Vibration control of classical columns using particle dampers

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Abstract
Particle dampers have been used for many years to reduce vibrations of machines and small structures. Ancient monuments like classical columns are in danger of collapsing in areas of high seismicity and need to be protected with methods that will not affect their overall appearance. Particle dampers can replace original drums looking exactly the same while inside they are hollow and contain particles. This paper examines the ability of particle dampers to reduce the response of classical columns to dynamic excitations. The experimental results indicate that particle dampers can effectively reduce the response of classical columns if they are designed properly.

1 Introduction

Preservation of ancient monuments and remains of national importance is a great concern of nations. Many ancient temples in areas around the Mediterranean Sea consist of multi-drum columns. The drums have been deteriorated through the years due to environmental causes and earthquakes. There is a need to restore and preserve this historical heritage with minimal alteration of its appearance. Restoration of ruined monuments includes reassembly of fallen parts or incorporating new material. Common restoration techniques may increase the seismic safety of monuments but also alter their appearance.

Past studies have examined the behavior of multi-drum columns under dynamic loads ([1]-[14]) but little attention has been given to the increase of their seismic safety. Particle dampers are simple passive devices that can reduce the vibrations of structures (primary systems) by exchanging momentum with the primary system and dissipating energy ([15]-[32]). A particle damper is a container consisting of particles that can be attached to the structure in different locations. In the present study the damper takes the form of a hollow drum containing particles. This hollow drum can replace a damaged or missing drum respecting the appearance of the monument. This paper investigates the effectiveness of particle dampers in reducing the vibration of multi-drum columns. A small scale classical column under dynamic excitations was used for this investigation. The effect of the system's parameters on the motion of the column was also considered.

2 Experimental test methods

A small scale model (1:8) of a replica of an ancient column from the temple of Hephaestus in Athens was used as our primary system. In order to facilitate the experimental investigation the marble drums had equal size (120 mm diameter and 93 mm height) and were placed one above the other without connection. The total weight of the column was 19.8 kg. The column was placed on a 140x140x20 mm marble plate attached on a steel plate. The whole arrangement was placed on a 3x5 shake table capable of moving in one direction. A safety structure was built around the column (Figure 1). The dampers used were hollow marble drums of the same outside diameter (120 mm) but varying diameter of their hollow part (90, 80 and 65 mm diameter respectively). Steel spherical particles of 20 mm and 50 mm diameter were used. The column with or without damper was excited by dynamic loads. The motion of the shake table and drums were recorded with accelerometers. The velocities and displacements of the drums were obtained by double integrations of the accelerations after removing the trend.

Figure 1: Column-model with safety structure.

3 Response of column under dynamic loads

The column was excited by a random signal containing frequencies from 1 to 7 Hz and its response was measured. Small imperfections of the set-up influence the response of the structure. To increase the robustness of the results the experiments were repeated several times. The results are presented for the top drum where the motion was highest.

3.1 Column without damper

Initially the response of the column without damper was obtained. Figure 2(a) presents the frequency response of the absolute acceleration of the top drum in the direction of motion for a representative experiment with mid-response. The natural frequencies of the system were close to 1, 1.6, 2.7, 3.4 and 4.3 Hz.

Several experiments were performed with the same conditions and the response of the column changed considerably from test to test. The rms (root mean square) of the response displacement with respect to the rms displacement of the base gives an indication of the response of the column with values varying from 2.8 to 9.

