

# Mechanical behavior of electrical hollow composite post insulators: Experimental and analytical study



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## ABSTRACT

Electrical post insulators are important components of electrical substations since any type of failure in such insulators leads to the breakdown of the local network. Although the electrical substations are often in service condition, any horizontal excitation due to the earthquake, or any extreme event, may cause lateral deformation and damage to the post insulators. Hollow composite post insulators, a new and evolving technology, have a very complex mechanical behavior due to their materials and connections. To date, the design of such post insulators has been based on the limited test results available in the literature. Most of experiments have been conducted on small-scale specimens focusing on the elastic response. This study presents a series of experiments conducted on a full-scale electrical hollow composite post insulator to investigate the static and dynamic mechanical behaviors, while a computational model is derived. The test series comprise, pull and cyclic quasi-static tests in addition to impact hammer tests, to assess the mechanical behavior of the insulators subjected to the lateral forces at different stages of damage. The key experimental results include the pre-peak force–displacement relationship, the cyclic response, the stiffness and strength deteriorations, and failure modes. The modal frequencies and the corresponding viscous damping ratios for the undamaged and damaged post insulator are calculated using the results of impact hammer tests. An analytical model is derived from the mechanical behavior to simulate the response of the un-damaged and damaged post insulator, and is verified by the test results.

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## 1. Introduction and background

Electric power supply is recognized as one of the most important services after an earthquake. A survey of 200 hospital employee including doctors and administrative personnel revealed that the power supply has the first priority after an extreme event [1]. Despite this fact, observations from past earthquakes show that electrical systems are among the least reliable services [1–4]. For example, after the Kocaeli (Turkey) earthquake in 1999 [1], Kobe (Japan) earthquake in 1995 [2–4], and Northridge (USA) earthquake in 1994 [2] most of the hospitals were not fed for few days. The damage to electrical equipment by Loma Prieta and Northridge earthquakes resulted in more than \$200 million worth of losses [5]. In the last twenty years, many studies have tried to raise reliability of the electrical power systems either in urban level [6,7] or by studying the seismic behavior of its components [8–12].

An electric substation consists of several parts such as, electrical transformers, bushings, and insulators. The voltage level continuously varies during the generation, transmission and distribution of electric energy. The electrical transformer is used to pass from medium voltage of the generation to the high voltage of transmission and back to the low voltage for distribution. Insulators are used to separate electrically metal parts with different voltage levels to avoid short-circuits and breakdown in the network.

Although insulators have been used for decades, the introduction of *composite hollow-core* insulators is relatively new and the technology is evolving [13–18]. Like other structural systems, earthquake-excitation is one type of loading that can cause severe damages to the insulators. Under seismic loads, insulators can be subjected to substantial lateral (“cantilever”) loads, simultaneously with complex axial compression and tension loads. Reinhorn et al. [19] tested hollow-core insulators to investigate the behavior of tube-flange connection and its failure modes. They conducted two types of tests: (1) pull tests using a series of loads with increasing magnitude, and (2) snap-back test performed after each pull load test. The cyclic response of insulators was not addressed in their study, which reported three major types of

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failures, namely cracking of the lower flange, failure of the bond between the flange and the tube, and the failure of the tube adjacent to the bonding material in the flange [20]. On the basis of these test results, it was shown that the Specified Mechanical Load (SML), which is the lateral load capacity corresponding to the flexural strength of the insulator and was assumed as 2.5 times the maximum mechanical load specified by the manufacturer, was much lower than the cantilever failure load measured from the tests. Roh et al. [21] and Cimellaro et al. [22] developed analytical models aimed to predict the response of insulator at different stages of the damage, using linear and nonlinear springs, viscous and frictional dampers, and inertial mass.

Due to the lack of information associated to the mechanical behavior of the column insulators in sustained dynamic motion, this paper addresses the static and dynamic characteristics of the column insulators through an organized test series. Results obtained from the pull, cyclic, and impact hammer tests are presented. An elaborated analytical model is proposed to simulate the structural response of the column insulator at different stages of the damage. The performance of the developed analytical model is compared to test data.

