

Insulator Swing Checks

Introduction

The objective of this technical note is to provide a better understanding of the two types of insulator swing checks offered in PLS-CADD and the way the results are presented in terms of Percentage (%) of Allowed Swing in the **Suspension Insulator Swing Angles and V-String Load Angles** section of **Structure Check Standard Report**. This will be accomplished through a couple of examples using suspension insulators and two-part insulators under different weather cases and cable conditions using different minimum and maximum allowed swing/load angle values.

Before we move to the calculations for each type of insulator, we will discuss how to set up the weather cases and the criteria to perform these checks. The first step is creating the weather cases in PLS-CADD using the command menu **Criteria/Weather**:

	Description	Air Density Factor (Q) (psf/mph ²)	Wind Velocity (mph)	Wind Pressure (psf)	Wire Ice Thickness (in)	Wire Ice Density (lbs/ft ³)	Wire Ice Load (lbs/ft)	Wire Temp. (deg F)	Ambient Temp. (deg F)	Weather Load Factor	NESC Constant (lbs/ft)	Wire Wind Height Adjust Model	Wire Gust Response Factor
8	No Wind (SWING 1)	0.00256						60.0	60.0	1		None	1
9	Moderate Wind (SWING 2)	0.00256	49.4123	6				32.0	32.0	1		None	1
10	Moderate Wind (SWING 3)	0.00256	49.4123	6				60.0	60.0	1		None	1
11	High Wind (SWING 4)	0.00256	90	20.736				60.0	60.0	1		None	1

Figure 1 : Creating Weather Cases

The next step is to select the criteria using the PLS-CADD menu command **Criteria/Insulator Swing & Uplift**, which lets you access the **Insulator Swing & Uplift Criteria Dialog**:

	Weather case	Cable condition
1	Condition 1	No Wind (SWING 1)
2	Condition 2	Moderate Wind (SWING 2)
3	Condition 3	Moderate Wind (SWING 3)
4	Condition 4	High Wind (SWING 4)

	Weather case	Cable condition
1	No Wind (SWING 1)	Creep RS
2	Moderate Wind (SWING 2)	Initial RS
3	Moderate Wind (SWING 3)	Creep RS
4	High Wind (SWING 4)	Creep RS
5		

Figure 2 : Insulator Swing & Uplift Criteria Dialog

The upper section of the dialog is where up to four separate combinations of weather cases and cable conditions can be entered. These will be the conditions under which the swing angles, in the case of suspension insulators, or the load angles, in the case of 2-part insulators, will be verified to be within the minimum and maximum limits defined in the structure models. These combinations of weather cases and cable conditions are often dictated by industry standards or code requirements.

Below is one possible setup based on recommendations provided by **NESC** and **Bulletin 1724E-200 Design Manual for High Voltage Transmission Lines** published by USDA's Rural Utilities Service Electric Staff Division:

Condition 1: Everyday condition with no wind and average temperature at final tensions. This is a condition under which the line will spend most of its life, and therefore it is the most likely condition to exist when a serious voltage surge occurs. *To avoid flashover under that condition, one may specify the most restrictive values of allowable swing.*

Condition 2: Cold condition with moderate wind pressure and initial tensions. Because of the cold temperature, this is a condition under which the vertical load may be too small to prevent a significant insulator swing, even under moderate wind. Because the probability of occurrence of a serious voltage surge under the cold and moderately windy condition is not as high as at any random time, one may specify less restrictive values of allowable swings than under Condition 1. *This condition is recommended for tangent and small angle structures.*

Condition 3: Average temperature with moderate wind pressure and final tensions. Because the probability of occurrence of a serious voltage surge under the moderately windy condition is not as high as at any random time, one may specify less restrictive values of allowable swings than under Condition 1. *This condition is recommended for angle structures where the force due to change in direction of the conductor holds the insulator string away from the structure.*

Condition 4: High wind condition with final tensions. High winds are rare events. The combined probability of their occurrence together with a voltage surge is even smaller, thus it may be appropriate to relax the swing requirements even more.

After the criteria is defined, it is time to provide allowable swing angles for suspension insulators or allowable load angles for 2-parts insulators. This can be done for Method 1 Structures, using the Structure Data Editor in PLS-CADD, as well as for Method 4 Structures, either in PLS-POLE or TOWER, depending on your structure model. There is a minimum and a maximum allowable swing or load angle for each condition. These values are entered using the menu command **Geometry/Insulators/Suspension** under the **Suspension Insulator Connectivity Dialog** or **Geometry/Insulators/2-Part** for the **2-Part Insulator Connectivity Dialog** in the structural applications.