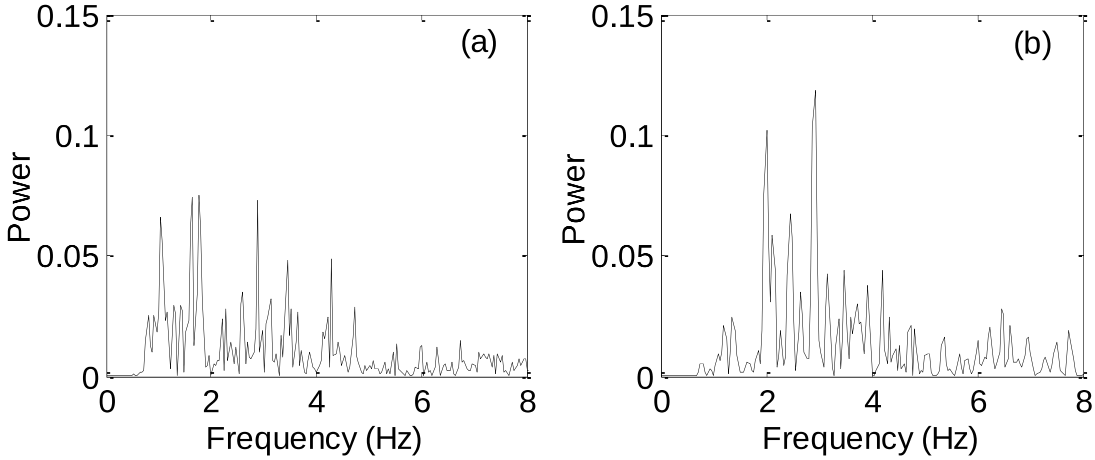

Figure 2: Frequency response of the absolute acceleration of the top drum: (a) without damper; (b) with damper.

The displacement of the column is presented in Figure 3 for the same representative experiment with mid-response. The column exhibited motion not only in the direction of the excitation (Figure 3a) but also in the out-of plane direction (Figure 3b). Most of the times, the motion of the column out-of-plane was smaller than the motion of the column in the direction of the excitation.

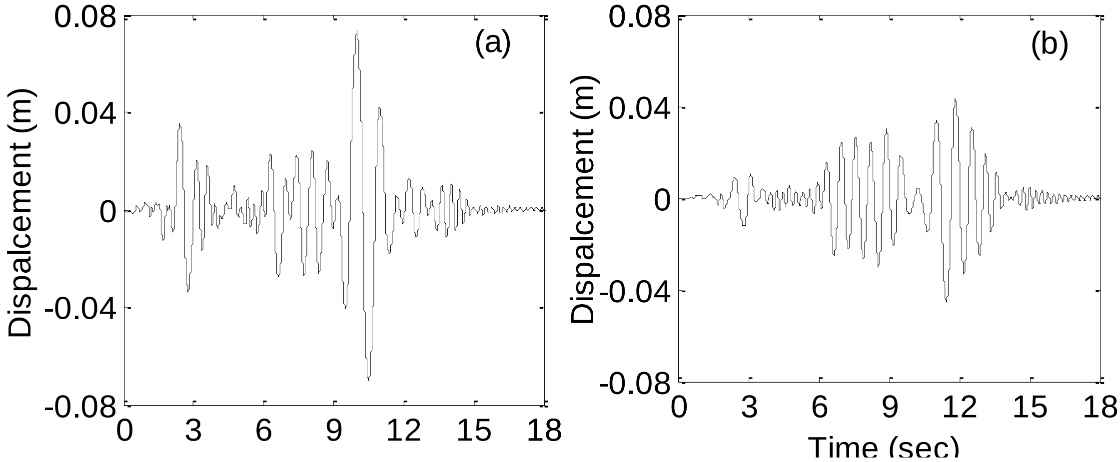

Figure 3: Displacement of top drum of column: (a) in the direction of the excitation; (b) perpendicular to the direction of the excitation.

3.2 Column with damper

The response of the column was obtained with a particle damper (Figure 4) replacing one of the drums. Only the drums above the mid-height were substituted since the motion was higher at the top part of the column. Initially the damper replaces the 5^{th} drum and then the top drum. Eight, sixteen particles and twenty two particles of 20 mm diameter were used corresponding to 1.33, 2.66, and 3.66 % mass ratio (mass of particles over mass of column). In addition one particle of 50 mm diameter was used corresponding to 2.6 % mass ratio. The response was considerably reduced when the damper of the large hollow part was used containing either eight particles of 20 mm diameter or the one particle of 50 mm diameter. The experiments were repeated several times to increase the robustness of the results. The response of the column with the damper was less variable than without the damper. The rms of the response displacement with respect to rms displacement of the base gives an indication that the response of the column was more stable with values varying from 2.7 to 3.6.

