Structural evaluation of FRP Pultruded Sections in overhead transmission line Towers

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ABSTRACT

This paper presents experimental investigation carried out on modular X-braced panels of a transmission line tower made from FRP pultruded structural profiles subjected to transverse and vertical loading. The modular elements are light weight, can be easily assembled for structural support of an overhead transmission lines. The member stresses were monitored using strain gauges during full scale testing. Mathematical model of 3-Dimensional panel were generated using standard FEM software to study the analytical correlation with the experiments. The results from this study illustrates the light weight FRP structural profiles is an alternate sections to the conventional rolled steel angle sections used in power transmission line towers.

Keywords: Pultruded profiles, Transmission line towers, Composite materials.

1. Introduction

In the last few decades power demand around the world has increased rapidly. The major problem facing utilities is how to build the transmission lines fast enough. Overhead transmission line system continues to age and due to the financial constraints they are receiving less inspection and preventive maintenance. Difficulties are being experienced by the power utilities in finding corridors for new Extra High Voltage (EHV) and Ultra High Voltage (UHV) transmission lines due to density of population in the urban areas, obtaining forest clearances and nature preservation philosophy. To ensure the electric power transmission to urban and suburban areas, it is necessary to technically develop compact 66 kV, 110/132 kV & 220 kV transmission line tower structures to minimize the tower dimensions, its visual impact, utilize the restricted Right of Way (ROW) and reduction land area along the transmission line route. In addition, there is a concern with worldwide for deterioration and corrosion of steel transmission line towers due to continuous exposure of hostile environment, i.e., wind, rain and salty environment. Further deterioration and corrosion may be prevented by using pultruded Fiber Reinforced Polymer (FRP) composite materials for overhead power line structures. The advantages FRP composites over traditional materials motivate their use in load bearing structures. Pultruded profiles are often the structural members of choice where significant corrosion and chemical resistance is required. Hsein-Yang Yeh, 1997 reported that feasibility of building a power transmission tower from a polymer composite material E-Glass and Vinyl ester resin. Hsein-Yang Yeh, 2001 presented the simple failure analysis of composite transmission tower. The American Society of Civil Engineers (ASCE) Manual No.104, 2003 brought out the recommended practice for Fiber- Reinforced polymer products for overhead utility line structures. Unlike
steel, FRP is a nonconductive material allowing the reduction or elimination of insulator strings which makes the transmission towers cheaper to construct. The objectives of this paper are to present the results of an experimental investigation of the behaviour of the FRP tower panel fabricated from pultruded structural sections subjected to axial loads (tensile & compressive) and to correlate the test results with analytical studies. Experiments were carried out on full scale FRP panel with normal framing eccentricities. Structure level FEM analysis was carried out to compare the buckling mode and load carrying capacity of axially loaded members. Buckling load predicted from analytical methods, FEM and experimental results are analysed and concluded.

2. Analytical Evaluations

Finite Element Analysis on FRP pultruded sections were carried out on the members in 3-Dimensional analytical models of full scale panel. A general purpose finite element program MSC/Marc has been used to analyse the buckling behavior and also to predict the ultimate member capacity of FRP pultruded sections. The analytical models generated for studying the buckling behavior of FRP pultruded sections are given in Table-1. 3-D Finite Element model was developed to examine the structural behaviour of the FRP tower panel. The SOLID46 3-D structural solid element (Eight noded element having six degrees of freedom at each node) was used to represent FRP materials. The material properties of FRP pultruded sections are considered from the data obtained from tensile test coupons, typical stress-strain curve is shown in Figure 1. Full scale 3-D FRP tower panel of dimension 1.0 x 1.0 m at base and top and 2.0 m height was analysed. The FE model was analysed for the load case, one to simulate the normal service condition of transmission line towers. The panel was analysed for fixed base condition and hence bottom nodes were arrested for translation and rotational degrees of freedom in all direction.

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Member Details</th>
<th>Section size ( mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Leg member</td>
<td>20 x70 x 2000</td>
</tr>
<tr>
<td>2.</td>
<td>Bracing member</td>
<td>50x50x6 x 2000</td>
</tr>
<tr>
<td>3.</td>
<td>Bracing member</td>
<td>Ø30x2000</td>
</tr>
</tbody>
</table>

Figure 1: Stress Vs. Strain behaviour of tensile test coupon
A linear elastic buckling analysis was performed on the Finite Element model of full scale panel to predict the ultimate load capacity. The displacement contours for all these members and deflected shape of the 3-D FRP panel are shown in Figure 2. The buckling load predicted as per the FE analysis of FRP panel is 122 kN.