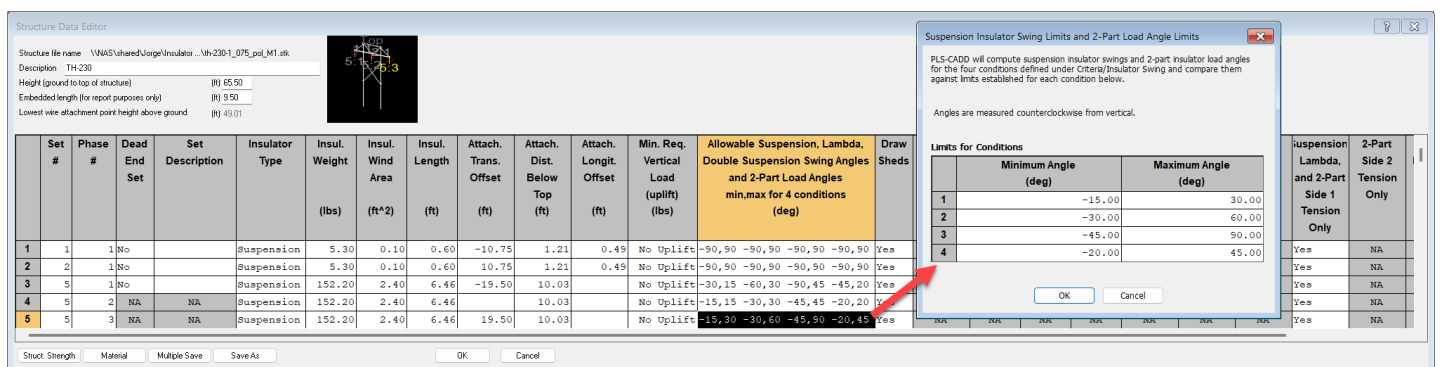
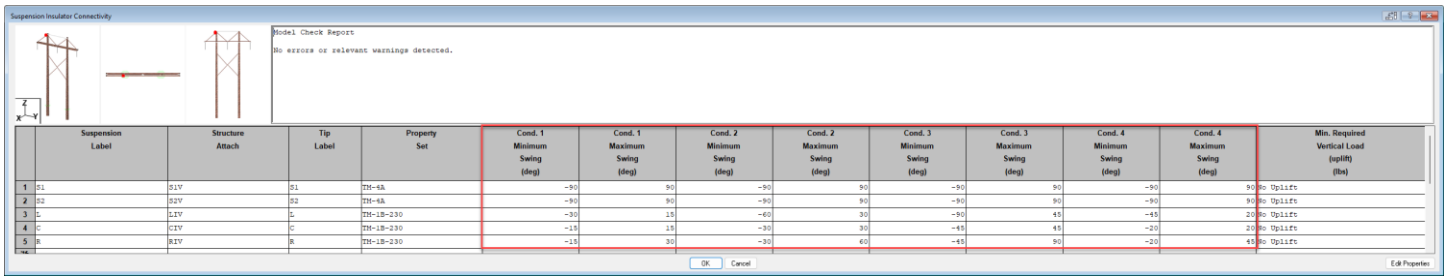


Figure 3 : Suspension Insulator Connectivity Table for Method 1 Structures

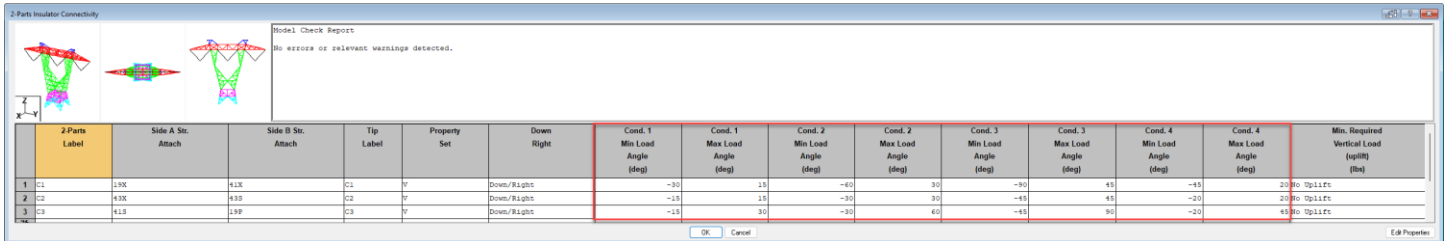


Model Check Report
No errors or relevant warnings detected.

	Suspension Label	Structure Attach	Tip Label	Property Set	Cond. 1 Minimum Swing (deg)	Cond. 1 Maximum Swing (deg)	Cond. 2 Minimum Swing (deg)	Cond. 2 Maximum Swing (deg)	Cond. 3 Minimum Swing (deg)	Cond. 3 Maximum Swing (deg)	Cond. 4 Minimum Swing (deg)	Cond. 4 Maximum Swing (deg)	Min. Required Vertical Load (uplift) (lbs)
1	D1	D1V	D1	TH-6A	-90	90	-90	90	-90	90	-90	90	90 No Uplift
2	D2	D2V	D2	TH-6A	-90	90	-90	90	-90	90	-90	90	90 No Uplift
3	E	E1V	E	TH-1B-230	-90	15	-60	30	-90	45	-45	45	20 No Uplift
4	F	F1V	F	TH-1B-230	-15	15	-30	30	-45	45	-20	20	20 No Uplift
5	R	R1V	R	TH-1B-230	-15	30	-30	60	-45	90	-20	45	90 No Uplift

OK Cancel Edit Properties

Figure 4 : Suspension Insulator Connectivity Table for Method 4 Structures



Model Check Report
No errors or relevant warnings detected.