Figure 2b presents the frequency response of the absolute acceleration of the top drum in the direction of motion for a representative experiment with mid-response for the large damper containing eight particles of 20 mm diameter. The frequencies below 2 Hz have been reduced considerably with respect to the frequency response obtained without damper but the higher frequencies have increased most likely due to the impacts of the particles with the container. The higher frequencies though contribute less to the motion of the column.

Figure 4: Particle damper (diameter of hollow part = 80 mm)

The displacement of the column is presented in Figure 5 for the same representative experiment with mid-response. The displacement of the column was reduced considerably (more than 40%) in all directions. In addition the motion died much faster.

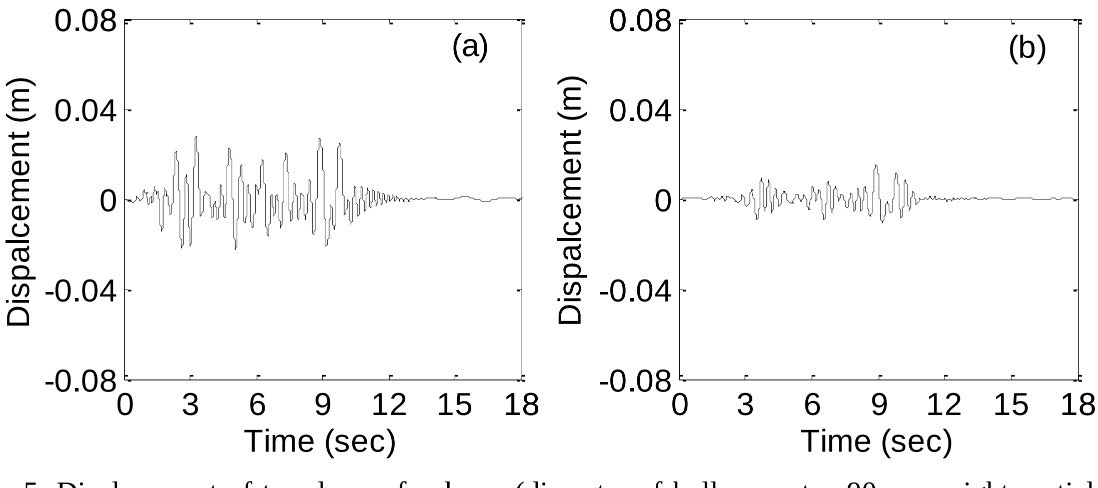

Figure 5: Displacement of top drum of column (diameter of hollow part = 90 mm; eight particles of 20 mm diameter): (a) in the direction of the excitation; (b) perpendicular to the direction of the excitation

Similar results were obtained when the one particle of 50 mm diameter was used. The particles need space to move to obtain the necessary momentum to reduce the response. For this reason the smaller size dampers and the larger number of particles used reduced the effectiveness of the damper. Similar results were obtained most of the times when the damper replaced the top drum but in some cases more sliding occurred at the top drum reducing the effectiveness of the damper.

3.3 Column with defects

Since many ancient columns have been damaged through the years the response of columns with defects was also examined. A column with a broken base and a column with inclination were considered. The dimensions of the drums were the same as the initial column-model without defects. The response was effectively reduced when the damper of intermediate hollow part replaced the fifth drum containing a single particle of 50 mm diameter. The smaller particles or the replacement of the top drum with the damper could not effectively reduce the motion of the column. Figure 6 presents the response of a column with base inclination of 2.5% without damper. The response of the column was high in both directions that is, parallel to the base excitation (Figure 6a) and perpendicular to the direction of the excitation (Figure 6b).

