Structural Simulation Laboratory
The University of Texas at Arlington

The University of Texas at Arlington
Department of Civil and Environmental Engineering

Project Summary Report 0-4470-S

Project 0-4470: Development of Design Criteria for CCTV Camera Poles

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PROJECT SUMMARY REPORT

Background

In recent years there has been a considerable increase in the use of tapered steel and fiber reinforced polymer (FRP) poles in structural engineering applications. This increase is primarily due to these materials' superior material properties such as light weight and corrosion resistance. One of the applications of steel and FRP hollow poles is in poles supporting closed circuit television (CCTV) cameras. These poles are commonly installed on interstate highways and bridges, which are among the key parts of an intelligent transportation system (ITS). Many states have begun to use CCTV cameras to aid in the efficiency of their respective highway systems. These camera systems would make it possible for the departments of transportation to capture related information for viewing in transportation management centers where this information can be shared with both the public and private sectors in order to increase the mobility, safety, and efficiency of the transportation system.

Steel poles are most commonly used by departments of transportation in general and by the Texas Department of Transportation (TxDOT) in particular. California Department of Transportation has recently installed several FRP poles on its infrastructure at different locations.

The need for understanding the stiffness and strength of steel and FRP poles has gained immense popularity among transportation officials, construction industry, and consumers due to the importance of these poles for stabilization of the images transmitted by the cameras. Wind-induced deformation of each pole is a function of the pole's geometric variables and loading, which vary immensely for different regions and applications. For example, commonly used tapered poles' height may vary from 20 ft (6.1 m) to 65 ft (19.8 m) depending on the applications, which in turn would cause variation of other parameters such as the base diameter, top diameter, pole thickness, end-plate thickness, bolt diameter, etc. Also, the wind loads vary in different regions, and vibrations caused by vehicle traffic would affect poles' deflections and ultimately the images transmitted by the cameras.

Currently, there are no general design specifications and guidelines for the camera poles. In particular, the load deformation behavior of the camera poles due to large deformation effects (geometric nonlinearities) is not known. Thus, the available information on the stiffness and strength characteristics of the poles has been under scrutiny, and the need for an in-depth investigation has been recognized by the Texas Department of Transportation.

What We Did

Several full-scale tests on steel and FRP poles were conducted and their load deflection characteristics were obtained incrementally. Test setup was designed to mimic the actual field conditions, in which the test pole was welded to the end-plate that was bolted to the concrete base, which was bolted to the laboratory reaction floor. Instrumentation consisted of a load cylinder, load cell, wire potentiometer, and digital data acquisition system. A pseudo-cyclic loading history was applied to each test pole until failure and the load versus tip deflection plots were obtained.

The failure mode for all the test specimens was determined to be excessive deflection. However, yielding of end-plate for steel poles and superficial cracks at early loading for FRP poles were observed.

Figure 1 Photographs of Failed Samples from Tests

A comprehensive finite element model (FEM) was developed using three-dimensional isoparametric solid elements, which included algorithms for contact, geometric, and material nonlinearities during the stress analysis. Since a plane of symmetry existed along a section through the longitudinal axis of the pole, one-half of the pole and its connection assembly were modeled. Three-dimensional solid elements were used to model the entire pole, end-plate, bolt assemblage, and concrete base. Thin shell elements were intentionally avoided due to their known vulnerability to membrane and shear locking. Bilinear stress-strain curves were used for steel and FRP. Transversely isotropic behavior of FRP pole was considered and the equivalent modulus was obtained for the analysis. Due to nonlinear system equation behavior, the full Newton-Raphson iteration was adopted and the converged solution was obtained by using Hilbert energy L-2 norm.

What We Found

The FEM-produced load-deflection plots indicated close correlation with the experimental results for most regions of loading. The maximum differences between the FEM and experimental results for steel poles ranged from 1.2% to 2.5%. Also, the maximum differences between FEM and experimental results for FRP poles were 2.3% to 3.7% and 1.2% to 1.9% for stresses and strains, respectively. To further verify the developed models, the geometric variables were varied one at a time while other geometric and force-related variables were kept constant at their intermediate values. The load-deflection plots showed that FEM models followed the trend that agrees with engineering intuition.

