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Research Paper

Analysis of Fibre Reinforced Polymer –Poles Made Using Filament Winding Technique

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ABSTRACT
This paper presents a theoretical analysis of light weight, glass fibre reinforced polymer (GFRP), pole structures. A finite element (FE) program was used to perform a nonlinear numerical analysis to model the static flexural behaviour of GFRP poles. The results of the FE analysis are compared to the experimental results conducted on full scale identical GFRP poles. A parametric study on 12 m (40 ft) GFRP poles was carried out to show the effect of fibre orientation and the number of circumferential layers on the load carrying capacity and deflection behaviour. The results show a good agreement between the FE analysis and the experimental data. The theoretical model is used to evaluate the performance of a GFRP pole and to determine the optimum cross section dimensions at three different zones along the height of the GFRP pole structure.
KEYWORDS: *Fibre Reinforced Polymers, FRP Structural Shapes, FRP poles, Filament Winding.*

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I. INTRODUCTION

The glass fibre reinforced polymer (GFRP) poles technology has been used for over thirty years in the application of the light poles and electrical transmission tower element, as a replacement for the conventional materials, due to their high strength-to-weight ratio and corrosion resistance (Ibrahim et al 2000 and Ibrahim et al., 1999). High quality surface coating and the ultraviolet radiation resistance treatment give the FRP pole a long service life, beyond eighty (80) years (Miller et al., 1995). A limited number of experimental and theoretical studies have been conducted on the behaviour of the tapered GFRP poles structure under lateral load (Lin 1995, Crozier et al., 1995, Derrick 1996). Due to the existence of a service opening at 2.7 m from the bottom of the FRP pole, and also due to small thickness-to-radius ratio, local buckling failure can reduce significantly the load carrying capacity. Therefore the part which includes this service opening must be addressed. It is important to find the optimum geometrical details for the region of the service opening, in order to be compatible with the upper and lower zones over the length of the pole. In this paper, a finite element program with a nonlinear numerical analysis was used to optimize the design of a 12 m (40ft), GFRP poles having a service opening.

II. FINITE ELEMENT ANALYSIS

A nonlinear finite element model was developed using the software ADINA finite element program. The finite element analysis was verified through comparison with the experimental data obtained from the static testing of full-scale GFRP poles, according to the recommendations described in ASTM and ANSI standard. The specimens were tapered hollow sections, and divided through the height into three zones, I, II and III. The 100 x 300 mm-(width x length) service opening is located at the center of the middle zone II and was in the compression side, when loaded. The typical specimen dimensions and details of the three zones are shown in Figure 1. GFRP poles are fabricated using the filament winding technique. E-glass fibres and Epoxy resin were used for these poles. The pole modeled with a total number of elements equal to 2288 (16 and 143 in the circumference and longitudinal direction, respectively). The mesh layout was fine for zones I and II, where maximum stresses and failure are expected to occur, and gradually becomes coarse at the top. This was made by the automatic mesh density option of the program. The general layout of the mesh distribution and the used finite element models are shown in Figure 1.

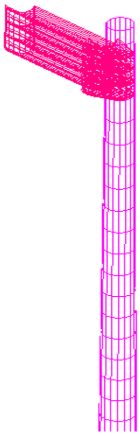
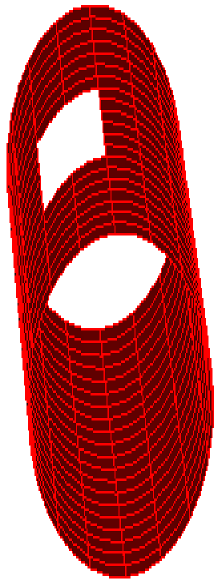
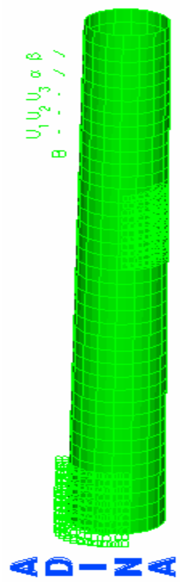


Figure 1.a Zone III with the applied load



Middle Zone II with opening



Zone I with Boundary condition

Fig. 1.b: Details of the finite element model.

FE Boundary Condition:

The under ground length of the GFRP poles were restraint along two opposite half circumference area, the first area at the end of the base and the second area at the ground line. This Configuration of restraints was to simulate the support condition described in standards ASTM D 4923-01 and ANSI C 136.20-2005.

