ASSESSMENT OF STRENGTH COMPLIANCE WITH STANDARDS FOR TANZANIA EUCALYPTUS WOOD POLES TREATED WITH COPPER-CHROMIUM-ARSENIC COMPOUNDS

Alex Lyatonga Mrema

Senior Lecturer, Department of Structural Engineering, College of Engineering and Technology, University of Dar es Salaam, Tanzania. Email: mrema@ce.udsm.ac.tz,

ABSTRACT

Samples of copper-chromium arsenic compounds (CCA) treated Eucalyptus poles for power transmission were sampled from a lot following Military Standard MIL-STD 105D, Single sampling, Tightened Inspection, Acceptable Quality Level (AQL) of 4 as provided for in the South African Standard SABS 754:1994 from lots containing 151-500 poles. Samples were randomly selected from a lot. Maximum fiber stresses were evaluated taking into account the actual taper in each pole. The cantilever loading test was performed on the samples following SABS 754:1994. It was found out that the average taper for the poles was smaller than that assumed in the standard due to the different pole growth characteristics and environment in Tanzania and that the average modulus of elasticity obtained for the poles was lower than the average assumed in SABS 754:1994. The poles also showed excessive deflections at working loads. It is recommended to the Tanzania Bureau of Standards that although SABS 754:1994 is meant to be used for eucalyptus poles grown in Southern Africa south of the Sahara that are treated with creosote or CCA there is a need to review it to take into account the actual characteristics of the poles grown in Tanzania where they are normally grown in highland areas with higher rainfall and colder climates.

Keywords: *eucalyptus poles, quality verification, cantilever load test*

INTRODUCTION

Over the past 150 years or so, wood poles have been used primarily for utility structures supporting wires for telecommunications and electric power. This has been possible because of the emergence of consensus standards (preservative treatment, strength tests and material specification). A major issue for most standards development has been the relationship between laboratory evaluation under controlled conditions and in-service performance. A full-size pole test provides a more direct assessment of pole capacity independent of failure location than using standard small clear specimens.

While standard tests provide a means of assessing relative values between species and pole sizes, they rarely address all design issues. In the case of wood poles, designated fiber stress values used to set pole size class in the United States include some adjustment to account for the effects of high temperature and conditioning. Research studies by Betts and Newlin (1915), Wilson et al (1930), Buckman and Rees (1938), Stamm (1956) and Thompson (1969) showed that there is a potential reduction of 15% in strength in poles for steaming and 10% for boultonizing. Wood *et al*., (1960) observed that previous studies on steam effects were non-conservative and that the average strength of treated western larch and southern pine poles was less than 85% that of untreated poles. Mac-Lean (1953), Erickson and Dohr (1959) found out that on average, poles that were steam conditioned at 245^{0}F (118.3^{0}C) for 15 hours showed a 16% loss in bending strength.

Wood drying in service has been found to have mix of effects on load carrying capacity: wood strength and modulus of elasticity increase with drying below the fiber saturation point while section property is reduced as a result of shrinkage (Wolfe, 2000). The offsetting effects of shrinkage and fiber strength ncrease with drying, combined with a study by Goodman *et al*., (1981) on poles taken out of service, suggest that taking an increase in strength for drying in service is non-conservative (Wolfe and Kluge, 2005). Rhatigan and Morrel (2002) reported an average of 19% to 40% moisture content at ground line for creosoted Douglas fir poles that had been in service for 35 years, suggesting that the assumption of dry in-service conditions is non conservative. Drying checks that open as poles dry may expose poorly treated wood to trapped dirt and moisture, promoting local decay pockets. Excessive drying and weathering in arid environments may cause poles to lose strength over time.

The relationship between in-service capacity and test capacity is influenced by physical aspects of the pole namely: 1) form: relating to round as opposed to prismatic sections (Newlin and Trayer, 1924); 2) taper: relating to change in section property over pole length ([Bohannan *et al*., 1974; Wood *et al*.,1960); 3) material variability; and 4) size: relating to weak-link theories, which suggest that average extreme fiber strength will decrease as size increases (Bodig and Goodman, 1986; Phillips *et al*., 1985; Wolfe and Kluge, 2005).

