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Seismic vulnerability assessment of a high voltage disconnect switch

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ABSTRACT

This paper deals with the seismic vulnerability of high voltage equipment typically installed in electric substations. In particular, the seismic response of a 380 kV vertical disconnect switch has been investigated based on the results of an experimental campaign carried out at Roma Tre University. According to a series of non-linear analyses, the influence of the most significant parameters on the seismic behavior of this apparatus has been analyzed and the corresponding fragility curves have been evaluated by using the Effective Fragility Analysis method. The results showed a limited vulnerability of the disconnect switch, whose most critical parts are the bottom joint of the ceramic support column and the steel column base.

1. Introduction

The seismic vulnerability of High Voltage (HV) equipment installed in electric substations within power transportation and distribution networks has been clearly shown during recent destructive earthquakes [1–4]. This is not surprising because many of these equipment are slender, with heavy masses placed at top and mostly composed by porcelain, a material with a good strength but extremely brittle.

Consequences of the failure of HV electric substation components are usually less important than the collapse of civil constructions, as buildings, bridges, etc., given that people injuries are unlikely. Nevertheless, indirect consequences might be important as well; for example, a blackout extended to the most struck zone could hamper the rescue operations, making hospitals and any other reception structure inefficient. In addition, economic losses could be particularly important. For this reason, different institutions, electric societies and the civil protection have often stimulated the interest of researchers on this topic, funding research programs devoted to a preemptive assessment of electric failure caused by a seismic event [5,6], and to strategies for reducing the consequent risk [7,8].

A realistic evaluation of the seismic risk of HV electrical equipment requires an accurate estimation of the fragility curves of its most vulnerable elements, which are mainly made of porcelain (circuit breakers, TA and TV current transformers, switchers, etc.), [9]. In the past, the National Italian Electric Authority (ENEL) carried out an experimental campaign on some of these apparatuses, [10], showing their high vulnerability; more recently, in California, a wide analytical and experimental campaign on the seismic response of electrical substation equipment has been performed, in which many aspects, including the fragility curves evaluation of a disconnect switch have been treated, [11,12]. Very recently the hybrid simulation technique has been applied to a disconnect switch for the evaluation of its seismic response, [13,14].

Given the scarce information available in literature on this topic, an important experimental activity has been carried out at the laboratory of Material and Structures of Roma Tre University, on similar HV components (i.e. electrical insulators, electrical breakers and TA transformers), typically employed in Italian substations. They are essentially made of slender ceramic elements connected through steel flange joints and welded to the ceramic parts with a special binder (e.g. sulfur or fiber-reinforced mortar). Because the nature of the binder can highly affect the mechanical behavior of the apparatus, the objectives of this test campaign, besides the evaluation of the mechanical properties of the ceramic

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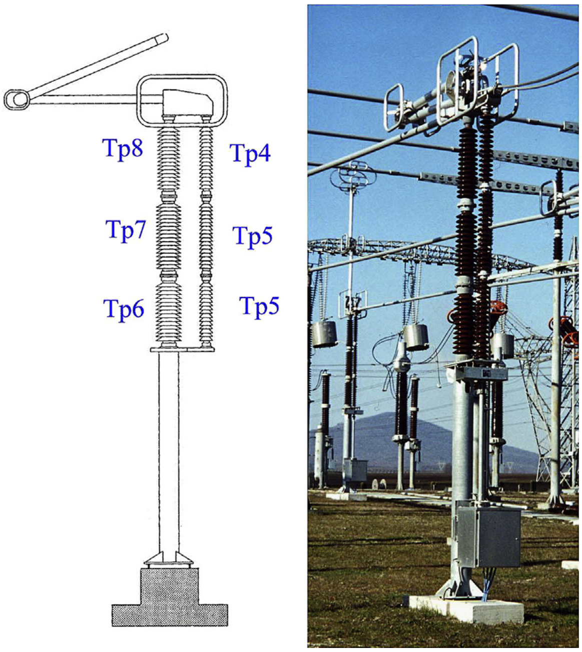

Fig. 1. Sketch and picture of the HV disconnect switch.

material and single elements, included also the evaluation of the cyclic behavior of flange joints [15].

