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Dynamic rehabilitation of mosque minarets by using a tuned mass damper (TMD)

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ABSTRACT: In this paper, the minaret of Nigde University's mosque is taken as an example structure model in order to rehabilitate the dynamic effects such as earthquake excitations. Kobe earthquake ground motion is used for the time history analysis. A mass which is attached to an elastic bar is located at the top of minaret as a tuned mass damper (TMD). Suitable mass and bar length are main factors for the design of TMD. Quantity of mass is chosen as 35 kg and bar length is selected in the 0.2 m-1.6 m range. Analysis operated by Sap2000 program shows that 1.2 m bar length gives the best performance for these models which is chosen among them. Outcomes exhibit that TMD rehabilitate the dynamic behaviours of mosque minaret model. Accordingly, a TMD can be implemented for tall and slender sectioned buildings for the dynamic rehabilitation.

1 INTRODUCTION

Tuned mass damper (TMD) is a device consisting of a spring, a mass and a dashpot. This device is used for mitigating harmful vibration effects on the structures. It runs in an opposite phase of main mass, so that it absorbs the energy by means of inertial forces. Rana and Soong (1997) showed that the device is effective while its natural frequency is close to excitation frequency. Wu (2000) explained that for various high rise buildings in order to decrease the effectiveness of vibration energy and make the structure more comfortable if TMD systems are used; and also observed that they are successful to reduce the displacement of building.

Hartog and Ormonyard (1928) performed the first theoretical investigation related to tuned mass dampers (TMD's). Hartog (1956) also developed optimum absorber parameters in the book titled "Mechanical Vibrations" which was first published in 1940. In the book, it is emphasized that while tuned mass dampers included same amount of damping, main mass did not involve any damping. Falcon et al. (1967) proposed to optimize the system by adding restricted amount of damping to main mass. Ioi and Ikeda (1978) developed correction factors related to tuned mass dampers (TMD's). Warburton and Ayorinde (1980) tabulated TMD parameters related to significant amount of damping for the mass ratio and main mass damping ratio. Thompson (1981) exhibited optimum TMD parameters depending on frequency. Villaverde and Koyoama (1993) investigated effectiveness of TMD which has a 4.2 % mass ratio located on top of the 10 story building subjected to Mexico City earthquake records. They found that TMD reduced peak building displacement to a 0.40% at the top. Soto-Brito and Ruiz (1999) researched behavior of structures under high density earthquake effect after locating TMD to nonlinear 22 stories building. They found that TMD's are effective to decrease peak response values of structure. Connor (2000) put forwarded that passive TMD's are generally tuned in order to decrease the first mode effect. In order to control the other modes active TMD's are chosen. Pinkaew et al. (2003) investigated the effectiveness of TMD for controlling of structures under the seismic ground motion. They demonstrated that although TMD cannot reduce the peak displacement of controlled structure after yielding, it can significantly reduce damage of the structure. Lee et al. (2006) determined optimal design parameters of TMD's in terms of the damping coefficient and spring constants corresponding to each TMD through minimizing a performance index of structural response defined in frequency domain. Christopoulos et al. (2000) and Takewaki et al. (2009) expressed that seismic reinforcement can be carried out by using many passive control devices. Sgabba et al. (2010) investigated the optimum design of TMD's for the seismic protection of inelastic structures. Their results confirm that the application of a system decreased the amount of hysteretic dissipated energy, which is a direct measure of damage in the structure; and so it is beneficial for the protection of buildings that develop a nonlinear behavior under servo dynamic loadings. Almazan et al. (2012) investigated the influence of TMD on symmetric and soft story building. They found that if tuned mass damper was tuned appropriately, it accomplished a decaying response. Daniel et al. (2014) made seismic design by using familiar optimization methods to achieve multiply modal control of three dimensional irregular structures.

Tuned mass damper (TMD) is a device consisting of a spring, a mass and a dashpot. This device is used for mitigating harmful vibration effects on the structures. Tuned mass damper runs in opposite phase of main mass, so that it absorbs the energy by means of inertial forces. Passive tuned mass dampers are usually tuned to a particular mode which is especially the first mode of structure.

In this study, different masses are located at top of minaret of Nigde University's mosque which is researched under seismic excitation. Firstly, effectiveness of different mass quantities is observed on structural displacement and acceleration. Secondly, analysis is repeatedly executed after choosing the 35 kg mass for different bar lengths.