1. TRESSES FOR A CIRCULAR "POLE" LOADED.

2.1 Stress distribution

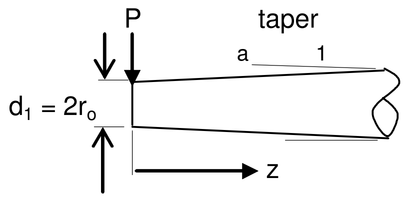


Figure 1. Formulation of stresses in a pole loaded at near its tip

Let $d_1=2r_0$ = diameter at point of lateral load
d_2 = diameter at base of pole and
$r' = d_2/d_1$

From Figure 1 above, if 'a' is the taper of the pole, the radius of the pole at a distance 'z' from the load is given by:

$$r = r_0 + az \quad (1)$$

The section modulus can be calculated as:

$$S_x = \pi r^3/4 \quad (2)$$

The moment at a section at distance z is given by:

$$M = Pz \quad (3)$$

The fiber stress, f_b, at a distance 'z' is given by:

$$f_b= M/S_x = - 4Pz / \pi (r_0 + az) \quad (4)$$

2.2 Maximum stress and its location

To locate max fiber stress, f_b, we differentiate equation (4) and set the derivative to zero:

$$df_b / d_z = r_0 – 2az = 0 \quad (5)$$

Maximum stress occurs at $z = r_0 / 2a$
or where

$$r = 1.5\, r_0 \quad (6)$$

Figure 2. shows a sketch of a pole loaded near its end and some definitions. The variation in stress along a pole as a function of the height ratio and taper ratio is shown on Figure 3. Information on the ratio of maximum stress (σ_{max}) to that at the base (ground line); (σ_{base}) is shown on Table1.