In this paper the mechanical characterization of all components of a 380 kV vertical disconnect switch is described, (Fig. 1). This apparatus, whose function is to connect or disconnect the line bars of an electric substation, is composed by six ceramic elements connected to the steel bars through a mobile arm and it is sustained by a steel column placed on a small reinforced concrete foundation. The tests have been performed on ceramic elements of the main and maneuver column.

The above results have been used to calibrate a simplified numerical model in OpenSEES, a well know platform for non-linear simulations of the seismic response of structure [16]. It has been used for the simulation of the seismic behavior of the disconnect switch and the evaluation of its fragility curves by using the Effective Fragility Analysis method [17].

2. Experimental analysis of the disconnect switch components

This section deals with the experimental tests performed on the main components of the disconnect switch of Fig. 1. The tests were conducted in static regime on full-scale ceramic elements and were carried out imposing monotonically and cyclically displacement histories at their top with increasing amplitude, until the failure ceramic or joints was attained. The main objective of the experimentation was the evaluation of the mechanical properties of the porcelain (strength and elastic modulus) and the evaluation of deformability and strength of the flange joints.

2.1. Typology of tested elements

Table 1
Geometrical characteristics of the disconnect switch components.

Element	Lenght (L) [cm]	Diameter (D) [cm]	Weight [kg]
TP4	105	7.50	32.8
TP5	115	7.50	35.8
TP6	105	17.5	127
TP7	108	15.2	103
TP8	122	12.8	83
Support column	300	27.3/6.3	120
Pantograph	4.6/2.3	–	230

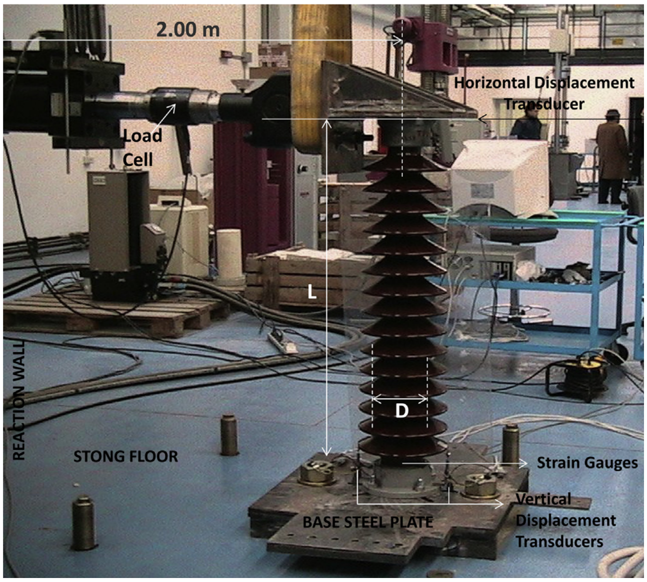

Fig. 2. Test Setup.

The disconnect switch is composed by two insulating columns connected by steel flange joints. The support column is composed of ceramic elements termed in the following as TP6, TP7 and TP8, whereas the other elements, components of the maneuver columns, are indicated as TP4 and TP5, (see Fig. 1). Both the columns are connected at the top to an aluminum pantograph. Finally, a tubular steel column, connected to the concrete foundation by anchor bolts, sustains the entire apparatus. The connection/disconnection mechanism of the switch is obtained by rotating the maneuver column. The characteristics of the single elements are reported in Table 1.

2.2. Test setup

The test setup is shown in Fig. 2. A 250 kN oleodynamic actuator with a stroke of 250 mm has been used to impose the displacements at the top of the specimen. The actuator is connected to a reaction wall through a $100 \times 100\ \text{cm}^2$ ribbed steel plate, and to the specimen by a special steel joint in order to maintain the applied displacement in the horizontal plane. Moreover, the ceramic element is fixed to the strong floor by a steel plate $100 \times 60\ \text{cm}^2$ with thickness of 50 mm, in order to guarantee a high stiffness.

The acquisition system used during the test is composed by a 250 kN load cell to measure the reaction force transmitted to the reaction wall, a wire LVDT to measure the imposed displacements at the top of the specimen, two LVDTs placed at the base of the ceramic column to acquire the vertical deformations of the ceramic element and consequently the relevant rotation, and two strain gauges at the bottom section of the ceramic element for the local deformation of the porcelain.

2.3. Testing program

The test consists essentially in static displacement histories, monotonically imposed at the top of the specimen until the failure occurs; the aim of the experiment is to determine both the stiffness and the strength of ceramic elements; the mechanical