2 STRUCTURAL MODEL ANALYSIS FINDINGS

Example of minaret which has a 40.20 m length, 1.8 m diameter and 0.25 m thickness is given below. Concrete class is chosen as C25. Figure 1 shows structural model of mosque minaret and different mode shapes of the minaret analyzed with a TMD.

TMD is designed by locating an elastic bar and a mass at the top of mosque minaret. In this research, different masses and bar lengths are examined by using Kobe earthquake acceleration record. Displacement and absolute acceleration time histories are also researched for different minaret altitudes.

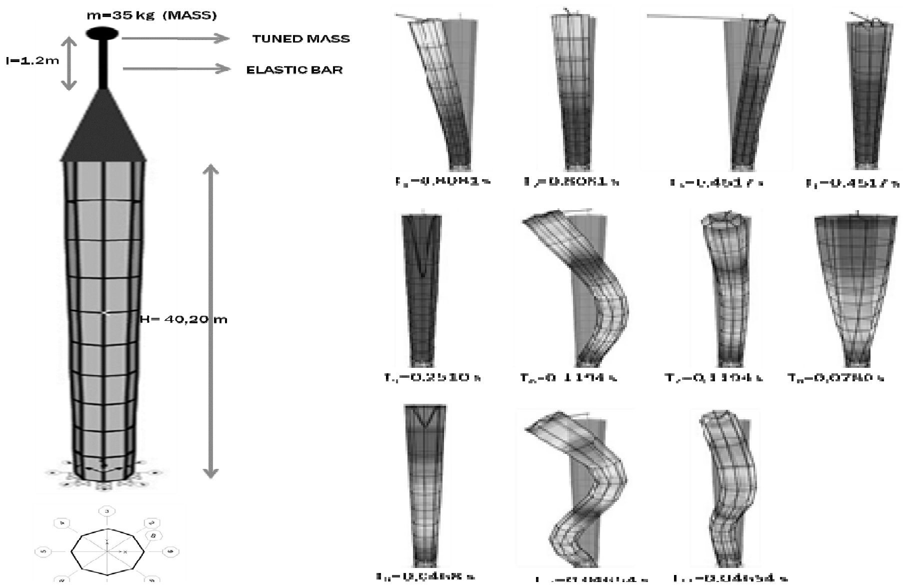

Figure 1. Structural model of mosque minaret and mode shapes of the analyzed system with a TMD mass

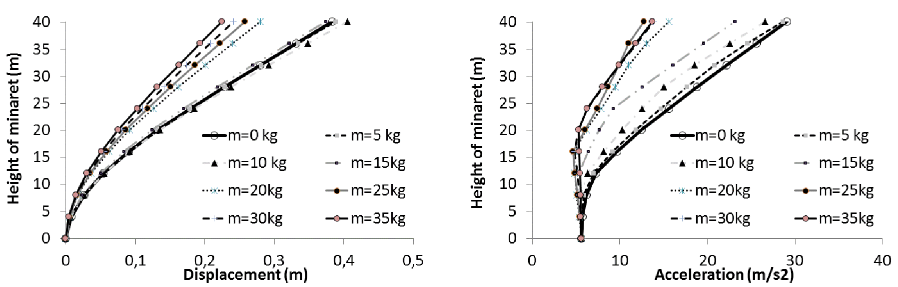

Figure 2. Peak displacement and acceleration profiles according to various tuned masses.

2.1 Displacement and acceleration response of minaret top without and with TMD

In this study, Kobe earthquake is used for the time history analyses. To understand whether TMD makes a contribution for decreasing minaret displacement is the first aim of rehabilitation under the earthquake effect. Masses of m=0kg, 5kg, 10kg, 15kg, 20kg, 30kg and 35kg are used for the analyses as shown in Figure 2. There is no change in the minaret displacement, acceleration and its dynamic performance up to a mass of 10 kg. Starting with addition of a 20 kg mass, significant effectiveness of TMD starts to be observed.