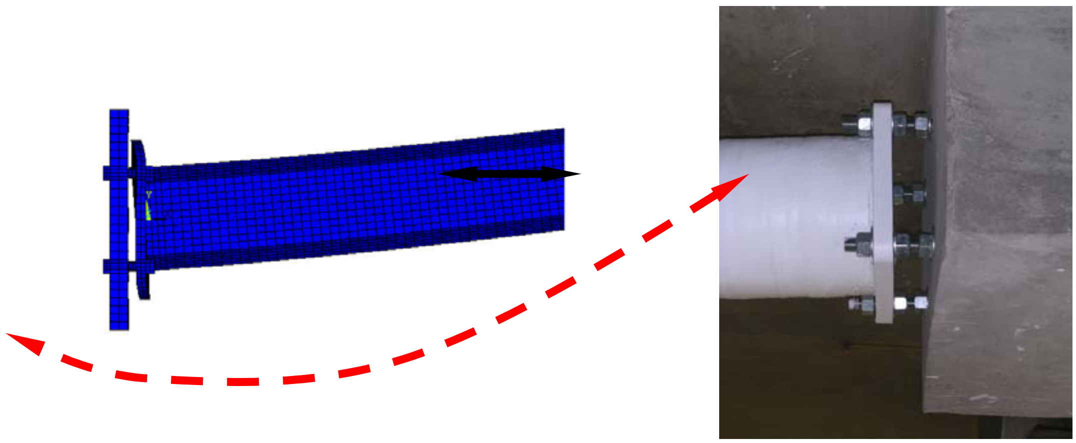
The verified FEM models were used to conduct a parametric study using several test cases in order to develop regression equations for the parameters of the three-parameter model equation as functions of poles' geometric and force-related variables. The three-parameter mathematical equation was identified to represent the behavior of the poles most accurately. The dependent variables were the parameters of the three-parameter model equations: ultimate load; reference plastic deflection; and rigidity. The independent variables were the geometric and force-related variables of the steel and FRP poles including pole length, thickness, yield stress, etc.

To validate the developed equations, error band and sensitivity analyses were conducted to determine the range of error and the behavior of each equation, respectively. The load deflection equations for both steel and FRP poles were presented to TxDOT as functions of both geometric and force-related variables.

The Researchers Recommend

Based on the experimental and analytical studies conducted on steel and FRP poles, the following should be considered:

- The developed equations are valid within the range of variations of the geometric and force-related variables used during their development. This range of variations was mostly determined with respect to TxDOT needs.
- Due to superficial cracks developed in the FRP test specimens at an early stage of loadings during the experimental testing, it is recommended that for now TxDOT use steel camera poles. Justifications for using FRP poles require a separate comprehensive research study in order to investigate different FRP poles from different manufacturers with versatile fiber orientations.



(a) Deformed FEM Pole　　(b) Deformed Experimental Pole

(c) Full Model　　(d) Half Model

Figure 2 Finite Element Models of the CCTV Poles

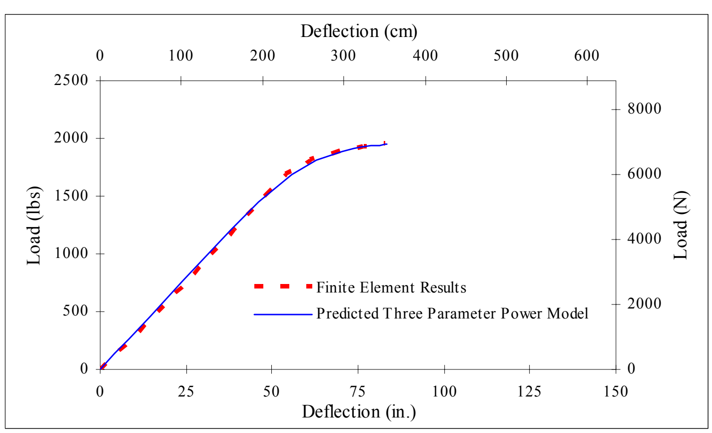


Figure 3 Typical Prediction Equation Behavior Compared to FEM

For More Details

This research is documented in Report 0-4470-2, Development of Design Criteria for CCTV Camera Poles.
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