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Research Paper

Behavior of Hollow Glass-Fiber Reinforced Polymer Tapered Pole Structures

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ABSTRACT
In this study a finite element modeling of the nonlinear behaviour of laterally loaded full scale tapered fibre reinforced polymer (FRP) pole structures has been conducted. Parametric study has been conducted to investigate the effect of longitudinal layers: number and orientation. The FRP poles are proposed to be fabricated using filament winding technique; E-glass fibre and Epoxy resin. The result to data indicated a good agreement between the results of the finite element analysis and the experimental data. The results indicate that the flexural behaviour is highly dependent on the fibre orientation, and number of layers. The total load capacity of the FRP poles and the stiffness are increased with increasing the number of longitudinal layers.
KEYWORDS: *Fibre Reinforced Polymers, FRP Structural Shapes, FRP poles, Filament Winding.*

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I. INTRODUCTION

In recent years, FRP composites, which are made of reinforcing fibres and a thermosetting resin, have been widely used as advanced construction materials. FRP provide several advantages over traditional construction materials (steel, concrete, wood): high strength to weight ratio, high stiffness, resistance to corrosion, ease of installation and high durability (Fujikake et al. 2004). Therefore, the tapered FRP poles are currently considered attractive in the application of the light poles and electrical transmission tower element. There is a lack to study the behaviour of the hollow tapered FRP pole structures. These due to the limited number of experimental and theoretical studies, which have been conducted on the behaviour of the tapered GFRP poles structure under lateral load (Lin 1995, Crozier et al. 1995; Derrick 1996; Ibrahim et al. 2000; Ibrahim and Polyzois,1999). The most of these studies were established on the behaviour of the FRP poles without service opening. The existence of service opening in the FRP poles, reduce the strength at the location of this opening, due to small thickness-to-radius ratio, ovalization and local buckling behaviour of the FRP poles. Therefore, the part which includes this hole must be addressed and finding the optimum geometrical details for it to be compatible with the upper and lower zones over the length of the pole to attain the required total capacity under lateral loads

II. DEVELOPMENT OF FE MODELING

In this study, an eight-node quadrilateral multilayered shell element was used in the model. Each node has six degrees of freedom, three translations (Ux, Uy, and Uz) and three rotations (Rx, Ry, and Rz). 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. Layers are numbered in sequential order starting from 1 at the bottom of the shell (ADINA. 2006).

Newton-Cotes with high order of 5×5 numerical integrations were used for the evaluation of the element matrices in the r-s plane of the shell element, to avoid spurious zero energy. 3-point Newton-Cotes numerical integration was used through the shell thickness to obtain an accurate profile of the transverse shear stress.

The material model which be used with the shell element is elastic-orthotropic with large displacement /small strain. In the large displacement formulation/small strain formulation, the displacement and rotation can be large, but the strains were assumed to be small. 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.

III. GEOMETRICAL MODELING

The specimens were tapered hollow sections, 10566 mm in length. The inner diameters at the base and at the top were 270.00 and 114.00 mm, respectively. The specimen divided through the height into three zones, I, II and III, The 101.6 x 304.8 mm-(width x length) service opening is located at the center of the middle zone II and was in the compression side. The typical specimen dimension, cross section and details of the three zones, are shown in Figure. 1. GFRP poles are fabricated using filament winding technique, different fibre angles with respect to the longitudinal axis of the pole were used: (90°, ±10°) at the bottom zone I, (90°, ±45°, ±10°) at the middle zone II and (90°, ±10°) at the top zone III. The layer thickness is 0.432 mm. The pole modeled with total number of elements 2256 (16 and 141 in the circumference and longitudinal direction, respectively), the mesh layout were fine in the bottom area of the maximum stress and expected failure zone, 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. 2.