	2 Parts Label	Side A Str. Attach	Side B Str. Attach	Tip Label	Property Set	Down Right	Cond. 1 Min Load Angle (deg)	Cond. 1 Max Load Angle (deg)	Cond. 2 Min Load Angle (deg)	Cond. 2 Max Load Angle (deg)	Cond. 3 Min Load Angle (deg)	Cond. 3 Max Load Angle (deg)	Cond. 4 Min Load Angle (deg)	Cond. 4 Max Load Angle (deg)	Min. Required Vertical Load (uplift) (lbs)
1	C1	L9X	R1X	C1	Y	Down/Right	-30	15	-60	30	-90	45	-45	45	20 No Uplift
2	C2	R9X	L1X	C2	Y	Down/Right	-15	15	-30	30	-45	45	-20	20	20 No Uplift
3	C3	R1X	L9X	C3	Y	Down/Right	-15	30	-30	60	-45	90	-20	45	90 No Uplift

OK Cancel Edit Properties

Figure 5 : 2-Part Insulator Connectivity Table for Method 4 Structures

When no entries are made for these minimum and maximum allowable swing/load angle values for any of the four conditions available, the software assumes that the values are zero. This will trigger a warning in PLS-CADD that lets you know that this structure and all other structures with zero values will ALWAYS have a swing violation.

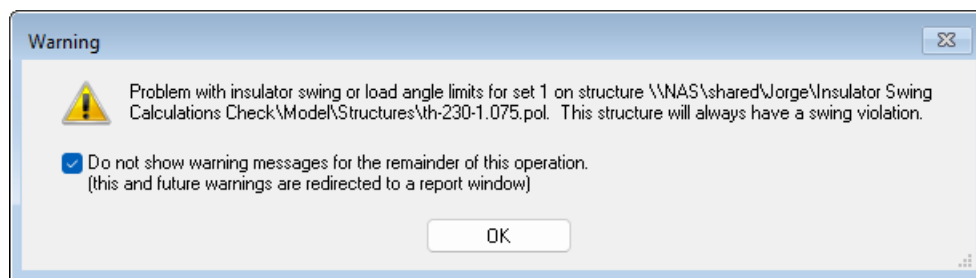


Figure 6 : Swing Violation Warning

Also note that if a calculated % swing or load angle value exceeds 200%, for the Percentage of Allowed Swing/Load Angles reported in the **Suspension Insulator Swing Angles and V-String Load Angles** section of **Structure Check Standard Report**, it will be reported as 200% under the Percentage of Allowed Swing/Load Angle column.

Insulator Swing Angle/Load Angle Sign Conventions

The swing angle (SA) for suspension insulator checks, or the load angle (LA) for 2-part insulator checks, is measured from vertical and is positive if the insulator, or load, moves in the positive transverse direction of the structure as shown in the figures below:

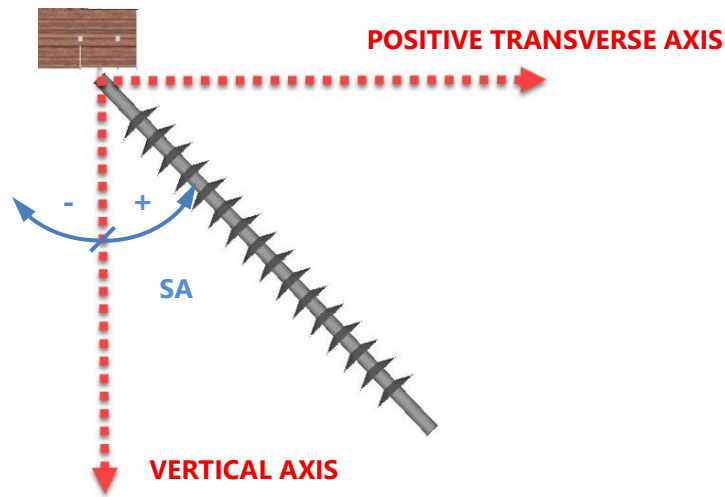


Figure 7 : Suspension Insulator Swing Angle Sign Convention

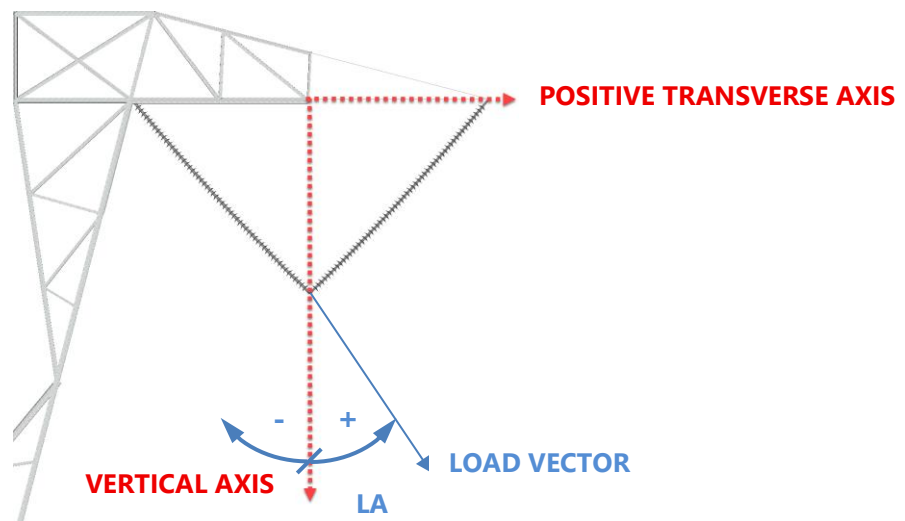


Figure 8 : 2-Part Insulator Load Angle Sign Convention

These allowable values are algebraic and should follow the sign convention in the figures above. Note that maximum swing is defined as that which translates the bottom point of the insulator the farthest in the transverse direction of the structure. This maximum value is then reported in terms of **Percentage (%) of Allowed Swing** in the **Suspension Insulator Swing Angles and V-String Load Angles** section of **Structure Check Standard Report** when the **Structures/Check** tool is used.