## 2. Experimental program

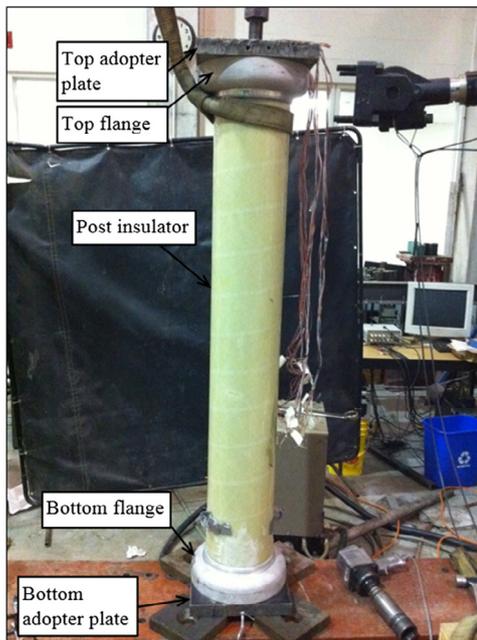
A full-scale electrical hollow composite post insulator was tested under a set of force-controlled (pull) loading and a

displacement-controlled cyclic loading at the Structural Engineering and Earthquake Simulation Laboratory (SEESL) at University at Buffalo. The following sub-sections of the paper describe the testing program and present key experimental results.

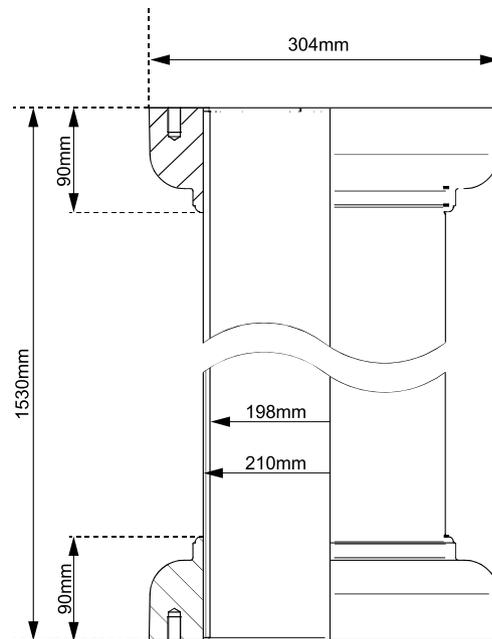
### 2.1. Test specimen description

The specimen consisted of a 6-mm thick tube of fiber glass reinforced polymer and metal caps at both ends of the tube (see Fig. 1). The tube was connected to the metal caps using a bonding material between the tube and metal caps. The height of the specimen was 1530 mm with the exterior and interior diameters of 210 mm and 198 mm, respectively. The mass of the tube and each metal cap was 35 kg and 6.8 kg, respectively.

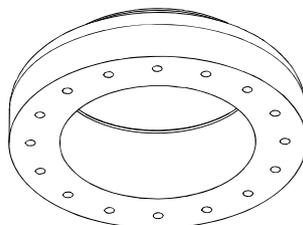
Fig. 2 presents the details of the connection between the specimen and test frame. The bottom flange of the specimen was connected to a 38-mm thick steel plate using 16 number equally spaced M12 bolts. Two bottom adopter plates (see Fig. 2(c) and (e)) were secured to the steel beam support using 4 number M 25 headed bolts. The top tube flange was connected to the top adopter plate using 12 number M12 bolts. A 26-mm diameter threaded stud attached to the center of the top adopter plate was used to connect the actuator to the top of the post insulator. The locations of the adopter steel plates at the top and bottom connections are presented in Fig. 3. It should be noted that the post insulator was attached to a rigid base using typical connections used in



(a) Specimen



(b) Elevation view of the specimen



(c) Top and bottom flanges

Fig. 1. Test specimen.

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