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Shake table tests of steel towers supporting extremely long-span electricity transmission lines under spatially correlated ground motions

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ABSTRACT

Transmission lines from electricity transmission systems crossing wide rivers or canyons can have much longer spans (e.g. longer than 1000 m) compared with components from conventional civil structures. Steel towers supporting such extremely long-span transmission lines are unavoidably subjected to spatially correlated ground motions together with the coupling action between supporting towers and transmission lines. However, the influence of spatial variation of ground motions is not considered in current seismic design of the towers supporting extremely long-span transmission lines. This research was focused on an electricity transmission system crossing the 2nd longest river in China (which is also the 5th longest river in the world) to address the influence of spatial variation of ground motions on seismic response of the towers supporting extremely long-span transmission lines. A reduced-scale experimental model of the prototype was tested using shake tables. Spatially correlated ground motions generated taking into account the wave passage effect, the effect of coherency loss and the effect of local site conditions were used as inputs of the shake table tests. It was found that the spatially correlated ground motions can significantly amplify tower responses and such an effect should not be neglected in seismic analysis and design. Based on the test database, an empirical model was proposed to modify the acceleration response, member stress response and top displacement responses of the towers supporting extremely long-span transmission lines from uniform ground motions as conservative estimates of responses of the system under spatially correlated ground motions with the same magnitude.

1. Introduction

An electricity transmission system typically consists of a group of steel lattice towers supporting transmission lines (i.e., conductors and ground wires) that distribute electricity from a power plant to electrical substations. Due to the dependencies of our modern life upon electricity, electricity transmission systems are required to cover almost all kinds of regions (unavoidably, the areas with seismicity). Different from most building structures that are excited by uniform excitations in earthquakes, electricity transmission systems are more likely to be excited by the spatially varying ground motions during an earthquake event since they typically extend over a large region.

Although research efforts have been made to develop improved models to quantify the influence of spatially varying ground motions on seismic response of civil structures [1–16], spatial variation of ground motions has not been considered in seismic design of supporting towers of electricity transmission systems. To date, very limited research, particularly experimental work, has been completed for electricity transmission system. A recent shake table test revealed that spatially varying ground motions can cause larger dynamic responses in the supporting towers of a transmission system as compared with the uniform ground motions with the same magnitude [17]. However, it should be recognized that the experimental model adopted in that test only represented the "ordinary" electricity transmission systems (which have constant spans of transmission lines up to 400 m along the system). It is unclear whether the data trend observed from that investigation remains valid in the supporting towers of an extremely long-span electricity transmission system. Note that extremely long-span transmission lines (which can be longer than 1000 m) are necessary when the systems cross wide rivers or valleys.

The supporting towers in extremely long-span electricity transmission systems deserve more attention from the seismic analysis perspective compared with these from the "ordinary" electricity transmission systems primarily for three reasons. First, the towers

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supporting extremely long-span transmission lines have much larger tributary gravity loads and reactive masses from the long-span transmission lines. Additionally, a minimum vertical clearance below transmission lines is usually required for safety. To meet the clearance requirement, the supporting towers in extremely long-span electricity transmission systems have to be much taller. Furthermore, the ground motions at the bases of the supporting towers tend to vary more significantly when the transmission lines span longer. Therefore, there is an urgent research need in investigating the influence of spatial variation of ground motions on response of supporting towers of extremely long-span transmission lines.

Focusing on the abovementioned critical knowledge gap, this research team experimentally addressed the influence of spatial variation of ground motions on responses of the towers supporting extremely long-span electricity transmission systems. Specifically, an experimental model representing a prototype consisting of three spans of transmission lines and four supporting towers were constructed and tested using shake tables. The test results obtained from this research help generate a database to demonstrate the influence of spatially varying ground motions on seismic responses of supporting towers and improve seismic design of the long-span electricity transmission lines. The following sections describe basic information of the prototype, design and construction of the experimental model, development of spatially correlated ground motions, test setup, instrumentation, interpretation and discussion of the test results, and synthesis of design recommendations.

2. Selection of prototype

As this investigation was focused on the supporting towers in extremely long-span electricity transmission systems, the prototype was selected among the systems with the transmission lines longer than 1000 m. Moreover, selection of the prototype was made from the systems over seismic regions and designed according to recent design guidelines. Further, for development of the experimental model, the prototype was identified among the candidate systems having detailed design information readily available.