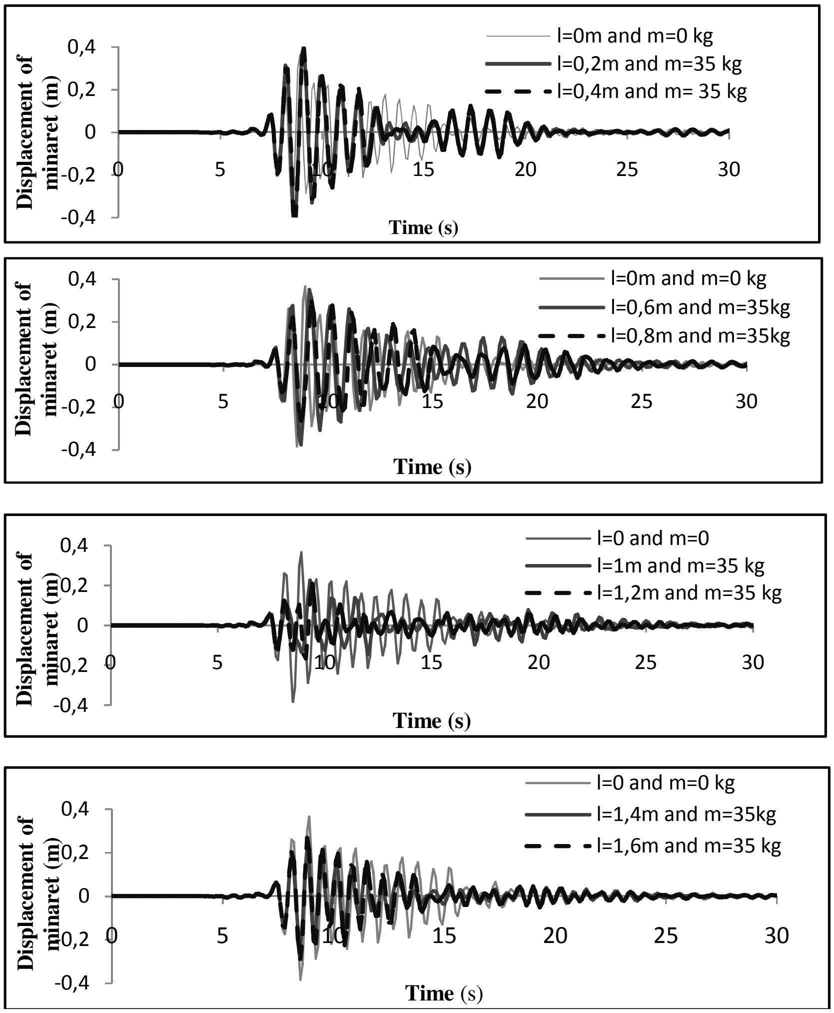

Figure 3. Top displacement time history for different bar lengths.

The bar length varies between 0 and 1.6 m. Bar lengths up to 1 m and at 1.6 m also do not give much contribution to the structure behavior. Even l=0.2 m effects the system adversely in terms of displacement. Bar lengths of 0.8 m and 1 m are the most suitable to decrease acceleration effect for this system. 1m and 1.2 m bar lengths are suitable for both displacement and acceleration rehabilitation of the system. A 35 kg mass and a 1.2 m bar length give appropriate values for the TMD system. Displacement behavior of the minaret versus time for a varying bar length is shown in Figure 3; and peak displacements of the minaret versus height of the minaret for a varying bar length is shown in Figure 4. In Figure 5, minaret acceleration versus time is shown. All these graphics are plotted for a 35 kg mass.

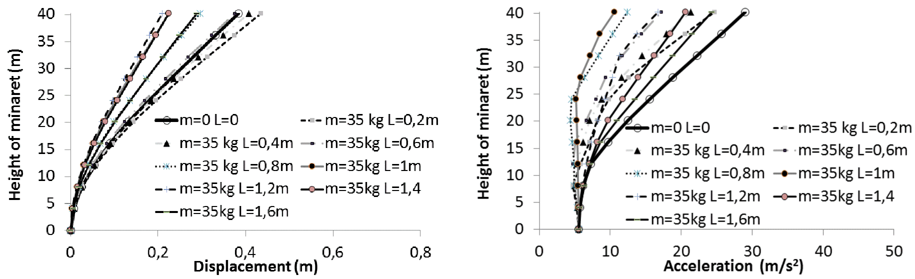

Figure 4. Peak displacements and accelerations of the minaret according to different bar lengths