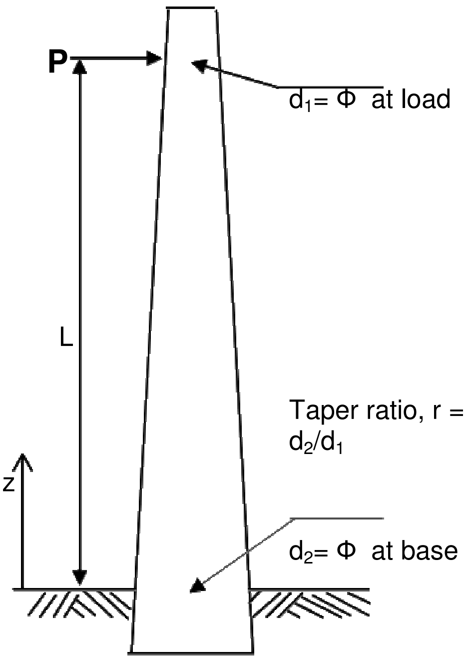


Figure 2. Pole loaded near its end. Definitions

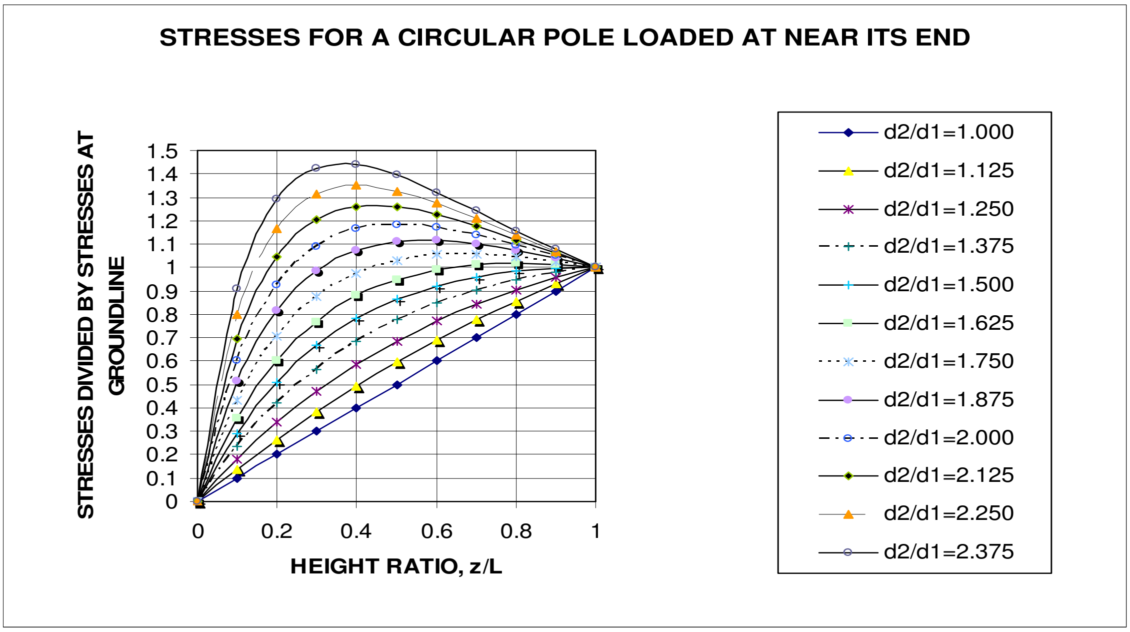
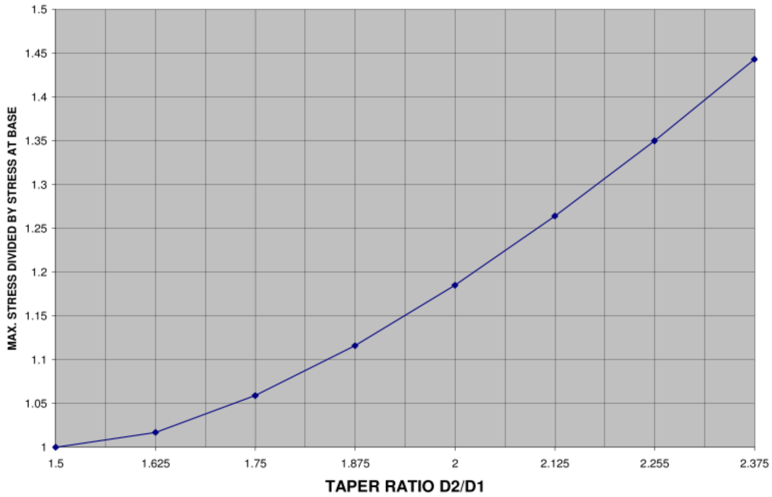


Figure 3. Stresses for a circular pole loaded at near its end

Table1. Information on maximum stress in a pole

Taper ratio $r' = d_2 / d_1$	z / L for σ_{max}	$\sigma_{max} / \sigma_{base}$
≤ 1.5	0	1.000
1.625	0.200	1.017
1.750	0.333	1.059
1.875	0.429	1.116
2.000	0.500	1.185
2.125	0.556	1.264
2.250	0.600	1.350
2.375	0.636	1.443

The maximum stress reached in a pole as a function of the taper ratio is plotted on Figure 4.