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.. Each node along the supported area was restrained against the vertical (in z-direction), the horizontal (in x and y directions) movements. This Configuration of restraints was to simulate the support condition described in standards ASTM D 4923-01 and ANSI C 136.20-2005 for measuring the Load- deflection behaviour of FRP poles.

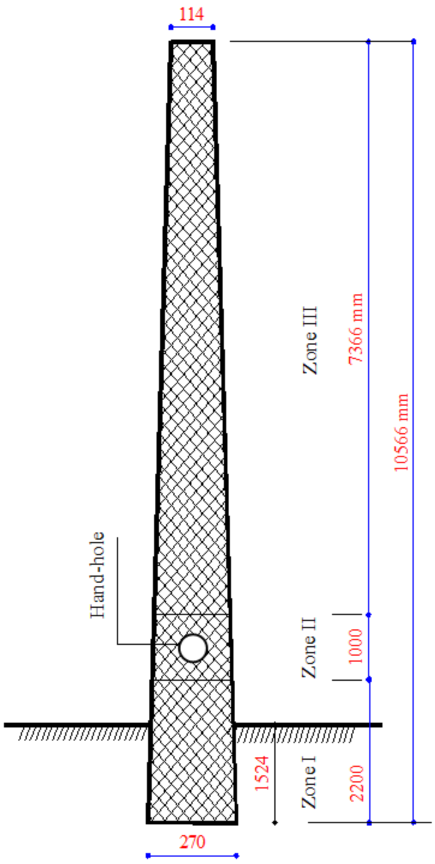

Figure 1. Dimension of full-scale FRP pole

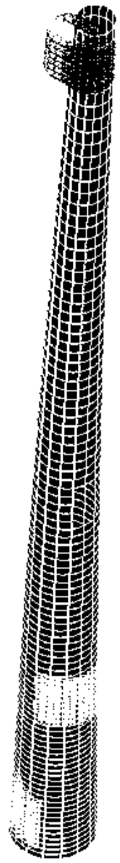

Figure 2. FE Model

IV. MACROSCOPIC FAILURE CRITERIA

The mechanical behaviour of advanced fibre reinforced composite materials is topic which has attracted a great deal of interest in recent years. Failure criteria have been developed to predict the materials strength properties of the orthotropic composite materials. Composite materials are anisotropic (properties vary depending on the direction in which they are measured); hence the strength properties of fibre-reinforced materials are strongly dependent on the direction of loading. Accordingly, more than one parameter is needed. The Tsai-Wu failure criteria are provided in ADINA for the analysis of shell structures using the elastic-orthotropic material models. This failure theory expands the Tsai-Hill criteria by including linear terms which characterize the different strength in tension and compression and quadratic terms. This criterion provides an ellipsoid shaped failure envelope in the stress space.

Table 1: Properties of E-Glass and matrix:

	Fibres
	E-Glass
Tensile modulus(MPa)	80 000
Shear modulus(Mpa)	30 000
Poisson’s ratio	0.25
	Epoxy resin Araldite GY 6010
Density (Kg / m^3)	1200
Tensile modulus(Mpa)	3380
Shear modulus(Mpa)	1600
Poisson’s ratio	0.4

V. RESULTS AND DISCUSSION

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-scale prototypes obtained by Masmoudi and al., 2006, was in terms of the load-deflection relationship and the ultimate load carrying capacity. Figure. 3 represent the load deflection relationship for the experimental and finite element analysis for 20 and 35 ft height GFRP poles. 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. The 35 ft GFRP pole failed at the ground level due to the local buckling and before this failure distortion of cross section at service opening location was occurred.

