SAFETY FACTOR FOR POLES CONTROLLED BY BUCKLING

This technical note was written to help you understand how you can use the powerful nonlinear analysis of PLS-POLE to provide safety against the so-called "buckling" of wood poles. As we will show you, the buckling load for a pole is only a theoretical concept. A real pole does not fail because a compression force in it exceeds a theoretical buckling capacity, but because a stress reaches its breaking value. This stress increases very rapidly as the load increases when the pole is near its stability limit.
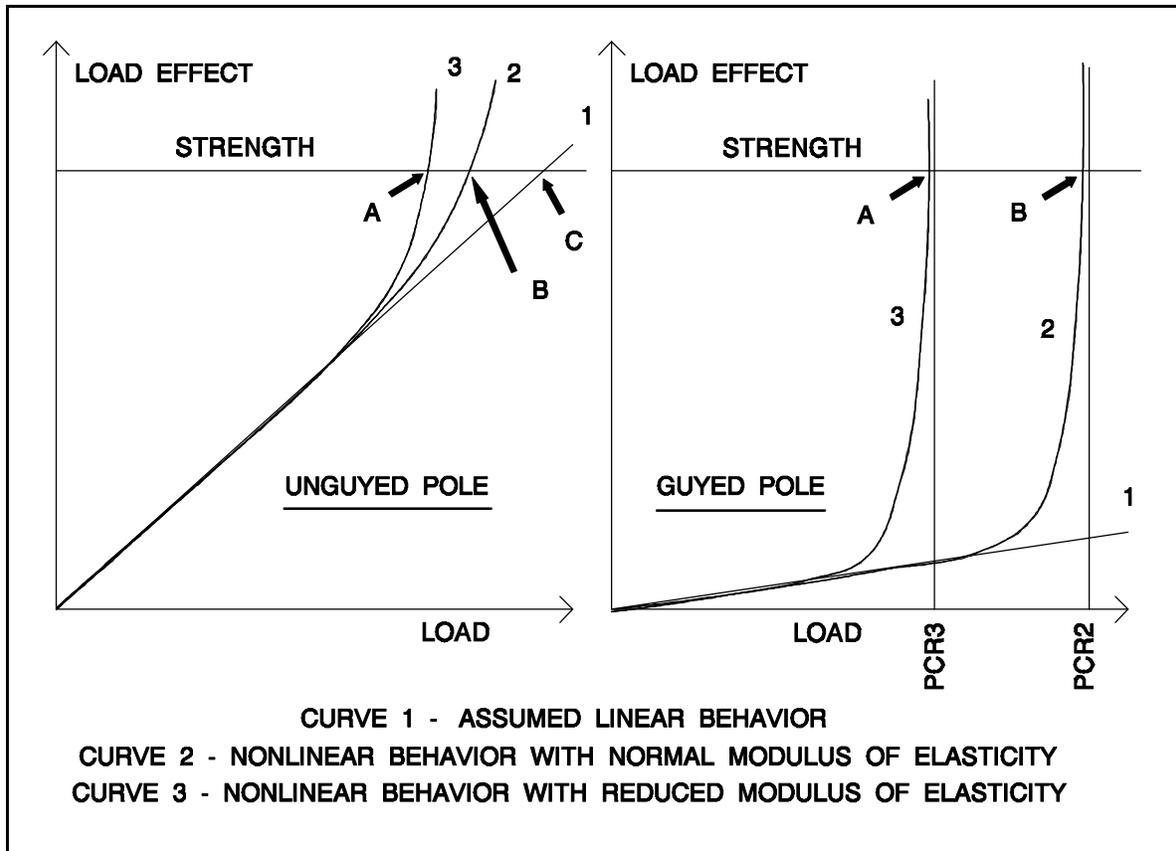

Fig. 1 Behavior of poles under increasing loads

Fig. 1 shows typical behaviors of unguyed and guyed poles subjected to increasing loads. Think of the load as a basic load (basic forces and pressures due to a combination of wind, ice and temperature) multiplied by an increasing factor. As the load increases, its effects on the pole increase. A load effect can be a displacement, a force, a moment or a stress. For our purpose, we will concentrate on normal stress (from axial force and bending moment), which is the one normally controlling the strength of a pole.