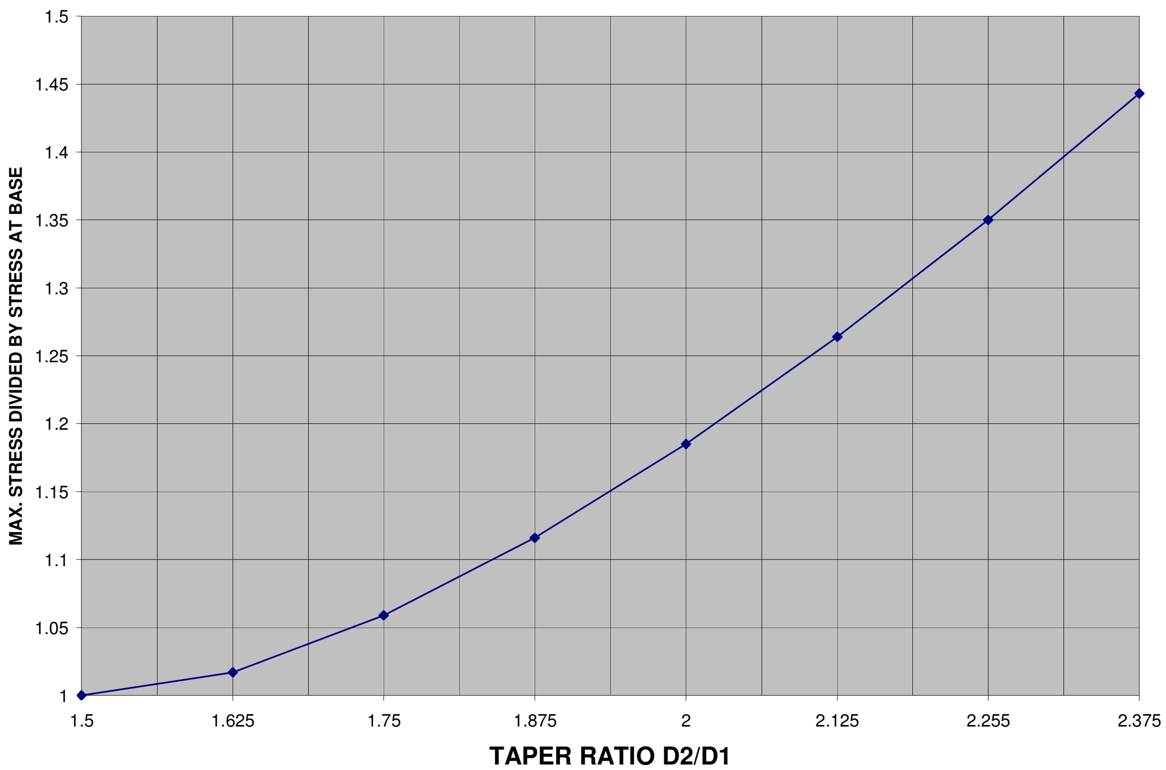


Figure 4. Maximum stress in a pole as a function of the taper ratio

2. OBJECTIVES OF THE INVESTIGATIONS

The objective of the investigations was to carry out site inspection and tests on wood poles which were intended for delivery to Tanzania Electric Supply Company. The inspection was to ascertain whether a lot of 300 poles intended for delivery complied with the requirements of the South African Standard SABS 754:1994.

3. INSPECTION AND TEST METHODS

3.1 Visual Inspection and dimensional verification

The species of the wood poles was eucalyptus saligna. The poles were of a length of 9m. A random sample of 20 poles were taken from the lot following the Military Standard MIL-STD-105D(1963): Inspection Level I, Single Sampling, Tightened inspection, Acceptable Quality Level (AQL) of 4 and the sampling requirements of Table B.1 (Sample Sizes) of SABS

754:1994/Ed4. This sample was then checked to comply with clause 6 (Marking) and annex C (strength tests and values for poles and cross arms) of the same standard.

Unfortunately out of the 20 poles inspected, seven (7) were rejected based on the tip diameter drawn both from visual inspections and dimensional verifications.

3.2 Sample for testing and test procedure

The remaining thirteen (13) samples which passed the visual inspection and dimensional verification were tested using the cantilever loading test. The apparatus used and the procedure for testing followed the requirements given in Annex C (Strength tests and values for poles and cross arms) of the standard. Figure 5. illustrates the cantilever load test.

Figure 5. A Cantilever load test

3.3 Evaluation of forces, Modulus of Elasticity(MOE), taper and stress distribution

The maximum force required to cause a fiber stress of 55 MPa was calculated using the formula given in the SABS 754:1994 standard:

$$F = (\sigma \times D^3)/ 10.2 \times L \qquad (6)$$

where

F is the force, in Newtons, required to cause a minimum fiber stress in cantilever loading of 55 MPa

σ is the minimum fiber stress

D is the minimum diameter, in mm, of the pole at the theoretical ground level (TGL) i.e. 1500 mm from the butt end based on the specified minimum top diameter and a taper of 5mm per meter length.

L is the distance in mm between the TGL and 600mm from the top end.