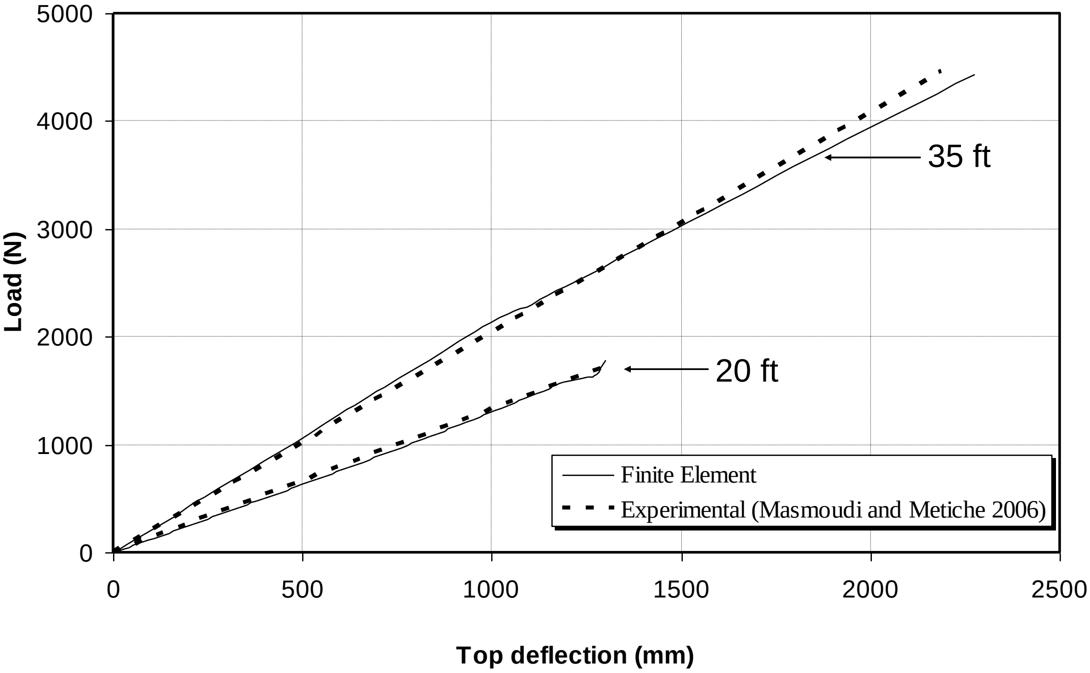

Figure 3. Comparison between experimental and FE load-deflection relationship for 20 ft and 35 ft poles

VI. PARAMETRIC STUDY

Based on the agreement of the finite element analysis, the effects of the following parameters were carried out to better understand the flexural behaviour of FRP poles fibre orientations of longitudinal layers, and fibre orientations of circumferential layers. The same finite element analysis was used to extend the study and examine these parameters effect of longitudinal and circumferential angle orientation of the fibre, number of circumferential layers and the effect of replacing glass fibre by carbon fibre on the FRP pole behaviours, with the same details of wall thickness, dimension of the GFRP pole (35 ft) and material properties. Table 2 shows the stacking sequence and fibre orientation for 7 prototypes models to study the effect of the first, second and third parameters. Po was taken the reference. P-1 and P-2 are proposed to study the effect of fibre orientations of longitudinal layers, by changing the fibre orientation from ±10 to ±20 and ±30 degree for P-1 and P-2, respectively. P-3 and P-4 are proposed to study the effect of fibre orientations of circumferential layers, by changing the fibre orientation from ±90 to ±70 and ±50 degree for P-3 and P-4, respectively. P-5 and P-6 are proposed to study the effect of number of circumferential layers, by changing the fibre orientation from ±90 to ±10 for P-5, it is meaning that this model has not any circumferential layers. Finally in P-6, the number of circumferential layers was assumed to increase for 4 layers.

