Multi-Celled Liquid Dampers to Eliminate Annoying Floor Vibrations
by

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INTRODUCTION

It is often quite difficult to eliminate annoying floor motion that results from human activity. Many past methods have proven to be either ineffective or economically and architecturally prohibiting. Although tuned mass dampers (TMDs) have been used to control floor movement, their success has been limited. This is primarily because peak floor vibration amplitudes are usually less than 1 mm (0.040 in.) and dampers require a much greater amplitude to dissipate energy. This paper presents a multi-celled liquid damping device supported on a steel plate together with the necessary mass that appears to be an effective solution.

BASIC CONCEPTS

A TMD consists of an additional mass attached to the structure by a parallel spring and damper. This acts as a single degree of freedom system and its natural frequency is tuned so that it matches the frequency of the original structure. TMDs control a structure by the reaction at the spring and damper. This reaction is a time dependent force acting in the opposite direction of structure movement. In the case of floor vibrations, there routinely exists more than one mode which is excited by human activity. Therefore, in order to eliminate all annoying vibrations, it is necessary to provide multiple TMDs.

TEST FLOOR

The test floor used in this study was designed and constructed to simulate floors commonly found in office and retail buildings. The floor consists of a 3-1/2 in. concrete slab on metal deck supported by open web steel joists. The joist span is 25 ft. and the spacing is 30 in. The width of the floor is 15 ft.

PROTOTYPE DAMPERS

The prototype damper, shown in Fig. 1, uses a 12 in. wide steel plate as the spring. The length of the plate ranges from 6 to 8 ft. and the thickness ranges from 5/8 to 1 in. The plate is supported at each end by an angle which simulates a pinned connection. The angle is positioned on a steel bearing pad which rests on the floor. Two stacks of 1/2 in. thick steel plates serve as the additional mass. This allows the mass to be adjusted in 10 lb. increments. Damping is provided by multi-celled liquid filled bladders confined in two rigid containers. This deviates from conventional TMDs which have a dashpot or damping element connecting the additional mass to the original structure.

TEST METHODS AND TUNING

The free vibration response of the floor was measured by conducting an impact test commonly known as a Heel Drop test. The standard Heel Drop test is performed by first standing on the balls of one's feet then leaning back allowing the heels to impact the floor. An accelerometer is placed in close proximity to the impact. The impact triggers the data acquisition system and the floor response is recorded for eight seconds. A Fast-Fourier Transform (FFT) is then performed on the acceleration history to extract the frequency response spectrum of the structure. In addition to the Heel Drop tests, acceleration histories were recorded while a person walked along the midspan of the floor perpendicular to the joists.

As with conventional TMDs, the dampers must be tuned to the frequency of the mode of interest. Since the bladders are as yet unpredictable in terms of the way they influence the frequency of the damper, this tuning must be performed experimentally.

The dampers are tuned by first placing them on a rigid surface such as a slab on grade. An accelerometer is placed on the plate and the plate is given an initial displacement. The plate is then released and the free vibration response is recorded. An FFT of the acceleration determines the frequency. Tuning is performed by changing the mass, the span, or both.

Once tuned, the dampers are positioned on the floor such that one end is located over the point of maximum amplitude for the mode shape under consideration. It is also important that no modal node is located between the two ends of the damper. Otherwise, the damper will tend to rotate as a rigid body and will not achieve the desired result. Once in place, final adjustments are made to the mass in order to optimize floor performance.

RESULTS

A heel drop at the center of the test floor indicated that the floor had two strong modes of vibration, one at 7.3 hz and the other at 17 hz. A total of four dampers were used to control the floor, two for each mode.

Fig. 2 shows the Heel Drop acceleration histories for the test floor with and without the dampers. The figure shows that there was very little damping inherent in the original floor. Without the dampers, the vibration took over three seconds to decay. Conversely, the vibration of the floor with dampers took only one second to decay.

The frequency response due to the Heel Drop is shown in Fig. 3. The lack of damping in the original floor is again illustrated in Fig. 3a by the two sharp peaks at 7.3 hz and 17 hz. Fig. 3b shows that these peaks are almost eliminated by the dampers.

Fig. 4 shows the acceleration histories of the floor with and without dampers while a person walked along the midspan. Average peak accelerations were reduced from 0.06 g to 0.01 g after the dampers were installed. Not only was a significant reduction in peak accelerations observed, but the damped acceleration response consisted mainly of high frequency vibration which is generally found to be less annoying to occupants.

CONCLUSIONS

The multi-celled liquid damping device proved to be an effective solution to the problem of annoying floor vibrations in a laboratory test floor. Further research focused on optimizing the parameters of the damper is planned. In addition, permanent installations have been completed and are being monitored for effectiveness. Measurements and preliminary reports from occupants thus far are very favorable.