The left part of Fig. 1 shows the relationship of Load Effect with Load on an unguyed pole for three analysis assumptions. Curve 1 assumes a linear behavior. Curve 2 shows the behavior from a nonlinear analysis with a normal Modulus Of Elasticity (MOE), i.e. the nominal value published in a Standard, such as ANSI 05.1. Curve 3 shows the behavior from a nonlinear analysis with a reduced (conservative) MOE, where the reduced value accounts for the fact that the actual pole may have a real MOE smaller than the published value. The pole fails when the load effect exceeds the corresponding strength, i.e. when the load reaches the value represented by Point C if the behavior is linear, when it reaches the value represented by Point B if the behavior is nonlinear with a normal MOE and when it reaches the value represented by Point A if the behavior is nonlinear with a reduced MOE. The horizontal distances A-C and B-C represent the reduction of load carrying capacity due to the so-called P-Delta effect. Except for the P-Delta effect, the Load Effect for an unguyed pole is proportional to the load.

The right part of Fig. 1 shows the relationship of Load Effect with Load for the linear assumption and two nonlinear analysis assumptions for a guyed pole controlled by stability. Linear analysis should never be used for a guyed pole as it is not capable of capturing the higly nonlinear behavior when the pole is near its stability limit. Again, Curves 2 and 3 show the behavior for analyses made with a normal and a reduced MOE, respectively. You will note that when the load is small, the behavior is fairly linear. However, as the load gets close to PCR3 for the reduced MOE case (PCR2 for the normal MOE), the load effect accelerates rapidly with the load. This is because the load approaches the stability limit of the pole. Just as the unguyed pole failed when its load effect exceeded its strength, the guyed pole will also fail for that condition. Therefore, the guyed pole will fail when the load reaches the value represented by Point B when it has a normal MOE and when it reaches Point A when it has a reduced MOE. For the guyed pole, the Load Effect is not even remotely proportional to the Load but is highly dependent on the MOE. For the unguyed pole (left of Fig. 1) the ratio of the load at Point A to that at Point B is not strongly dependent on the MOE. However, for the guyed pole (right of Fig. 1), the ratio of the load at Point A to that at Point B is affected by stability and will often be close to the ratio of the MOE's (remember the simple Euler formula for a buckling load which is proportional to the MOE).

To illustrate the effect of the MOE on the behavior of a guyed structure, consider the structure in Fig. 2. The left pole is the most likely to buckle as it is subjected to the largest compression load and is not partially restrained by the ground wires. Fig. 3 shows the results of three analyses under the same loads (loads shown in Fig. 2). The numbers in Fig. 3 are percent of strength used (stress divided by ultimate value). Deflections are shown at scale, i.e. the top geometries of the three poles are actual positions under the load. The left pane in Fig. 3 is when the MOE of the 3 poles is assumed to be 1,600 ksi. The center pane is for a value of MOE derated by the factor
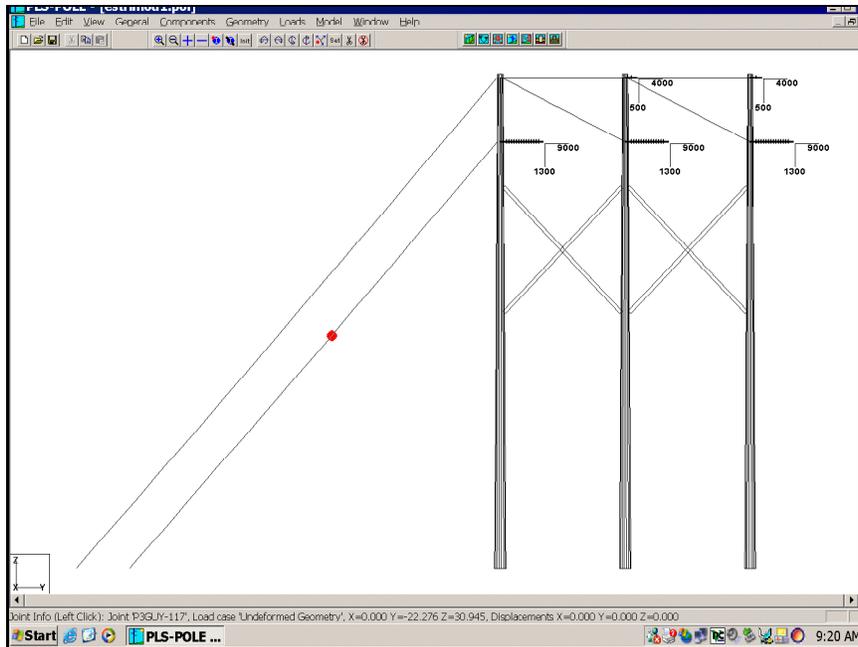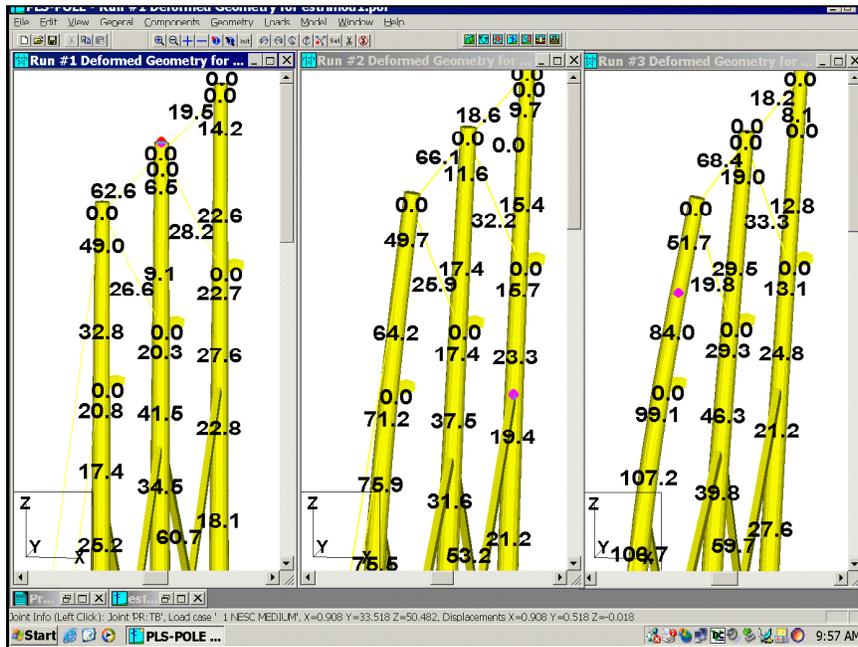
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Fig. 2 Three-pole guyed structure