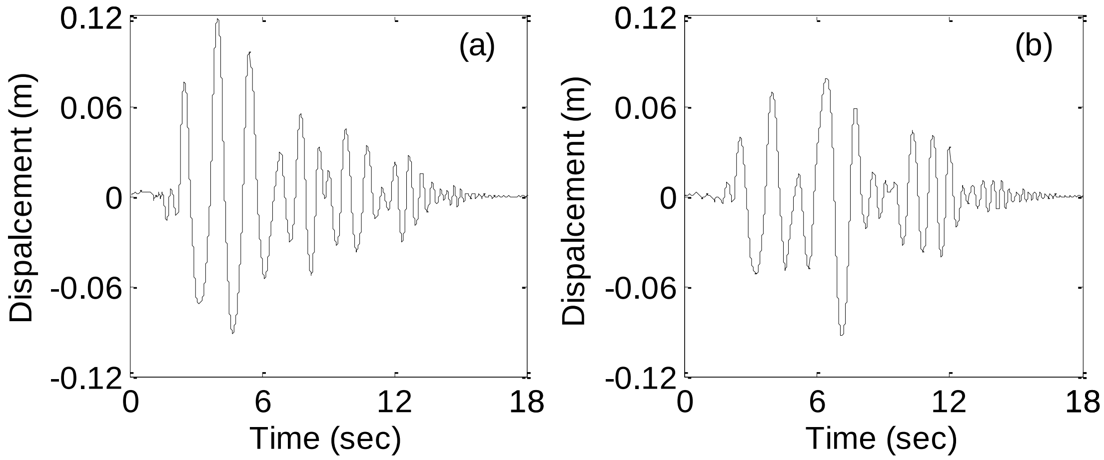

Figure 6: Displacement of top drum of column: (a) in the direction of the excitation; (b) perpendicular to the direction of the excitation

Next, the particle damper replaced the fifth drum. Figure 7 shows that the response of the column with the damper was reduced in both directions.

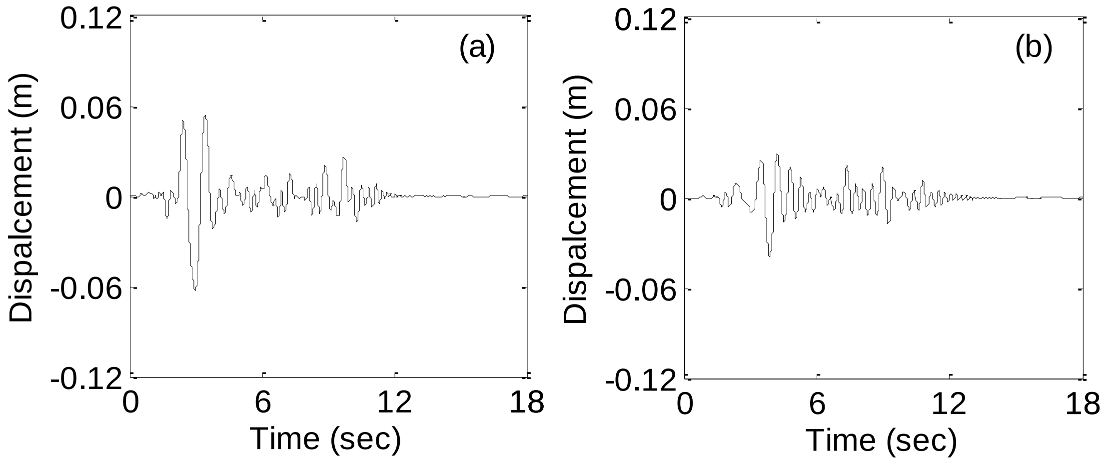

Figure 7: Displacement of top drum of column (diameter of hollow part = 80 mm; one particle of 50 mm diameter): (a) in the direction of the excitation; (b) perpendicular to the direction of the excitation

4 Conclusions

Conventional methods for the protection of monuments from dynamic loads can be intrusive altering their architectural features. A simple passive technique like particle dampers can be used to increase the seismic safety of monuments respecting their overall appearance. This paper examined the use of particle dampers in reducing the motion of multi-drum columns. A particle damper, in the form of a drum resembling the rest of the drums but being hollow containing particles, replaced a damaged or missing drum. When the damper was placed above the mid-height but below the top drum it effectively (more than 40%) reduced the vibrations of a multi-drum column.

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