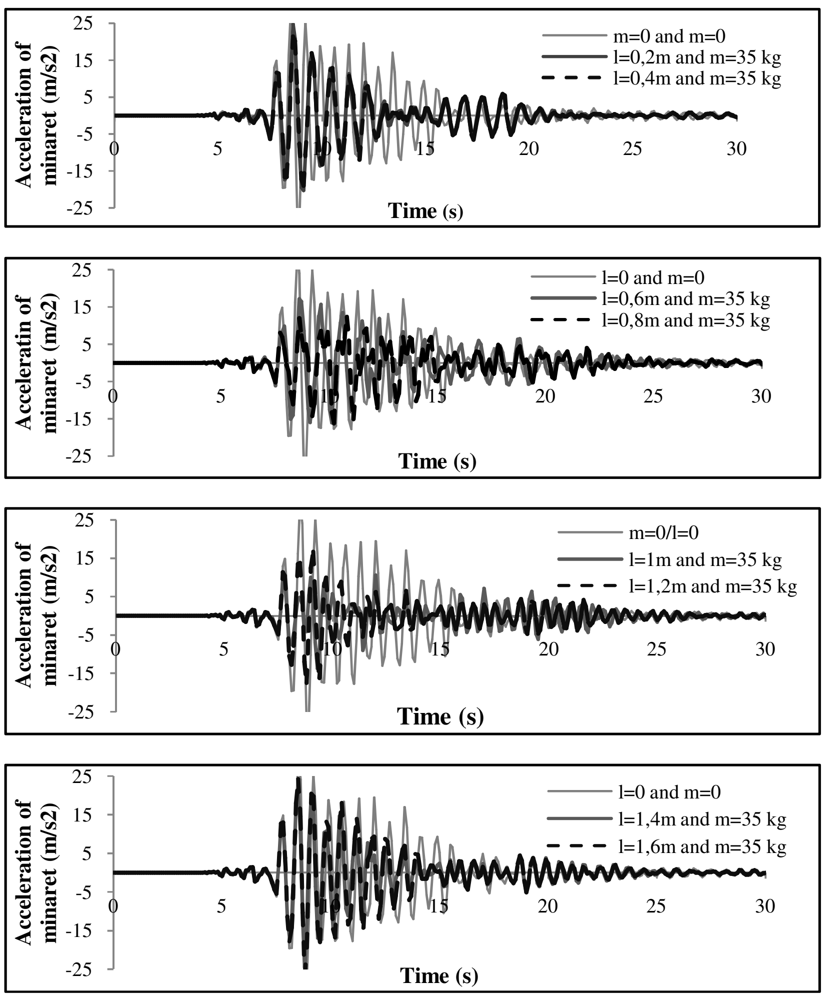

Figure 5. Top acceleration time histories according to different bar lengths

As seen in Figures 2, 3, 4 and 5, if an appropriate mass and an elastic bar are attached to top of the minaret, system behavior under the seismic excitation is rehabilitated. In literature, it is well known that TMD performance under the wind excitation is better than under the seismic excitation. Therefore, this study can be also valid for wind excitation rehabilitation. After this episode, the next step is detailing mass and bar length for either reinforcement concrete or steel material. Performance of the minaret of Nigde University mosque both without TMD and with TMD is investigated under the Kobe earthquake excitation. This study is executed with a real example minaret by using numerical analysis. Within this scope, TMD models can be implemented for long-thin and slender structures such as towers and standing water tanks. In this research, only one earthquake acceleration record is used but other records can be also used for future studies. In addition, nonlinear effectiveness of soil of minaret on performance of TMD also should be researched. In this investigation, reinforced concrete minarets are examined. Behaviors of historical and stacking stone minarets need to be more detailed with finite element analysis.

3 CONCLUSION

From this study, the following significant conclusions can be expressed as below:

Mass quantity and bar length influence the behavior of mosque minaret under vibration. Choosing suitable mass quantity and bar length is very important for effectiveness of TMD system attached to top of the minaret. TMD makes an important contribution to the investigated minaret model which was defined previously. When subjected to Kobe earthquake ground motion, appropriately designed simple bar with a mass decreases both displacements and accelerations of the minaret, especially at the top. Because of TMD reduction of acceleration of minaret, shear force effect on the structure is also reduced. Therefore, this case plays an important role for design in terms of both cross-section and height of minaret. For the mosque minarets, a TMD system is suggested for dynamic rehabilitation due to its easy utilization; and its good performance during an earthquake excitation.

Wind excitations have more specific modes than earthquakes. Therefore, a TMD can be predicted to be very beneficial for rehabilitation of tall, slender and thin structures subjected to wind excitations. To increase the resistance of structures against both seismic and wind effect, the use of TMD can be predicted to be beneficial for rehabilitation.

TMD supplies damage reduction, if its elements’ masses and springs are chosen appropriately. It is estimated that TMD makes the structure more comfortable, when subjected to an annoying wind or a moderate earthquake excitation by decreasing the vibration effect on the structure.

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