The modulus of elasticity was evaluated using the formula:

$$E = kPL^3/\delta D_A^4 \qquad (7)$$

where:

E is the modulus of elasticity (MOE) in megapascals.

k is a constant, derived from the ratio between diameters at the point of clamping, D_B, and the point of load application, D_A, taken from Table G.1 of the standard.

L is the test span in millimeters.

δ is the measured deflection in millimeters.

Using this standard test procedure, two (2) out of the thirteen poles tested failed to meet the specification requirements with respect to the required force to cause a fiber stress of 55

N/mm^2 as required in the standard and hence statistically the lot was rejected at Acceptable Quality Level of 4 (i.e. 4 percent defectives)

The actual taper in the poles were evaluated and the actual stress distribution in the individual poles were calculated using equation (4).

4. TEST RESULTS

The average measured taper in the thirteen poles tested was 2.27mm per meter with a standard deviation of 0.53 mm/m when the degree of freedom is taken into account. The coefficient of variation for taper was calculated to be 23.1%.

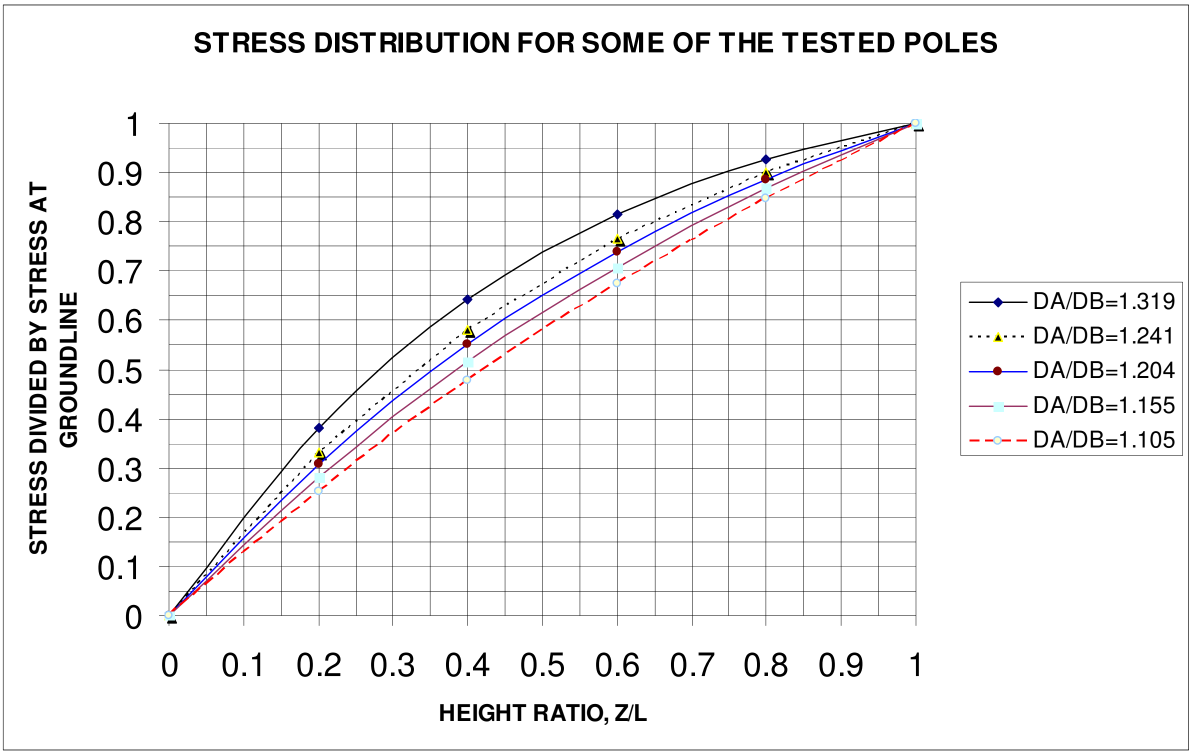


Figure 6. Stress distribution for some of the tested poles

The stress distribution along the tested poles when the actual taper of the pole is taken into account is plotted on Figure 6. For purposes of clarity of the graph only some of the results of the tested poles are presented. Also presented are the load deflection curves for some of the tested poles as measured during the test (Figure 7).