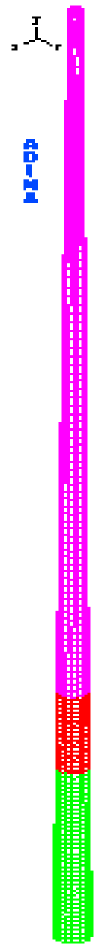


Fig. 1.c: Finite element model of FRP pole.

FE Loading Condition

The GFRP pole was subjected to a horizontal pressure load (W) from the top of the pole edge by 300mm according to the ANSI C 136.20-2005 recommendations. The pole was incrementally loaded using 100-200 time steps. To avoid local failure under the applied load, a pressure-load has been used to simulate the same effect as in the experimental testing.

FE Shell Element

An eight-node quadrilateral multilayered shell element is used in the model; each node has six degrees of freedom, three translations (U_x, U_y, and U_z) and three rotations (R_x, R_y, and R_z). The composite shell elements are kinematically formulated in the same way as the single layer shell elements, but an arbitrary N number of layers can be used to make up the total thickness of the shell. The basic equations used in the formulation of the Multilayered Shell Element are given in the reference Bathe 1996.

FE Material Modeling

The material model used with the shell element is elastic-orthotropic with large displacement /small strain. The mechanical properties of the FRP laminate were obtained from the material properties of the E-glass fibre and the epoxy resin. Orthotropic material properties in the fibre and transverse to the fibre direction were defined. Fibre orientation for each layer was specified by defining the fibre angle with respect to the element axes. The effective materials properties were taken as follows: E_1 = 45.5 GPa, E_2 = 10.5 GPa, G_{12} = 4.875 GPa,, υ_{12} =0.31, where, E1, E_2, G_{12} and υ_{12} are the Young's modulus in the fibre direction, the Young's modulus in the transverse direction, the shear modulus, and the Poisson's ratio, respectively. Table 1 presents the fiber orientations and the stacking sequences for the actual and new designs.

Table 1. Stacking sequences for the proposed new designs

Zone	New design Fibre orientation θ (Degrees)
I	[90, (±10)$_5$, 90]
II	{90, ±45, [90, (±10)$_5$, 90]±45, 90 }
III	[90, (±10)$_5$, 90]

III. RESULTS AND DISCUSSION

Failure Mode and Load-Deflection Results

Failure of the modeled FRP poles was determined when the divergence of the solution was achieved or when the Tsai-Wu failure criterion value reached unity. A comparison between the finite element analysis and the results obtained from experimental testing of full-sale prototypes obtained by tests, was in terms of the load-deflection relationship and the ultimate load carrying capacity. Figure 2 represents the load deflection relationship for the experimental and finite element analysis. It is evident from this figure that there is a strong correlation between the results obtained from the finite element analysis and the experimental results.

Effect of Fibre Orientation

Because of this agreement, the same finite element analysis was used to extend the study and examine the effect of fibre orientation of circumferential layers on the flexural behaviour of GFRP poles. To study this parameter, the circumferential layers with fibre orientation of 70 degree were changed to 90, 60, 50 and 30 degree, with the same details of wall thickness, dimension of the GFRP pole and material properties. Figure 3 shows the relation between fibre orientations of circumferential layers and stiffness of GFRP pole for different models. It is clear that 90 degree of the fibre orientation gives the highest stiffness.

