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Structural Assessment of Fiber-reinforced Polymer Composite Electric Poles

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Abstract

Engineers are increasingly tasked with designing and operating structures that incorporate the philosophy of resiliency across a variety of critical infrastructure sectors. Electric distribution and transmission systems are examples of the critical infrastructure sectors. The majority of existing electrical poles supporting electric distribution systems in the United States are made out of wood. It is estimated that up to 3.6 million existing electric wood poles have to be replaced every year. One of the primary hardening strategies is upgrading wooden electric poles and supporting structures with stronger materials that withstand hurricane-force winds. This paper presents finite element analysis of fiber-reinforced polymer composite poles including parametric studies on geometric characteristics, fiber orientation, number of layers, and lamina thickness.

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Keywords: Fiber-reinforced polymers; Finite element analysis; FRP poles; Shell elements

1. Introduction

In the face of frequent natural and man-made disasters, engineers are increasingly tasked with designing and operating structures that incorporate the philosophy of resiliency across a variety of critical infrastructure sectors. Electric distribution and transmission systems are one example of the critical infrastructure sectors. A recent report on economic benefits of increasing electric grid resilience to weather outages estimates that the US economy lost $18 billion to $33 billion annually during 2003-2012, and identifies several strategies to increase the nation's electric grid resiliency [1]. The majority of existing electrical poles supporting electric distribution systems in the United States are made out of wood. It is estimated that up to 3.6 million existing electric wood poles have to be replaced every year. One of the primary hardening strategies identified is upgrading wooden electric poles and supporting structures with stronger materials that withstand hurricane-force winds [2].

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The strategy of upgrading wooden poles includes FRP strengthening of existing wood poles or installing new poles made from alternative and relatively new materials, such as fiber-reinforced polymers (FRP) composite poles. For example, Saafi and Asa [3] investigated the feasibility of in-situ FRP strengthening system to repair and extend the service life of damaged wooden poles. They proposed an in-situ “wet layup FRP” method using epoxy impregnated E-glass jacket consisting of four layers and concluded that using the FRP wraps extends the service life of damaged wood poles by 25 years. In addition to strengthening of wood poles with FRP, poles completely made out FRP are gaining popularity. In fact, the global FRP pole market is expected to grow at a compounded annual growth rate of 8.9% during 2014-2019 [4]. The use FRP poles is on the increase because they are light weight, offer corrosion resistance properties, can be tailored to satisfy specific strength and deflection requirement, and have low cost of construction and maintenance. FRP poles can also be used in places where poles of other materials face problems, such as coastal areas where salinity may be detrimental, and areas with high temperature fluctuation.

Fouad and Mullinax [5] presented an overview on the use of fiber reinforced composite poles for electric distribution lines. They provided a rationale why FRP poles are advantageous when compared to wood, steel and concrete. The main reasons include easy installation, high strength, smooth texture, high electric insulation properties and economical cost in terms of installation. They discussed the lack of national standards for FRP utility poles, but pointed out related standards for FRP poles used in highways signs and street lighting. Oliphant [6] discussed the potential confusion that occurs when standards attempt to use “equivalent wood class” poles when using non-wood structural material such as FRP poles. He highlighted that careful consideration should be given to limit deflection and stresses when treating FRP poles as an “equivalent class wood” pole. In the past two decades, a number of researchers performed static and dynamic analyses to study different behaviors of FRP poles such as ovalization, buckling, bending and flexure. Ibrahim and Polyzois [7] investigated the ovalization behavior of tapered FRP poles subjected to bending. They proposed two design methods for computing the critical ovalization load based on the critical moment that can be carried by the pole and the position in which maximum ovalization occurs. They concluded that both methods correlate very well and the proposed models can be used efficiently to calculate the FRP critical ovalization load.

Desai and Yuan [8] presented a numerical model to study the buckling and bending behavior of FRP utility poles. They studied the effect of section variables, including rigidity length ratio (a/l) defined as the length of the bottom portion of the pole section to the overall length of pole, moment of inertia ratio (IT/IB) capturing the change in cross section of upper and lower portion of pole, and the overall pole length. They concluded that the rigidity length ratio has little effect on the buckling of poles that are taller than 9.14 m (30 ft) and they showed that the moment of inertia ratio between the top and the bottom sections of the FRP poles had a significant effect on the buckling behavior. In addition, they concluded that the buckling load of carbon FRP poles was 175% higher than glass FRP poles with the rigidity length ratio having a major influence on the bending stress of the poles. Masmoudi et al. [9] investigated the deflection and bending strength of glass fiber reinforced polymer poles fabricated by filament winding with service openings (holes) using a 3-D non-linear finite element analysis. They proposed a new design with optimized number and thickness of longitudinal and circumferential layers, fiber orientation and stacking sequence of layers. Their new design was shown to provide excellent results. The finite element analysis results predicted failure and flexural behavior of poles very well when compared with experimental results.

Khalili and Saboori [10] used a combination of beam finite element formulation and time integration methods to investigate the transient dynamic analysis of tapered fiber reinforced polymer transmission poles. They studied thin walled circular cross-sections that are subjected to dynamic cable tension and vehicle impact. Transmission poles under step, triangular and sine pulses have been evaluated considering the effect of fiber type, fiber orientation, pole geometry and concentrated mass at the pole tip. They found that the maximum deflection of the pole tip is the greatest for the step pulse force followed by the sine and triangular pulses respectively. They concluded that increasing fiber orientation with respect to pole axis and decreasing top diameter with respect to base diameter increases the amplitude of deflection history of the pole tip. Furthermore, they showed that using tougher fibers at the inner and the outer laminas of the pole cross-section decreases the tip deflection significantly. Saboori and Khalili [11] presented a linear static analysis of FRP transmission poles. They investigated the behavior of the poles using a second-order shell finite element model considering the effect of various parameters such as fiber orientation and type, volume fraction, and number of layers and geometry. They developed a computer code in MATHEMATICA for conducting their analysis and verified their findings partly with ANSYS and partly with a