Table 2: Stacking sequence and fibre orientation of layers

Pole model Id	Zone I, III	Zone II
P_o	$[90, (\pm10)_5, 90]$	$\{90, \pm45\ [90, (\pm10)_5, 90]\ \pm45, 90\}$
P-1	$[90, (\pm20)_5, 90]$	$\{90, \pm45\ [90, (\pm20)_5, 90]\ \pm45, 90\}$
P-2	$[90, (\pm30)_5, 90]$	$\{90, \pm45\ [90, (\pm30)_5, 90]\ \pm45, 90\}$
P-3	$[70, (\pm10)_5, 70]$	$\{70, \pm45\ [70, (\pm10)_5, 70]\ \pm45, 70\}$
P-4	$[50, (\pm10)_5, 50]$	$\{50, \pm45\ [50, (\pm10)_5, 50]\ \pm45, 50\}$
P-5	$[10, (\pm10)_5, 10]$	$\{10, \pm45\ [10, (\pm10)_5, 10]\ \pm45, 10\}$
P-6	$[90_2, (\pm10)_4, 90_2]$	$\{90, \pm45\ [90, (\pm10)_4, 90]\ \pm45, 90\}$

The load deflection relationships are plotted for the numerical results of the different models in Figures 4, 5, and 6. It is observed that increasing the fibre orientations of the longitudinal layer a significant droop in the failure load and an increase of the deflection at all load level was occurred as shown in Figure. 6. Also decreasing the fibre orientation of the circumferential layers from 90 to 70 and then 50 degree the load decreased and deflection increased as shown in Figure. 6. It is cleared from Figure. 8 that the importance of the inner and the outer circumferential layers with the longitudinal layers for the FRP poles. This is evident from the result of the model P-5, it hadn't any circumferential layer and a significant droop in the failure load and an increase of the deflection at all load level was occurred.

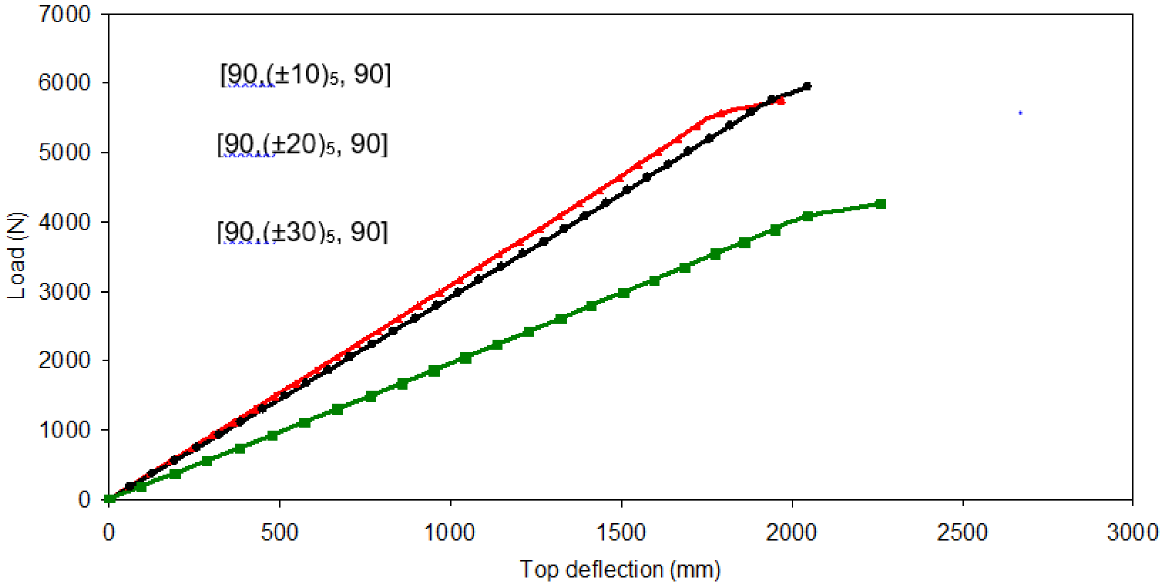

Figure 4. Effect of fibre orientations of longitudinal layers on load deflection relationship