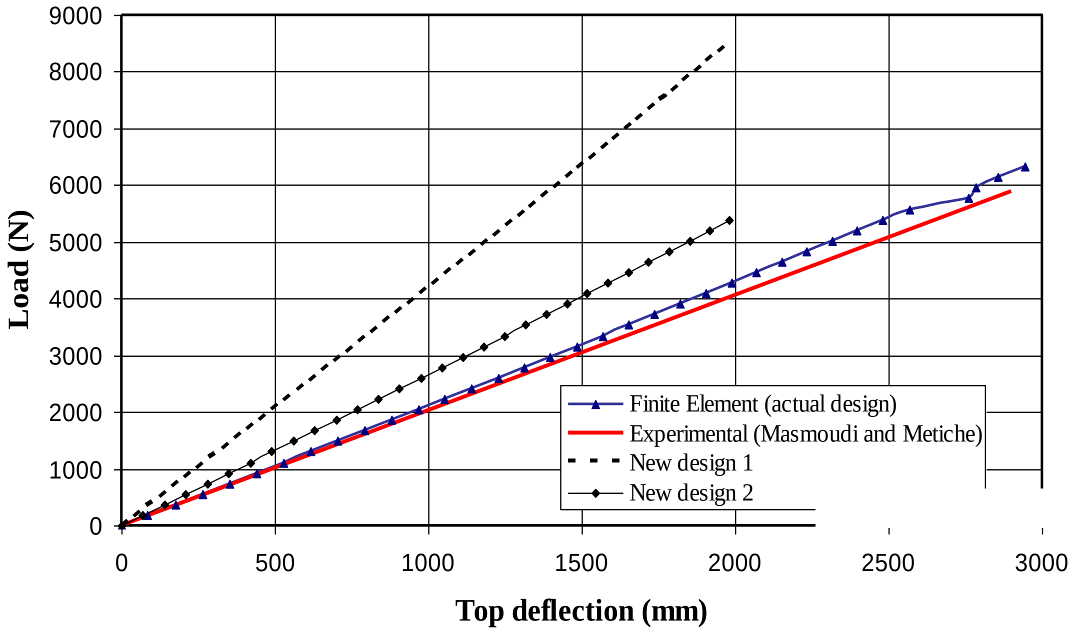


Figure 3. Load-deflection curve

GFRP Pole Design Equivalent to Classes 2 and 4 of Wooden Pole

The design criteria to satisfy the requirement strength criteria as given in the ASTM D 4923-01, AASHTO, and the general standard specifications of ANSI C 136.20-2005 for maximum deflection, ultimate load capacity and minimum embedment depth. The different combinations of parameters such as fibre orientation, number of longitudinal and circumferential layers and layer thickness are considered. It was also assumed that the total number of layers to be constant equal to 12 layers, (10 longitudinal and two circumferential layers in zone I, II, III). However, in order to reinforce zone II (service opening), 6 additional layers are used (3 inside the 12 previous layers and 3 outside the 12 previous layers), which make the total layers of this zone equal 18. The fibre angles assumed to be +10°/-10° for longitudinal layers and 90° for circumferential layers. The (90°, +45°/-45°) orientation are used for the 6 additional layers. The thickness of each layer was varied from 0.40 mm to 0.8 mm and for the thickness of each additional was assumed to be twice the previous thickness.

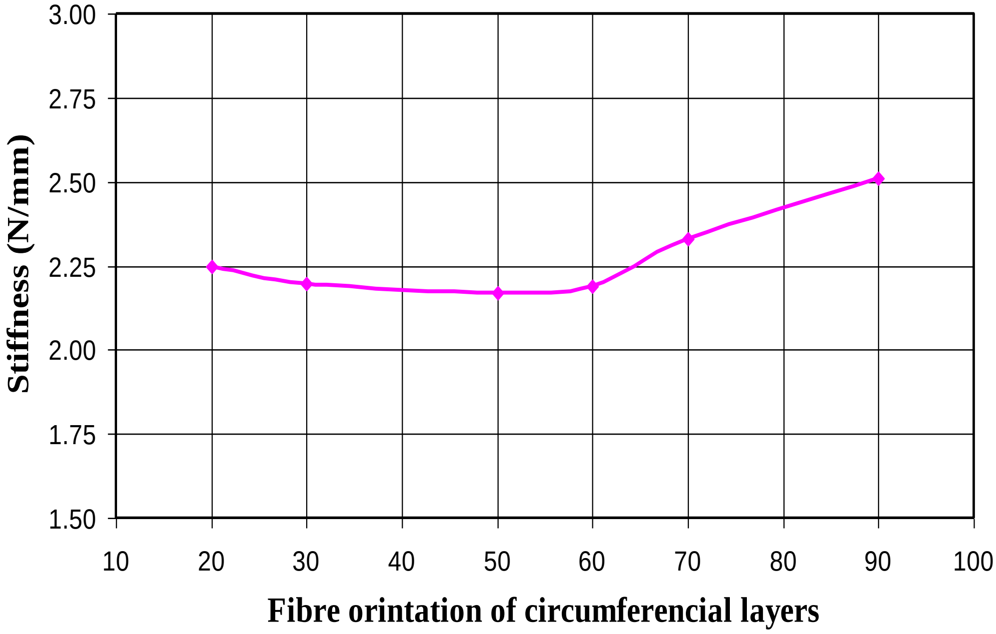


Figure 3: Effect of fibre orientations of circumferential layers on the stiffness of GFRP pole