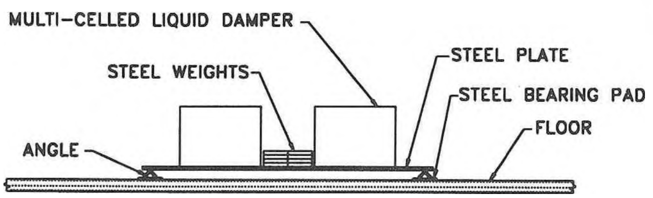

Figure 1. Prototype Damper

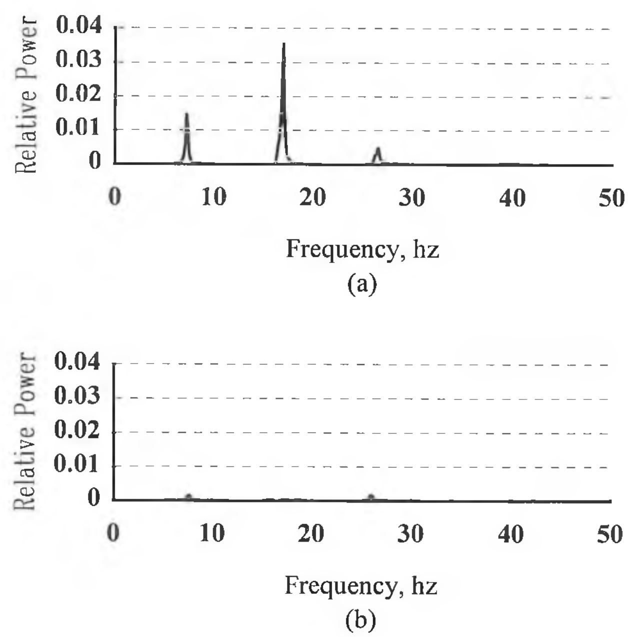

Figure 3. Heel Drop Frequency Response.
(a) Without Dampers, (b) With Dampers

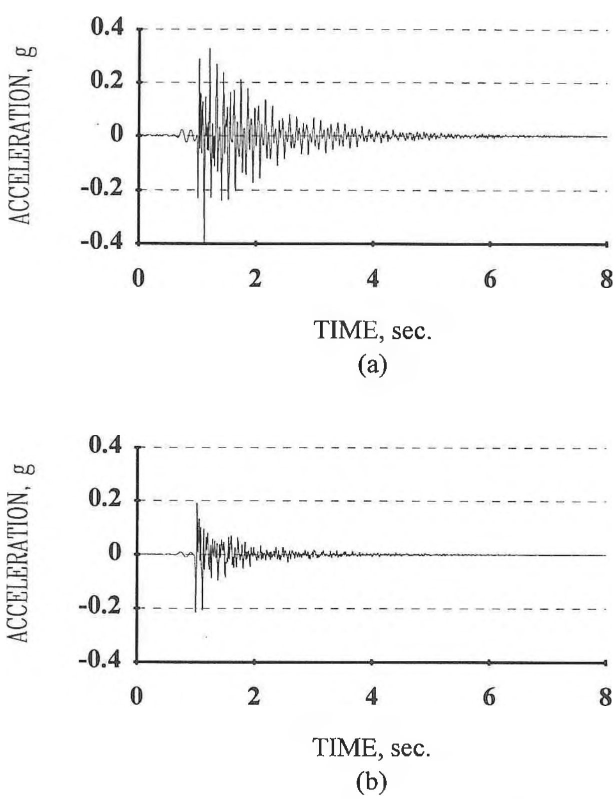

Figure 2. Heel Drop Acceleration Histories.
(a) Without Dampers, (b) With Dampers

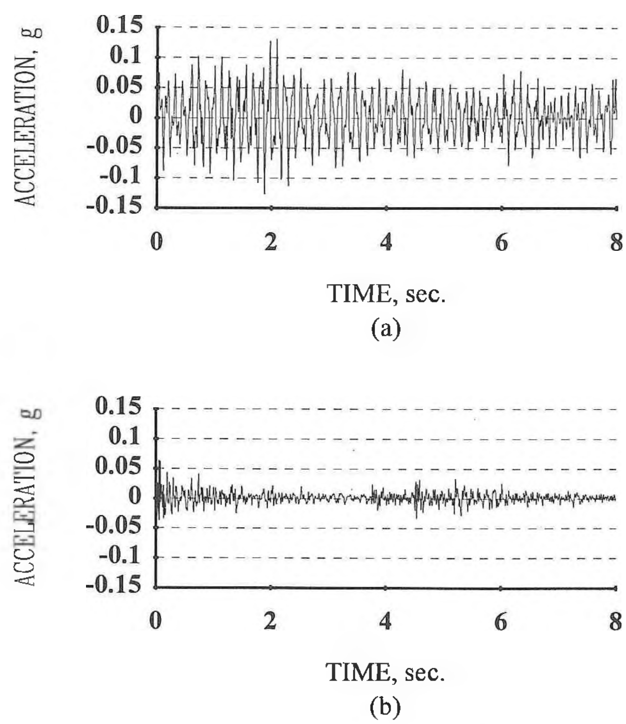

Figure 4. Walking Acceleration Histories.
(a) Without Dampers, (b) With Dampers