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Horizontal and Vertical Vibration Control of The Power Transmission Tower Cable Using Optimal TMDs

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ABSTRACT: Using Tuned Mass Dampers (TMDs) is among the most typical methods for passive control of structures subjected to earthquake excitations. TMDs often reduce the displacement response of structures by influencing their first mode of vibration. The structure of these dampers consists of three main parameters: mass, damping, and stiffness. Since the parameters of TMDs are constant during the vibrations, optimal tuning of these parameters is very important. Finding the optimal values of the key parameters for a TMD in nonlinear structures using numerical methods involves numerous nonlinear dynamic analyses; therefore, the computations would be time-consuming. Recent studies, carried out on the application of the TMDs in the building structures, have mainly focused on reducing the lateral displacements of the building structures. However, in this research, the application of TMDs and their effectiveness were investigated for cables of the power transmission tower in both the lateral and vertical directions simultaneously. In order to numerically study the behavior of the power transmission tower, the structure of the telescopic steel tower was modeled in the OpenSEES software and to reduce the volume of computation, a numerical search method was used to find the optimal values for the parameters of the TMDs to minimize the lateral displacement in the middle of the cable span. The mass ratio of the TMDs was equal to 0.5% of the total mass of the structure. Using this mass ratio, numerical analyses of the system indicated that the maximum reduction of the lateral displacement in the middle of the cable mitigated due to implementing the TMDs is about 50% under the applied earthquakes with 0.5g maximum acceleration.

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1. INTRODUCTION

Today, controlling structural vibration has become a new challenging field for researchers and engineers. Structural damages by the recent earthquakes that caused human and financial losses in different countries highlight the importance of controlling structural vibrations due to earthquakes. As the use of electrical energy is increasing, the permanent power transmission lines are expanding because the main and fundamental energy exchange in global networks is carried out by high-capacity energy transmission lines. Undoubtedly, conductors are the main elements of any energy transmission networks through which the power flow passes.

The dynamic behavior of elastic catenary power cable was studied by Simpson (1966). Simpson aimed to determine the natural frequencies of in-plane vibrations of multi-span power transmission lines [1]. Henghold et al. (1977) studied the 3D-free vibration of the cables. They also provided the experimental formula for calculating the lowest natural frequency [2]. In 1999, the 3D nonlinear static analysis of the cables was reviewed by Daneshjoo using the minimization of the total potential energy and considering instability effects [3]. The parametric study of free vibrations of the sagged cables by Gambhir (1978) can be referred to as another study on cable dynamics [4]. The innovations of this study include the application of curved elements and considering the expansion characteristics of the cables. The curved element used for the analysis of catenary cables was improved in the study of Jayaraman and Knudson (1981), which has better accuracy and performance than previous elements for modeling the cable weight, pre-stressing and use in the nonlinear analysis [5]. Tian et al. (2013) studied the progressive damage analysis of the grid power transmission towers under earthquakes [6]. Other researchers such as Zahrai and Amirzadeh [7], Mohebi and Shabani [8], and Kordi and Alamatian [9], presented some studies on absorbing the energy.

The application of dampers is rarely studied in power transmission lines. One of those few studies belonged to Tian et al. (2013), where the mass damper was installed on the crest of the tower, and the behavior of the tower was reviewed under seismic investigation. In this study, using the numerical search methods, the frequency values and damping of the mass damper connected to power transmission cable were determined in three vibrational directions; vibration of

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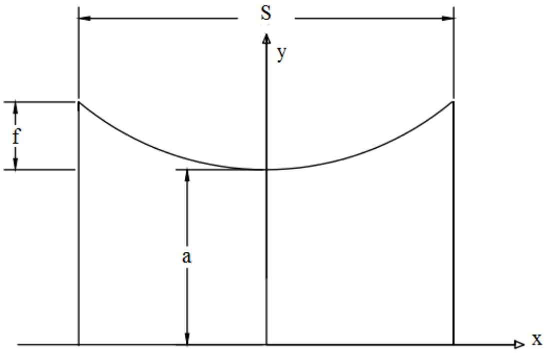

Fig. 1. Cable characteristics between two towers

Table 1. The earthquakes applied to the tower structure.