The finite element analysis was employed to optimize the design of the 12 m (40 ft) FRP pole to achieve an equivalent ultimate load capacity required for class 4 and class 2 wooden poles. After several FE simulations with different thickness, the results indicate that; the requirements for the FRP pole class 2 and class 4 achieved when the thickness of each layer were to be equal 0.5 mm and 0.75 mm, respectively. Thus, the total thickness of the laminate in zone I and zone III for class 4 and class 2 equal 6 mm and 9 mm, respectively, where the total thickness in zone II will be over by the thickness of the 6 additional layers which is equal to 12 mm and 18 mm for FRP class 4 and class 2, respectively. The mode of failure for these model occurred at the ground level due to the local buckling. Figure 2 shows the load deflection relationships for GFRP poles equivalent to class 2 (New design 1) and class 4 (New design 2) wooden poles.

IV.CONCLUSION

The finite element program ADINA (version 8.2) was used to perform a nonlinear numerical analysis of tapered GFRP poles. Layered composite shell elements were used in this finite element analysis. The program accounts for the nonlinear behaviour of the poles and includes a strength failure check by applying the Tsai-Wu failure criterion. The results were in an excellent agreement with the experimental results. The finite element method used in this investigation provided an excellent prediction of the critical buckling and material failure loads, as well as the corresponding modes of failure for thin-walled GFRP poles. The load-deflection curve of GFRP poles under lateral loading can be considered linear up to failure. The fibre orientation of circumferential layer with 90 degree for the tapered GFRP poles gives the higher load capacity and stiffness. The internal and external additional three layers (90, ±45) for the laminate at the middle zone II, improved the flexural behaviour due to the existed hand-service opening. The proposed models with 12 layers with two circumferential with 90 degree and ten with 10 degree give excellent result. Optimum designs for 12 m (40 ft) GFRP poles equivalent to class 4 and class 2 wood poles were obtained using the finite element model, to satisfy the requirement strength criteria as specified in the ASTM, AASHTO and ANSI standards for the maximum deflection and ultimate load capacity.

REFERENCES

[1]. ADINA (2004), *Theory and Modeling Guide*, Volume I, Chapter 3, Version 8.2. *ADINA R&D Inc*., Watertown, MA, USA.

[2]. American Association of State Highway and Transportation Officials, AASHTO (2001), "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic signals*"*.

[3]. American National Standard Institute. (2005). "Fiber-Reinforced Plastic (FRP) Lighting Poles, American National Standard for Roadway Lighting Equipment*"*, USA, *ANSI* C 136.

[4]. American Society for Testing and Materials. (2001). "Standard Specification for Reinforced Thermosetting Plastic Poles", Annual book of ASTM Standards, D 4923 – 01, USA.

[5]. Bathe, K.J. (1996). *Finite Element Procedures*. Prentice-Hall.

[6]. Crozier, W., Dussel, J.P., Bushey, R., West, J. (1995). "Evaluation of deflection and bending strength characteristics of fibre-reinforced plastic lighting standards". Department of Transportation, New York, State of California, USA.

[7]. Derrick, G. L. (1996). "Fiberglass Composite Distribution and Transmission Poles", Manufactured Distribution and Transmission Pole Structures Workshop Proceeding, July 25-26, Eclectic Power Research Institute, pp. 55-61.

[8]. Ibrahim, S., and Polyzois, D., and Hassan, S. (2000). "Development of glass fiber reinforced plastic poles for transmission and distribution lines". *Can. J. Civ. Eng*. Vol. 27, pp. 850-858.

[9]. Ibrahim, S., and Polyzois, D. (1999). "Ovalization analysis of fiber reinforced plastic poles". *Composite Structures*, Vol.45, pp 7–12.

[10]. Lin ZM. (1995). "Analysis of pole-type structures of fibre-reinforced Plastics by finite element method", Ph.D. Thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

[11]. Miller, M. F., Hosford, G.S. and Boozer III, J.F. (1995). "Fiberglass Distribution Poles: A Case of Study" IEEE transactions on Power delivery, Vol. 10, No. 1, pp. 497-503.

[12]. Tsai, S. W., and Wu, E. M. (1971). "A General Theory of Strength for Anisotropic Materials" *Journal of Composites materials*, Vol. 5, pp. 58-80.