It should also be noted that the procedure used by the **Structures/Check** tool to compare an actual swing, or load angle, to the corresponding allowable value systematically blows the wind perpendicularly to each of the two spans adjacent to the structure and in both directions, i.e. the swing calculation is done twice for each specified weather condition. From these calculations, the largest and smallest values are kept for comparisons with the maximum and minimum allowable values.

Suspension Insulator Swing Angle Checks

We will now describe the formulas used in the calculations. The figure below displays the different angles and other variables used to calculate the **Percentage of Allowed Swing**.

It is important to note that all the **Percentage (%) of Allowed Swing** outputs calculated by PLS-CADD relate back to the center of the allowable arc of swing (shown between α_{MIN} - α_{MAX} in the image below) and not the vertical axis:

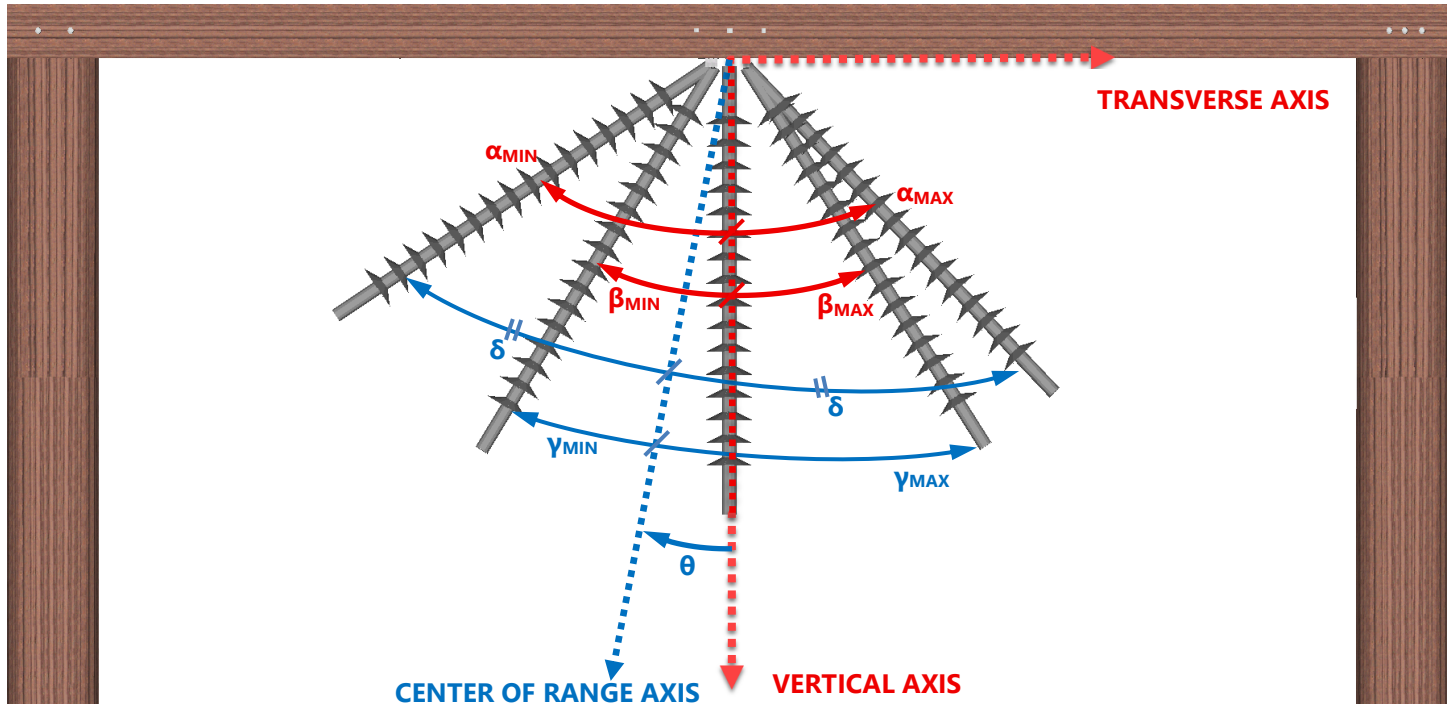


Figure 9 : Suspension Insulator Swing Angle Variables

The equations are as follows:

$$\theta = \alpha_{MIN} + \frac{\alpha_{MAX} - \alpha_{MIN}}{2} \quad \delta = |\alpha_{MIN} - \theta| = |\alpha_{MAX} - \theta|$$

$$\gamma_{MIN} = \beta_{MIN} - \theta \quad \gamma_{MAX} = \beta_{MAX} - \theta$$

$$\phi_{MIN} = \left| \frac{\gamma_{MIN}}{\delta} \right| \quad \phi_{MAX} = \left| \frac{\gamma_{MAX}}{\delta} \right| \quad \phi = \text{MAX} (\phi_{MIN}, \phi_{MAX})$$