As a result, a 220 kV electricity transmission system in Shandong Province, China, was selected. The entire system extends about 58.4 km and was designed for the seismic hazard having a probability of exceedance of 10% in 50 years. The corresponding Peak Ground Acceleration (PGA) considered in the original design was 0.2 g. Given that it is impossible to consider the entire transmission system in shake table tests, only one segment of the system consisting of three spans of transmission lines and four supporting towers was targeted as the prototype in this investigation.

Fig. 1 illustrates the prototype. As shown, the prototype includes three spans of transmission lines (which are 294 m, 1118 m and 285 m, respectively). The interior span of the prototype (i.e., designated as Span 2 in Fig. 1) is the longest and it actually crosses the Yellow River (which is the 2nd longest river in China and also the 5th longest river in the world). In addition, the prototype consists of four towers designated as Towers 1–4 in Fig. 1. Towers 1 and 4 have the same member configuration as SDF5A while member configuration of Towers 2 and 3 is categorized as SKT12 according to *the Rules of Nomenclature for Transmission Poles and Towers* [18]. Compared with Towers 1 and 4, Towers 2 and 3 are much taller and they support the extremely long-span transmission lines. Therefore, the research team focused on Towers 2 and 3 in development of the experimental model and instrumentation.

Fig. 2 shows elevation of the supporting towers. As shown, Towers 2 and 3 consist of two crossarms at the elevations of 102 m and 112.5 m, respectively. Two ground wires are supported at the top of each tower. The upper and lower crossarms support two and four conductor lines, respectively. The ground wires and dual-core conductor lines are OPGW-180 and LHBGJ-400/95, respectively. Table 1 lists properties of the ground wires and conductor lines. All the supporting towers in the prototype are made of Q235 or Q345 steel tubes. Note that the nominal yield strengths of Q235 and Q345 steel are 235 MPa and 345 MPa, respectively. Detailed information about sizes of the components in the towers is presented elsewhere [19].

3. Design and construction of experimental model

The experimental model was tested at the laboratory of Central South University of China. The laboratory has an array of three identical 6-DOF shake tables for tests of long-span structures subjected to multiple-point excitations. Each table has a payload of 30 ton, the size of 4 m × 4 m, the maximum stroke of 250 mm, the maximum velocity of 1 m/s, the output frequency ranging from 0.1 Hz to 50 Hz and the output acceleration up to 1.0 g along the horizontal directions. When aligned along the same direction, adjacent tables can be spaced up to 50 m. Moreover, the laboratory can only accommodate specimens up to 15 m high.

Considering the abovementioned constraints, the research team decided to adopt a reduced-scale experimental model for the prototype. Given that the prototype includes 4 supporting towers while the laboratory only has three shake tables and also considering this investigation primarily focused on the towers supporting the extremely long-span transmission lines, it was determined to place Towers 2 and 3 of the experimental model on the shake

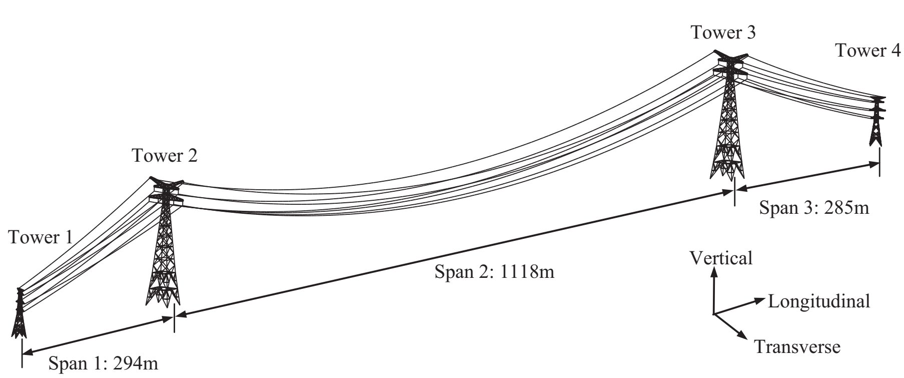

Fig. 1. Sketch of prototype.