach the brace member to. This is defined under the ***Geometry/ Insulators/ Post…*** menu by specifying a joint in the column titled "**Brace Attach**".

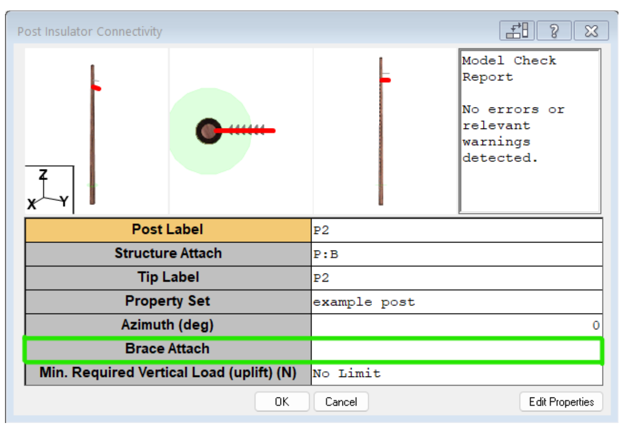


Figure 11: Post Insulator Connectivity dialog indicating where you indicate the attachment joint of the brace element

It is important to note that PLS-POLE has no way of updating the Interaction Curve for the insulator if a brace is included or not. As such, you would likely have a separate component post property for a braced and an unbraced post insulator as they will have very different interaction curves.

2. Sign convention for transverse loads

There can sometimes be a mismatch between the load charts provided by manufacturers and the input required by PLS-POLE when it comes to the sign convention for transverse loading.
PLS-POLE requires that a transverse load putting the post into tension loading is a positive value (T+), and a transverse load putting the post into compression is a negative load (T-).
This means that you might need to transpose the values of these capacities when entering the data into PLS-POLE.

3. Does the post orientation matter?

Post insulators can be mounted on poles in a variety of ways, as indicated in Figure 1 and Figure 2 of this Technical Note. However, when working with post insulators it should be noted that each orientation (horizontal, vertical or inclined at any angle) requires that a unique set of Interaction Curves be entered for that insulator.

While the focus of this Technical Note is on the Interaction Curves, it is noted that for vertical configuration post insulators it can be simpler to define the strength of the insulator using the **TENCAP**, **COMCAP** and **CANCAP** values as shown in the right-hand drawing of Figure 2. In all configurations the loads are resolved into the respective components to measure against the stated axial and cantilever capacities as this makes more sense than our other load definitions considering the predominant loading on the insulator.

4. Number of points on the interaction curve

Interaction curve data is provided by manufacturers. Often this data is logged during physical testing or may be calculated based on other numerical techniques. Sometimes this curve data is provided with a large number of points being used to define the interaction surface. We note that users of our software are hesitant to modify manufacturer's data, and justifiably so.

A large number of datapoints is actually not necessary, and a dramatically reduced number of points may provide a very similar or even identical interaction curve. In addition, these large number of points can lead to the curves having inadvertent (albeit slight) concavities which lead to input errors in PLS-POLE.

The example images below show the same interaction surfaces. Initially with 190 points and a filtered version with only 34 points describing the same interaction surfaces.

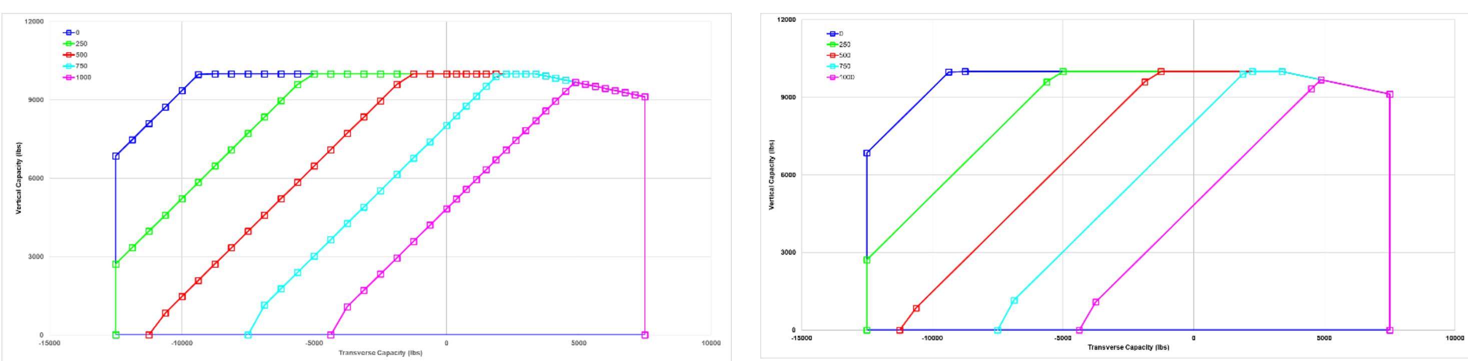


Figure 12: Comparison of interaction curves with redundant points removed

While PLS-POLE can do some filtering and can re-order the points to ensure they are counterclockwise, we do recommend that users review and inspect the data points before blindly importing them into PLS-POLE.

5. Post Insulator stiffnesses:

Post insulators that are made composite material or FRP cores are relatively flexible components. This flexibility can be accounted for in the PLS-POLE, inside the component library for the Post Properties (See Figure 5 and the menu path ***Components/ Insulators/ Post Properties…***). You can enter separate values for the Longitudinal and Vertical stiffness of the post insulator. If these stiffness values are not entered, then an assumed value of 10,000 lbs./ft is used (i.e., assumed to be very stiff an almost rigid).

The true value of entering this data is only manifested when using higher order FE (Level 3 or Level 4) analyses inside PLS-CADD. Essentially, by considering the flexibility of the post insulators, longitudinal load imbalances can be significantly reduced, and this means that insulators and structures are typically more lightly loaded. Note that in Level 3 SAPS modelling only the longitudinal stiffness is considered when making the structures stiffness matrix and in any SAPS sag-tension calculations. Level 4 SAPS modelling will make use of both the vertical and longitudinal stiffness values.