Where:

$\alpha_{MIN/MAX}$	= Minimum/Maximum Allowed Swing Angle
$\beta_{MIN/MAX}$	= Minimum/Maximum Calculated Swing Angle
θ	= Center of Range Angle (Measured from Vertical Axis to the midpoint between min. and max. allowed swing angles)
$\gamma_{MIN/MAX}$	= Minimum/Maximum Calculated Swing Angle from Center of Range
δ	= Allowable Swing Angle (Measured from center of range axis)
$\phi_{MIN/MAX}$	= Calculated Percentage of Minimum/Maximum Allowed Swing Angle
ϕ	= Percentage of Allowed Swing Angle

For these checks the minimum and maximum allowed swing angle values used for calculation purposes are listed in the figure below:

Suspension Label	Structure Attach	Tip Label	Property Set	Cond. 1 Minimum Swing (deg)	Cond. 1 Maximum Swing (deg)	Cond. 2 Minimum Swing (deg)	Cond. 2 Maximum Swing (deg)	Cond. 3 Minimum Swing (deg)	Cond. 3 Maximum Swing (deg)	Cond. 4 Minimum Swing (deg)	Cond. 4 Maximum Swing (deg)	Min. Required Vertical Load (uplift) (lbs)
1 D1	D1V	D1	TH-4B	-90	90	-90	90	-90	90	-90	90	2000 UpLift
2 D2	D2V	D2	TH-4B	-90	90	-90	90	-90	90	-90	90	2000 UpLift
3 C	C1V	C	TH-1B-230	-15	15	-30	15	-45	25	-75	55	5000 UpLift
4 C	C2V	C	TH-1B-230	-15	15	-30	30	-35	35	-65	65	4500 UpLift
5 B	B1V	B	TH-1B-230	-15	15	-15	30	-25	45	-50	75	7500 UpLift

Figure 10 : Minimum and Maximum Allowed Swing Angle Values for Suspension Insulators Used for Calculations

The results reported in the **Suspension Insulator Swing Angles and V-String Load Angles** section of **Structure Check Standard Report** for this particular example are listed in the figure below:

Suspension Insulator Swing Angles and V-String Load Angles

Set #	Phase #	Swing Cond. #	Weather Case Description	Wire Condition	Min. Allowed (deg)	Max. Allowed (deg)	Min. Calc. (deg)	Max. Calc. (deg)	% of Allowed Swing	OK
1	1	1	No Wind (SWING 1)	Creep RS	-90.0	90.0	-40.6	-40.6	45.1	OK
		2	Moderate Wind (SWING 2)	Initial RS	-90.0	90.0	-68.0	-8.2	75.5	OK
		3	Moderate Wind (SWING 3)	Creep RS	-90.0	90.0	-65.6	-0.8	72.9	OK
		4	High Wind (SWING 4)	Creep RS	-90.0	90.0	-84.6	72.2	94.0	OK
2	1	1	No Wind (SWING 1)	Creep RS	-90.0	90.0	45.5	45.5	50.5	OK
		2	Moderate Wind (SWING 2)	Initial RS	-90.0	90.0	13.7	70.9	78.8	OK
		3	Moderate Wind (SWING 3)	Creep RS	-90.0	90.0	5.9	68.9	76.6	OK
		4	High Wind (SWING 4)	Creep RS	-90.0	90.0	-75.2	85.8	95.4	OK
5	1	1	No Wind (SWING 1)	Creep RS	-15.0	10.0	-11.0	-11.0	68.0	OK
		2	No Wind (SWING 1)	Creep RS	-10.0	10.0	0.5	0.5	4.6	OK
	2	1	No Wind (SWING 1)	Creep RS	-10.0	15.0	12.2	12.2	77.7	OK
		2	Moderate Wind (SWING 2)	Initial RS	-30.0	15.0	-37.8	15.0	134.6	NG
	3	2	Moderate Wind (SWING 2)	Initial RS	-30.0	30.0	-27.2	28.2	93.8	OK
		3	Moderate Wind (SWING 2)	Initial RS	-15.0	30.0	-13.9	39.1	140.4	NG
	1	3	Moderate Wind (SWING 3)	Creep RS	-45.0	25.0	-36.1	16.5	75.6	OK
		2	Moderate Wind (SWING 3)	Creep RS	-35.0	35.0	-26.9	27.7	79.0	OK
	3	3	Moderate Wind (SWING 3)	Creep RS	-25.0	45.0	-15.5	37.3	78.0	OK
		4	High Wind (SWING 4)	Creep RS	-75.0	50.0	-66.6	56.9	111.0	NG
	2	4	High Wind (SWING 4)	Creep RS	-65.0	65.0	-62.5	62.9	96.8	OK
		3	High Wind (SWING 4)	Creep RS	-50.0	75.0	-56.8	67.4	110.8	NG

Figure 11 : Suspension Insulator Swing Angles

Let's look at the suspension insulator assigned to **Set 5 Phase 2 at High Wind (Swing Condition 4)** to verify the associated results reported:

First we calculate the Center of Range Angle (θ):
$$\theta = -65 + \frac{65 - (-65)}{2} = 0 \text{ deg}$$

Then we proceed with the Allowable Swing Angle (δ):
$$\delta = |-65 - 0| = 65 \text{ deg}$$

Next we continue with the Minimum and Maximum Calculated Swing Angle from Center of Range ($\gamma_{\text{MIN/MAX}}$):

$$\gamma_{\text{MIN}} = -62.5 - 0 = -62.5 \text{ deg} \quad \gamma_{\text{MAX}} = 62.9 - 0 = 62.9 \text{ deg}$$

Finally, we move on to the Calculated Percentage of Minimum/Maximum Allowed Swing Angles ($\phi_{\text{MIN/MAX}}$) and Percentage of Allowed Swing Angle (ϕ):

$$\phi_{MIN} = \left| \frac{-62.5}{65} \right| = 96.2\% \quad \phi_{MAX} = \left| \frac{62.9}{65} \right| = 96.8\% \quad \text{then} \quad \phi = \mathbf{96.8\%}$$

Let's look at another example, this time we will pick a case where our limits are exceeded. We will use the suspension insulator for **Set 5 Phase 1 at Moderate Wind (Swing Condition 2)** to verify the associated results reported:

First we calculate the Center of Range Angle (θ): $\theta = -30 + \frac{15 - (-30)}{2} = -7.5 \text{ deg}$

Then we proceed with the Allowable Swing Angle (δ): $\delta = |-30 - (-7.5)| = 22.5 \text{ deg}$

Next we continue with the Minimum and Maximum Calculated Swing Angle from Center of Range ($\gamma_{MIN/MAX}$):

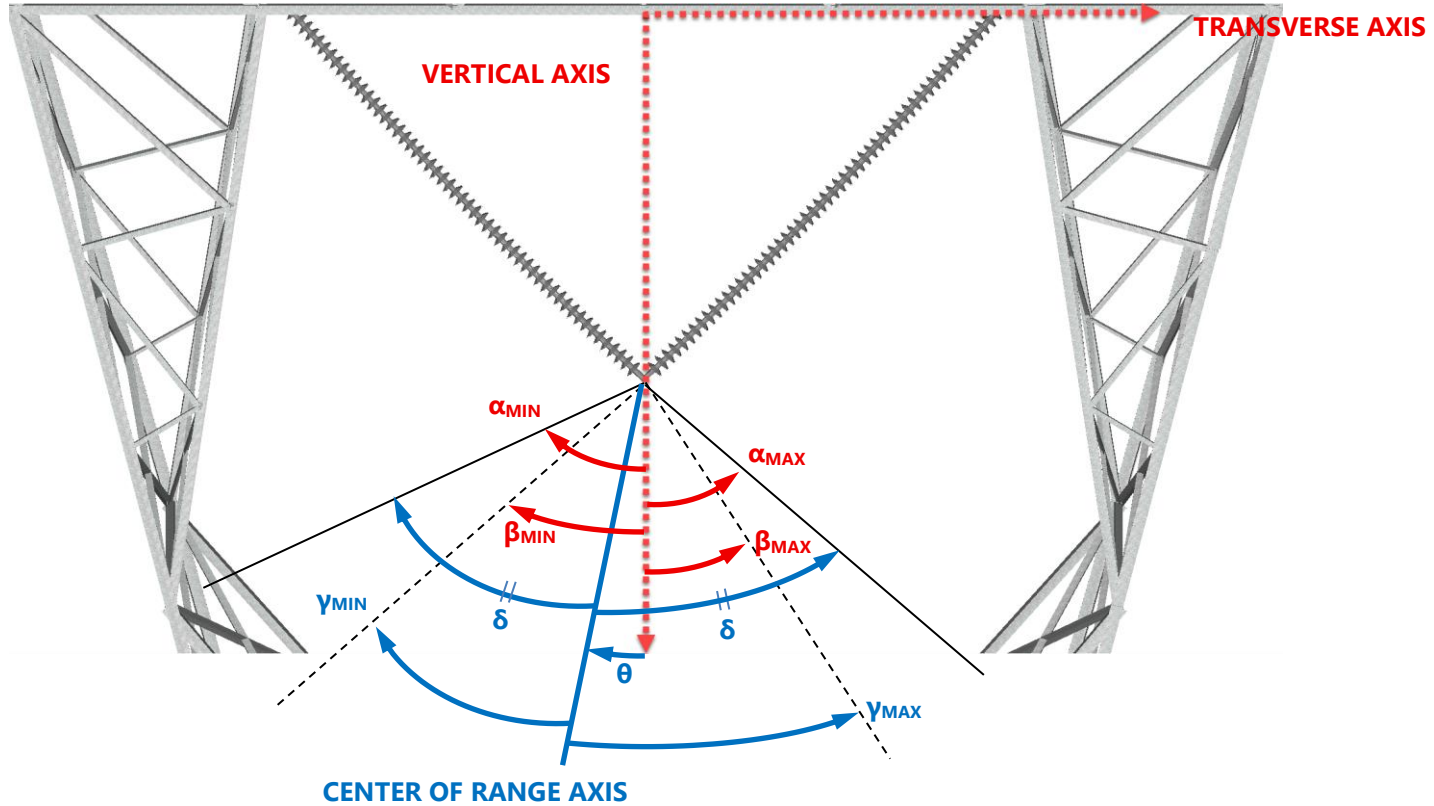
$$\gamma_{MIN} = -37.8 - (-7.5) = -30.3 \text{ deg} \quad \gamma_{MAX} = 15 - (-7.5) = 22.5 \text{ deg}$$