Figure 2a: Displacement contours  Figure 2b: Displacement contours under buckling

3. Experimental Evaluation of FRP tower panels

3.1 Normal load condition

Transmission line towers are generally designed for environmental and climatic loads. The self-weight of the conductors and associated hardware components act in the direction of gravity (vertical loads). The wind loads on conductors and tower structure acts in horizontal direction (transverse loads). Transmission line towers are normally subjected to these loads throughout the life span of the structure and hence this combination of load is referred as Normal load condition. Hence, the normal load case is a combination of vertical load and transverse loads. This condition is simulated with loads at the top four corners of the panel in the horizontal and the vertical directions of equal magnitude as shown in Figure 3.

Figure 3: Normal condition load distribution
A typical 3-Dimensional X-braced panel of dimension 1.0 m x 1.0 m base width at the bottom and top with a height of 2.0 m was fabricated and tested up to ultimate loads. The sizes were chosen to simulate an actual panel at the normal tower level of a transmission line tower. Two panels were tested one with solid rod of Ø 30 mm as diagonal bracing and horizontal bracing, 20x70 mm solid rectangle section for leg members and other with 50x50x6 mm angle section for diagonal and horizontal bracing, 20x70 mm solid rectangle section for leg members. The bracing members are connected with leg member through M12 bolts (8.8 grade) at each end. The end clamps of leg members are attached with adhesive bonding and riveting. The FRP panels were instrumented with 16 Nos. of strain gauges installed on the leg members and bracing are shown in Figure 4.

Figure 4a: Strain gauge locations
Figure 4b: Strain gauge bonding

4. Load application system

Figure 5 shows the schematic diagram of the test set up and control system arrangement for the application of the loads in transverse and vertical directions on a full scale FRP panel. The strain gauges were mounted at critical locations on the leg and bracing members for the behaviour of structure under loading, the load cells and strain gauges were connected to the data acquisition system where the load to be applied to a structure under test and corresponding strain in each channel can be monitored. Initially the load slip tests were conducted on both the panels by loading them up to 25 % of ultimate load for three cycles. Then the actual test was conducted with load increments of 5% of the ultimate load. The overall lateral deflections of the top of the panel were monitored continuously using LVDT displacement transducer is attached at the top of panel in each stages of loading like 25 %, 50%, 75% & 100 % of ultimate load. The panel has been loaded in steps within the linear range for normal load conditions. The panel was subjected to a normal load 20 kN of transverse load and 12.75 kN of vertical load. The strain variations in the members and lateral deflections of the panel were recorded using data acquisition system automatically. The panel was loaded further up to failure to obtain the ultimate load carrying capacity of the panel. The panel withstood up to 25.5 kN of transverse load and 16 kN of vertical load. While increasing the load, the bolts got sheared at the joint between leg member and bracing at the bottom of the panel.
5. Discussion of results and conclusion

From the table-2, comparing the finite element analysis results with experimental results the member stresses of leg members in full scale panel are within the margin of 15% (compression) & 10% (tension) and bracings are within 16%. The overall deflection at the top of panel from FE Analysis is 16.4 mm and from experiment is 11.2 mm. The load versus axial shortening and axial deformation behaviour for the leg and bracing members were tested. The strain variations of the leg member and bracing member showed that, the strain variations are linear up to ultimate load, irrespective of whether it is in tension or in compression.

In this paper a comprehensive analytical and experimental program for the analysis and design of pultruded FRP structural profiles to be used as an alternate material for rolled steel angle sections in transmission line towers are investigated. The analysis is limited to linear-elastic response including buckling considerations. The experimental study discussed in this paper includes three type of FRP sections used in the full scale panel predicts the deflections and strains are in close agreement with the experimental results and finite element analysis with MSC/Marc. The buckling mode of full scale panel is in close agreement with experiment and FE analysis. The result of this study indicate that the building of power
transmission line tower structure with FRP pultruded structural sections with suitable joining technique is feasible.

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