Fig. 3 Effect of MOE on behavior of Structure of Fig. 2

of 0.70. The right pane is for a value of MOE derated by the factor of 0.65. You can see that the percent use of the left pole right above the attachment to the cross-brace increases from 17.4 (for MOE = 1,600 ksi) to 75.9 (for MOE derated by a factor of 0.70) and to 107.2 (for MOE derated by a factor of 0.65).   The pole is obviously nearing its stability limit for the MOE derated by 0.70 and has failed (percent use greater than 100 percent) for the MOE derated by 0.65. For the reduced MOE's, the PLS-POLE analysis correctly accounts for the fact that the left pole is being helped by the center pole through the short cable link between these two poles. From the above example, one would conclude that the structure of Fig. 2 is safe as long as its MOE does not fall below 0.7 x 1,600 = 1,120 ksi. We are not aware of any simplified method (nominal buckling) that would have detected the fact that the structure weak point is actually above the brace.

For design purposes, we want to avoid failure, i.e. we want:

Strength > Effect of Load

Since real Strength and real Loads are random variables, we simplify the problem by using checking equations which are always of the form:

S.F. x Nominal Strength > Effect of [L.F. x Nominal Load]

where:

S.F.	=	Strength Factor which should account for the uncertainty in strength and the definition of Nominal Strength
Nominal Strength	=	Whatever strength number you are using (for wood poles it is generally the ultimate fiber bending stress as specified by the ANSI 05.1 Standard).
L.F.	=	Load Factor which should account for the uncertainty in load and the definition of Nominal Load
Nominal Load	=	Whatever load your code or company specifies
Effect of [ ]	=	Transformation of applied load into stress, moment or force using an analysis based on a Nominal MOE, i.e. a value that you can obtain from a published source. When you use PLS-POLE, the Nominal MOE is the MOE value that you enter in the Wood Material Properties table that you reach with

Components/ Wood Pole Material.

Sources of data you can use for Nominal MOE are the mean MOE values listed in one of the confusing tables in Annex C of ANSI 05.1 - 2002 (Annex entitled Reliability Based Design) or in Table A1 of the Canadian Standard CSA-015-90 - 1990. Or you can use the MOE properties published in Table 13-1 of REA Bulletin 1724E-200 - 1992.