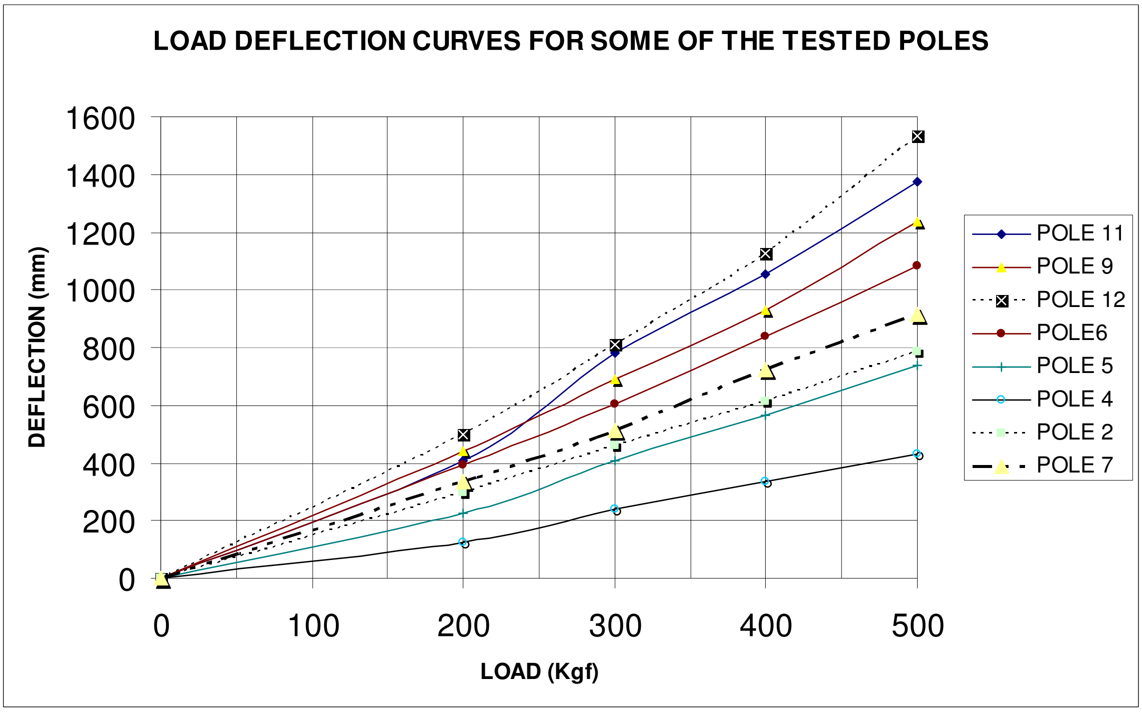


Figure 7. Load deflection curve for some of the tested poles

The modulus of elasticity of the thirteen individual poles tested is shown on Figure 8. These were evaluated using equation (8).