No.	Earthquake name	Station name	PGA(g)
1	Northridge	Beverly Hill	0.52
2	Northridge	Canyon Country-WLC	0.48
3	Duzce, Turkey	Bolu	0.82
4	Hector Mine	Hector	0.34
5	Imperial Valley	Delta	0.35
6	Imperial Valley	El Centro Array #11	0.38
7	Kobe, Japan	Nishi-Akashi	0.51

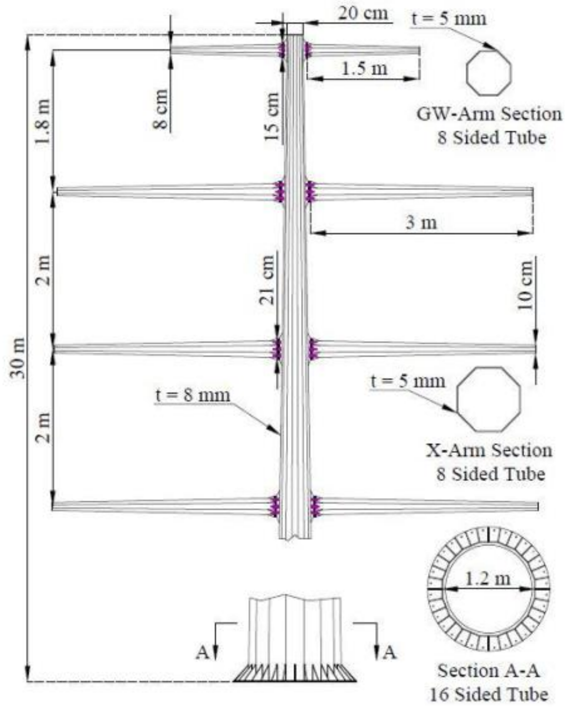

Fig. 2. Power transmission tower model in this study [10]

the power transmission cables was reviewed, and the effect of the dampers installed on the different points of cables, including mid-span and along with one-third of the span, was investigated.

2. RELATIONSHIPS OF POWER TRANSMISSION CABLE CURVE

The power transmission cable curve is a string curve that is completely flexible and hangs from two holding points. It is under a distributed uniform load like its weight. It can be shown that the wire curve (cable) is obtained from Eq. (1):

$$y = a\cosh(\frac{x}{a}) \quad (1)$$

where, a is the wire parameter. Figure 1 indicates the parameters introduced in Eq. (1).

In this study, Eq. (1) was used as the power transmission cable curve.

3. NUMERICAL MODELING OF THE POWER TRANSMISSION TOWER, CABLE, AND THE CONNECTED MASS DAMPER

In this study, the cable modeled in PLS-POLE software was used to investigate the behavior of the tower, the design of which follows the ASCE 48-05 regulations. The geometric characteristics of the designed tower are shown in Figure 2.

The cable model, as well as power transmission towers and TMDs, were modeled in OpenSEES software. The distance between the tower piers is 90m while the length of cable is 100m, which for two spans the model includes three telescopic towers and the power transmission cables.

4. DETERMINING THE OPTIMAL FREQUENCY AND THE DAMPING OF DAMPERS

The numerical search method was used to determine the optimal frequency and damping of dampers. In order to achieve this goal, a connection was made between MATLAB and OpenSEES software, in which calling OpenSEES using MATLAB software creates the cable formed model and the frequency and damping inside the loops of MATLAB program changes so that all the modes were investigated and ultimately an optimum mode was determined. These dampers are able to reduce undesired vibrations of the cables in all three vibrational directions; therefore, they are modeled in all three directions. The damping and frequency values of these mass dampers were 9.4% and 0.08 rps, respectively. The mass of the mass damper was also 0.5% of tower mass.

5. THE EARTHQUAKE RECORDS APPLIED TO THE STRUCTURE

The accelerometers considered for time-history analysis should, as far as possible, have characteristics similar to possible earthquakes in the site (construction site); hence, it is recommended the selected accelerograph features, such as magnitude, distance from the fault, and seismic springs, be similar to the construction site, as much as possible. In this study, the tower structure and the cables in between were under the effect of seven earthquakes, the characteristics of which are indicated in Table 1.

According to the regulations, for time-history analysis, it is necessary for earthquake records to be scaled. In this study, scaling was done on the maximum acceleration of the earthquake, and the incremental dynamic analysis was conducted. The maximum value of earthquake acceleration was in the 0.1g - 1.0g range.

6. CONCLUSION

In this study, TMDs were used to control undesired vibrations of the power transmission tower cables. The numerical search method was used to increase the efficiency of TMDs in their optimal state. Then, the power transmission line was under the effect of seven earthquakes to evaluate the response of the structural system with and without dampers, and the effect of using dampers in reducing vertical and horizontal displacement at mid-span of the cables was investigated.

According to the results, the effect of mass dampers for maximum lower accelerations of the earthquake had good functionality and was able to reduce the responses up to 60 percent. Due to the fact that under maximum lower accelerations, the structure is linear, the frequency of the first mode of the structure did not change and since the dampers are adjusted for frequencies of the first mode of transmission towers and cables, they showed better functionality. However, the structural frequency changed when entering the nonlinear region and the dampers get farther from their optimal adjustment mode leading to less efficiency. Moreover, the Duzce earthquake of Turkey had larger acceleration response spectra than other earthquakes at the equivalent period of the tower system along with its cables and had a greater effect in cable vibrations. The average improvement in behavior under this earthquake using the dampers was 59.6%.

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