The ratio of L.F. / S.F. has been referred to in the past as the Safety Factor. For example, the REA Design Manual for High Voltage Transmission Lines (REA Bulletin 1724E-200, Sept. 1992) recommends a minimum Safety Factor of 3 against buckling of deadend and large angle structures.

The NESC 2002 specifies the following for Grade B wood poles controlled by bending:

Rule 250 B:

   0.65 x ANSI fiber stress >
   Stress from [1.5 Dead Load + 2.5 Wind Load + 1.65 Tension Load]

Rule 250 C:

   0.75 x ANSI fiber stress >
   Stress from [Dead Load + Extreme Wind Load + Tension Load]

For Grade B wood poles controlled by buckling, it is implied by the NESC rules that:

Rule 250 B:

   0.65 x Nominal buckling capacity, P_{CR}, expressed as a single number >
   Axial load from [1.5 Dead Load + 2.5 Wind Load + 1.65 Tension Load]

Rule 250 C:

   0.75 x Nominal buckling capacity, P_{CR}, expressed as a single number >
   Axial load from [Dead Load + Extreme Wind Load + Tension Load]

For steel and prestressed concrete poles, the NESC strength factor S.F. is always equal to 1.

Unfortunately, the Nominal buckling capacity, P_{CR}, is a number that someone can only approximate in very simple cases of guyed wood poles (see Section 3.1.2.3.2 of the PLS-POLE manual). There is no simple formula for multiple guy levels and for poles in complex frames. The nominal buckling capacity is calculated using the Nominal MOE.

Since we believe that the only scientific way to detect buckling is with a nonlinear analysis, one needs to understand how to approach the safety implied in the strength and load factors of the NESC when stability controls the design of a guyed pole. If the PLS-POLE nonlinear analysis is based on one of the methods described below and it converges on a configuration for which the stresses are less than the allowable fiber stress, then you can be assured that buckling has been checked with the strength factors of the NESC 2002.

Method A:

You should use the same load and strength factors as you would for an unguyed pole, but derate the variable which is the most important in determining the buckling strength, i.e. the Nominal MOE, by the smallest of the strength factors in Rule 250B and Rule 250C. This can simply be done for Grade B poles by multiplying the Nominal MOE by 0.65. For example, instead of using a published Nominal MOE of 2,000,000 psi, we would use a value of 1,300,000 for the guyed wood pole model.

If you want additional safety beyond the minimum required by the NESC, you can derate the Nominal MOE even more, for example by derating it by a factor of 0.5 or 0.33.

Derating the Nominal MOE by a certain factor was always possible manually in the Wood Material Properties table. However, one had to be careful to only use the derated MOE for guyed poles, but still use the Nominal MOE for unguyed poles (the Nominal MOE is the recommended number to use for the analysis of unguyed poles where it will control the magnitude of the P-Delta effect). A better approach is to use the derating function which is now implemented in the General/ Wood Pole Buckling Assumptions dialog box. With this approach, the derating properties are associated with the actual guyed pole model. You should choose "Nonlinear Analysis with MOE Factor" in the **Buckling Load Method** pick list and enter the "derating factor" in the **Buckling Strength/ MOE Factor, BAF** field.

Method B:

With this method, instead of derating the Nominal MOE, you amplify the loads on

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guyed wood poles by the reverse of the strength factor which you want on the buckling load, i.e.

Rule 250 B (Grade B):

   ANSI fiber stress >
   Stress from [(1.5 Dead Load + 2.5 Wind Load + 1.65 Tension Load) / 0.65]

Rule 250 C (Grade B):

   ANSI fiber stress >
   Stress from [(Dead Load + Extreme Wind Load + Tension Load) / 0.75]

This method is equivalent to using a different strength factor for each load case. However, we think that it may be too conservative in certain situations and has the risk of overloading components of your structure which are not directly affected by the pole buckling. Amplifying loads to account for strength weaknesses (the old Overload-Capacity factor concept of the NESC) is not a good way to approach safety.

Using Method A or Method B will affect the percent stress usage of your existing guyed wood pole structures if you had not used them before. If you use PLS-POLE to determine the allowable wind and weight spans of your guyed wood poles, these spans will also be affected.

Method A or Method B should never be used for unguyed poles as they would result in totally unrealistic P-Delta effects.

There is no need to make any adjustment when you run a nonlinear analysis of steel and prestressed concrete poles for the purpose of checking stability under the NESC 2002 provisions because the strength factor for these structures is always equal to 1.