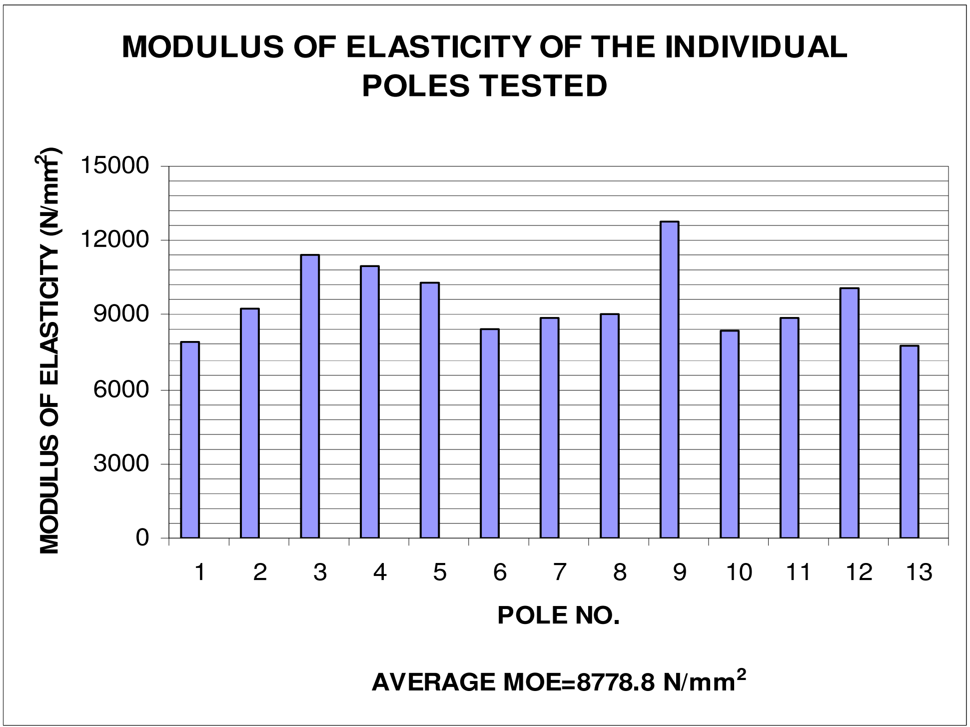


Figure 8. Modulus of elasticity of the tested poles

5. DISCUSSION OF RESULTS

From the analysis done in section 2 of this paper maximum stresses in a pole loaded near its tip occur at the ground line (base) only if the taper ratio is less than 1.5. For bigger taper ratios maximum stresses occur above the ground line. The bigger the taper ratio the higher the ratio of maximum stress to the stress at the base (Table 1).

While the South African Standard SABS 754:1994 assumes an average taper of 5mm per meter length of a pole for eucalyptus poles when calculating required force to cause a fiber stress of 55MPa, actual measurements of taper in this study showed a much lower average value of 2.27 mm per meter length.

Also the standard assumes an average modulus of elasticity of 11000 MPa. In this study the average MOE obtained was 8779 MPa. This difference is not surprising since wood is a product of nature rather than a manufacturing process. Its strength varies not only between trees but also within a tree. Between tree variability in strength is attributed to growing conditions e.g. nutrients, rainfall, length of growing season and competition.

It is recommended that the maximum deflection at working loads should not exceed 5% of the pole length. For a 9m pole this maximum value is 450 mm. In this particular case at hand the working load was 400kgf and looking at figure 6, nearly all poles showed excessive deflections. This was of course due to the lower pole stiffnesses.

6. CONCLUSIONS

The South African Standard SABS 754:1994 is a specification for the requirements for eucalyptus poles, grown in Southern Africa that are treated with creosote, a mixture of creosote and waxy oil, or a mixture of copper-chromium-arsenic compounds (CCA) and that are intended to be used as upright supports for telephone systems, and as upright supports, cross-arms and spacers (in five-pole structures) for power distribution lines.

The Southern Africa Region is a very diverse region with an equally diverse pole growth conditions. No single standard can adequately cater for the whole region because pole properties are very different.

It has been observed in this study that while SABS 754:1994 assumes an average taper of 5mm per meter length of a pole, the average taper measured was much less, 2.27mm per meter length. Also the average modulus of elasticity of the poles in this study was 8779 MPa which is much lower than the 11000 MPa assumed in the standard.

Using SABS 754:1994 to assess Tanzania eucalyptus poles leads to a substantial rate of rejections. For example in this study the pole lot under assessment was rejected at an Acceptable Quality Level (AQL) of 4 (i.e. 4% defectives). The same lot would have been acceptable at an AQL of 10.

Since Tanzania is endowed with a lot of poles, sufficient for both domestic use and for export, it may be cheaper to set a higher AQL than 4 rather than relying on expensiveimported poles.

There is therefore a need to research more on the current pole species that are available and come up with realistic average pole properties which can then lead to the review of SABS 753:1994 and or the development of a local standard i.e. a Tanzania Standard. The development of standards in Tanzania is under the Tanzania Bureau of Standards (TBS).

ACKNOWLEDGEMENTS

The author is grateful to the Tanzania Electric Supply Company (TANESCO) for having given him this consultancy work.

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