Finally, we move on to the Calculated Percentage of Minimum/Maximum Allowed Swing Angles ($\phi_{MIN/MAX}$) and Percentage of Allowed Swing Angle (ϕ):

$$\phi_{MIN} = \left| \frac{-30.3}{22.5} \right| = 134.6\% \quad \phi_{MAX} = \left| \frac{22.5}{22.5} \right| = 100.0\% \quad \text{then} \quad \phi = \mathbf{134.6\%}$$

2-Part Insulator Load Inclination/Load Angle Checks

We will now describe the formulas used in the calculations. The equations are identical as the ones for the suspension insulator checks but they are defined in terms of load inclinations or load angles. These are the angles the load vector makes with respect to the vertical axis. The figure below displays the different angles and variables used to calculate the Percentage of Allowed Load Angle. It is important to note that all the **Percentage (%) of Load Angle** outputs calculated by PLS-CADD relate back to the center of the allowable arc of swing (shown between α_{MIN} - α_{MAX} in the image below) and not the vertical axis:



The equations are as follows:

$$\theta = \alpha_{MIN} + \frac{\alpha_{MAX} - \alpha_{MIN}}{2} \quad \delta = |\alpha_{MIN} - \theta| = |\alpha_{MAX} - \theta|$$

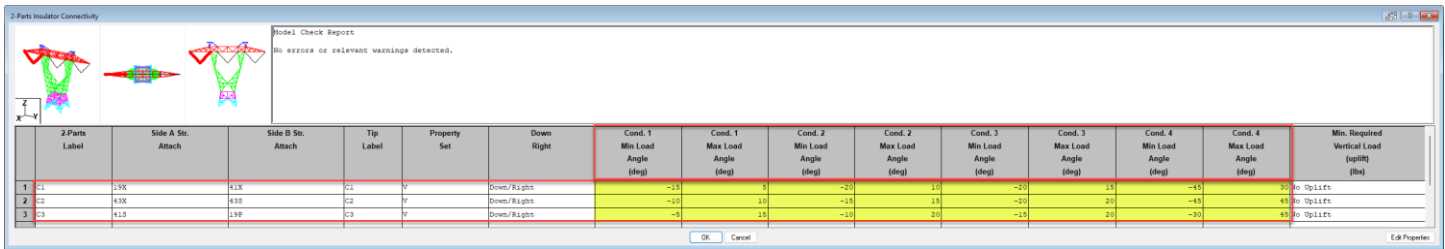
$$\gamma_{MIN} = \beta_{MIN} - \theta \quad \gamma_{MAX} = \beta_{MAX} - \theta$$

$$\phi_{MIN} = \left| \frac{\gamma_{MIN}}{\delta} \right| \quad \phi_{MAX} = \left| \frac{\gamma_{MAX}}{\delta} \right| \quad \phi = \text{MAX}(\phi_{MIN}, \phi_{MAX})$$

Where:

$\alpha_{MIN/MAX}$	= Minimum/Maximum Allowed Load Angle
$\beta_{MIN/MAX}$	= Minimum/Maximum Calculated Load Angle
θ	= Center of Range Angle (<i>Measured from vertical axis to the midpoint between min. and max. allowed load angles</i>)
$\gamma_{MIN/MAX}$	= Minimum/Maximum Calculated Load Angle from Center of Range
δ	= Allowable Load Angle (<i>Measured from center of range axis</i>)
$\phi_{MIN/MAX}$	= Calculated Percentage of Minimum/Maximum Allowed Load Angle
ϕ	= Percentage of Allowed Load Angle

For these checks the minimum and maximum allowed load angle values used for calculation purposes are listed in the figure below:



2-Part Label	Side A Str. Attach	Side B Str. Attach	Tip Label	Property Set	Down Right	Cond. 1 Min Load Angle (deg)	Cond. 1 Max Load Angle (deg)	Cond. 2 Min Load Angle (deg)	Cond. 2 Max Load Angle (deg)	Cond. 3 Min Load Angle (deg)	Cond. 3 Max Load Angle (deg)	Cond. 4 Min Load Angle (deg)	Cond. 4 Max Load Angle (deg)	Min. Required Vertical Load (uplift) (lbs)
C1	10K	41K	C1	Y	Down/Right	-10	5	-20	10	-20	15	-45	30	No Uplift
C2	41K	430	C2	Y	Down/Right	-10	10	-15	15	-20	20	-45	40	No Uplift
C3	410	100	C3	Y	Down/Right	-10	10	-20	20	-20	20	-20	40	No Uplift

Figure 12 : Minimum and Maximum Allowed Load Angle Values for 2-Part Insulators Used for Calculations

The results reported in the **Suspension Insulator Swing Angles and V-String Load Angles** section of **Structure Check Standard Report** for this example are listed in the figure below:

Suspension Insulator Swing Angles and V-String Load Angles

Set #	Phase #	Swing Cond. #	Weather Case Description	Wire Condition	Min. Allowed (deg)	Max. Allowed (deg)	Min. Calc. (deg)	Max. Calc. (deg)	% of Allowed Swing	OK
1	1	1	No Wind (SWING 1)	Creep RS	-90.0	90.0	11.5	11.5	12.8	OK
	1	2	Moderate Wind (SWING 2)	Initial RS	-90.0	90.0	-43.4	57.7	64.1	OK
	1	3	Moderate Wind (SWING 3)	Creep RS	-90.0	90.0	-42.3	55.3	61.5	OK
	1	4	High Wind (SWING 4)	Creep RS	-90.0	90.0	-82.4	84.0	93.3	OK
2	1	1	No Wind (SWING 1)	Creep RS	-90.0	90.0	-12.4	-12.4	13.8	OK
	1	2	Moderate Wind (SWING 2)	Initial RS	-90.0	90.0	-59.8	45.9	66.4	OK
	1	3	Moderate Wind (SWING 3)	Creep RS	-90.0	90.0	-57.7	44.8	64.1	OK
	1	4	High Wind (SWING 4)	Creep RS	-90.0	90.0	-84.7	83.2	94.1	OK
5	1	1	No Wind (SWING 1)	Creep RS	-15.0	5.0	3.1	3.1	80.5	OK
	2	1	No Wind (SWING 1)	Creep RS	-10.0	10.0	-0.0	-0.0	0.0	OK
	3	1	No Wind (SWING 1)	Creep RS	-5.0	15.0	-3.1	-3.1	80.5	OK
	1	2	Moderate Wind (SWING 2)	Initial RS	-10.0	20.0	-9.5	17.1	96.4	OK
	2	2	Moderate Wind (SWING 2)	Initial RS	-15.0	15.0	-13.3	13.3	88.9	OK
	3	2	Moderate Wind (SWING 2)	Initial RS	-20.0	10.0	-17.1	9.5	96.4	OK
	1	3	Moderate Wind (SWING 3)	Creep RS	-20.0	15.0	-9.7	16.2	107.0	NG
	2	3	Moderate Wind (SWING 3)	Creep RS	-20.0	20.0	-13.0	13.0	65.1	OK
	3	3	Moderate Wind (SWING 3)	Creep RS	-15.0	20.0	-16.2	9.7	107.0	NG
	1	4	High Wind (SWING 4)	Creep RS	-45.0	30.0	-38.2	45.3	140.8	NG
	2	4	High Wind (SWING 4)	Creep RS	-45.0	45.0	-42.0	42.0	93.3	OK
	3	4	High Wind (SWING 4)	Creep RS	-30.0	45.0	-45.3	38.2	140.8	NG

Figure 13 : 2-Part Insulator Load Angles

Let's look at the 2-part insulator for **Set 5 Phase 3 at Moderate Wind (Swing Condition 2)** to verify the associated results reported:

First we calculate the Center of Range Angle (θ):
$$\theta = -20 + \frac{10 - (-20)}{2} = -5 \text{ deg}$$

Then we proceed with the Allowable Load Angle (δ):
$$\delta = |-20 - (-5)| = 15 \text{ deg}$$

Next we continue with the Minimum and Maximum Calculated Load Angle from Center of Range ($\gamma_{MIN/MAX}$):

$$\gamma_{MIN} = -17.1 - (-5) = -12.1 \text{ deg}$$

$$\gamma_{MAX} = 9.5 - (-5) = 14.5 \text{ deg}$$

Finally, we move on to the Calculated Percentage of Minimum/Maximum Allowed Load Angles ($\phi_{MIN/MAX}$) and Percentage of Allowed Load Angle (ϕ) :

$$\phi_{MIN} = \left| \frac{-12.1}{15} \right| = 80.7\% \quad \phi_{MAX} = \left| \frac{14.5}{15} \right| = 96.4\% \quad \text{then} \quad \phi = \mathbf{96.4\%}$$

Let's look at another example, this time we will pick a case where our limits are exceeded. We will use the suspension insulator for **Set 5 Phase 1 at Moderate Wind (Swing Condition 3)** to verify the associated results reported:

First we calculate the Center of Range Angle (θ): $\theta = -20 + \frac{15 - (-20)}{2} = -2.5 \text{ deg}$

Then we proceed with the Allowable Load Angle (δ): $\delta = |-20 - (-2.5)| = 17.5 \text{ deg}$

Next we continue with the Minimum and Maximum Calculated Load Angle from Center of Range ($\gamma_{MIN/MAX}$):

$$\gamma_{MIN} = -9.7 - (-2.5) = -7.2 \text{ deg} \quad \gamma_{MAX} = 16.2 - (-2.5) = 18.7 \text{ deg}$$

Finally, we move on to the Calculated Percentage of Minimum/Maximum Allowed Load Angles ($\phi_{MIN/MAX}$) and Percentage of Allowed Load Angle (ϕ) :

$$\phi_{MIN} = \left| \frac{-7.2}{17.5} \right| = 41.1\% \quad \phi_{MAX} = \left| \frac{18.7}{17.5} \right| = 107.0\% \quad \text{then} \quad \phi = \mathbf{107.0\%}$$