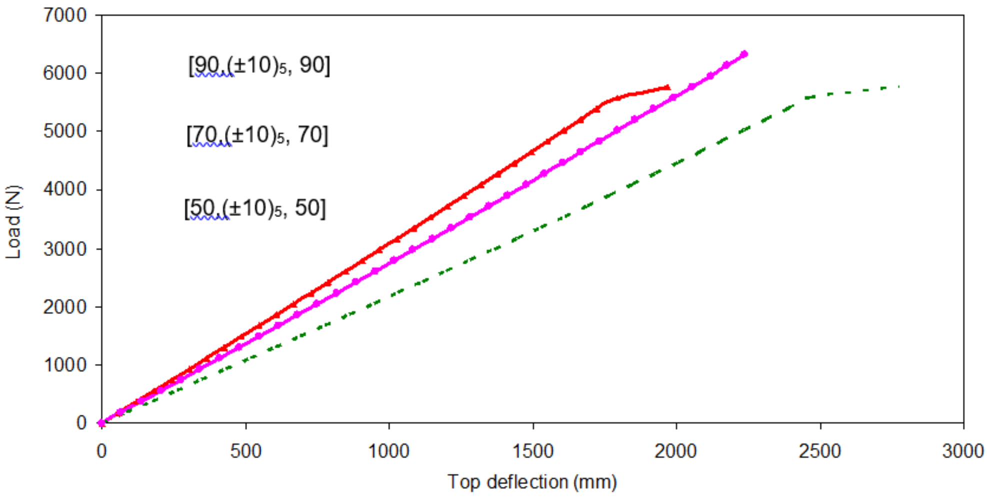

Figure 5. Effect of fibre orientation of circumferential layers on load deflection relationship

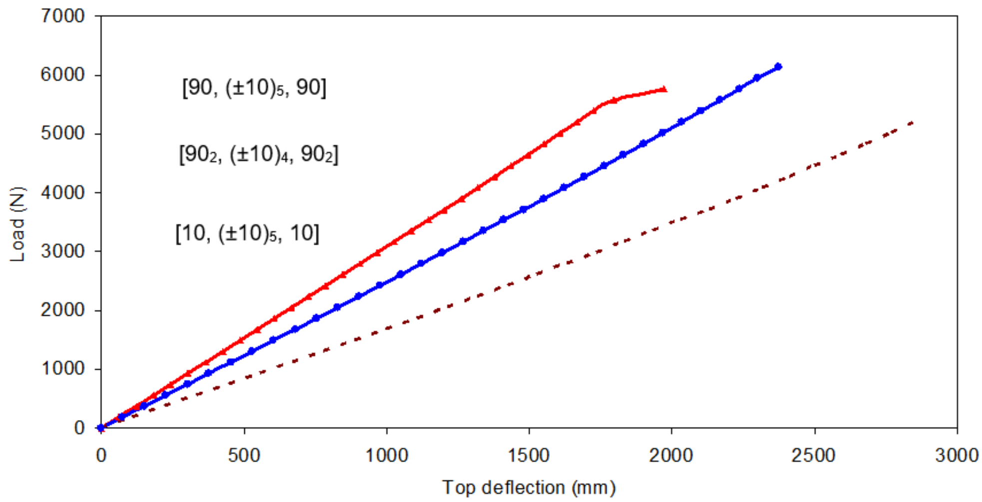

Figure 6. Effect of number of circumferential layers on load deflection relationship

VII. CONCLUSIONS

The results of FE 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. The program accounts for the nonlinear behaviour of the poles and includes a strength failure check by applying the Tsai-Wu failure criterion. The load-deflection curve of GFRP poles under lateral loading is linear up to failure. When the fibre orientation of the longitudinal layer is 10 degree, this yields a higher load capacity with lower deflection. Circumferential layers improve the flexural behaviour of GFRP poles in terms of ultimate load capacity and deflection. Decreasing the fibre orientation of the circumferential layers from 90 to 70 and then 50 degrees resulted in the load decreased and deflection increased.

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