Vibration Abatement of a Monumental Staircase Using a Tuned Mass Damper

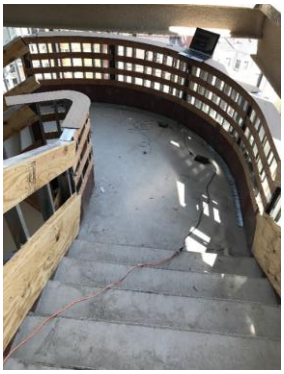
Tuned mass dampers (TMDs) are tuned damping devices commonly used for dampening the vibration of a structure at a particular resonant frequency. TMDs come in various configurations. The commonality between all of them is their make-up which includes an inertia element (mass) suspended by an energy dissipating (damping) device and a restoring (resilient) element.

Following the evaluation of the dynamic attributes of a monumental staircase (in an upscale financial office building), one 500 lb tuned mass damper (TMD) was designed, fabricated, and shipped to the job site. Two views of the nearly completed staircase are shown in Figure 1.

The natural frequency was measured at 6.1 Hz and damping ratio at 2%.

Monumental, aesthetically pleasing staircases are getting incorporated more and more in the architectural design of institutional and commercial buildings. The long unsupported span, low mass, and low damping ratio of such iconic staircases normally result in a structure with low natural frequency and negligible damping. Such structure are highly responsive to human-induced vibration.

Experimental work carried out at the University of London, have shown that forces up to 3 times the static body weight were generated during fast descents while forces up to 2.5 times the static body weight were generated during fast ascents. As such, in addition to being response to vibration, monumental staircases are also very forcefully perturbed exacerbating their vibration issues.



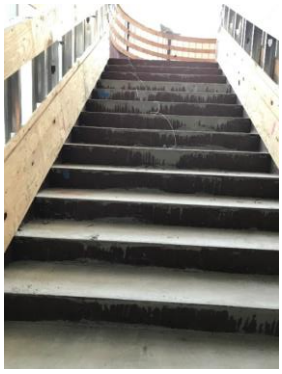


Figure 1 Views from the top (left) and bottom (right) of the nearly completed staircase

Idealizing the staircase with a slanted, simply supported beam, the acceleration at the landing was predicted at 5% of *g* for a fast descent by one person weighing 168 lb. This acceleration was also measured at 4-5% of *g* at the natural frequency, in response to footfall perturbation of one person moving up and down the stairs at the fast pace of 3 steps/sec; both predicted and measured vibration levels exceeded the recommended limits.

In Design Guide 11, tolerance limit of vibration acceleration for staircases subject to a normal descent by a 168 lb person is 1.5% of *g*. This limit is extended to 3% g for fast descents.

The TMD was installed in the cavity underneath the landing. Figure 2 shows an image of the TMD installed in the cavity underneath the landing and a technician unlocking it.

Stiffening monumental staircases by either using large stringers or placing posts underneath them would take away from their splendor and beauty. This leaves increase in damping, using TMDs, as the potential solution for addressing the vibration issues of such staircases.

The TMD was commissioned and fine-tuned by locking it up first and measuring the vibration of the staircase, in response to a heel drop perturbation, followed by unlocking the TMD and repeating the measurement.

Figure 2 The TMD installed in the cavity underneath the landing (left) and a technician commissioning it (right)

The blue traces in Figure 3 depict the power spectral densities (PSDs) and time traces of the measured landing acceleration with the TMD locked. The red traces in Figure 3 show the same measurements as those of blue traces, except with the TMD unlocked and fine-tuned.

Comparison of the red and blue traces in Figure 3 clearly points to the effectiveness of the tuned mass damper in dampening its target mode, abating the vibration of the staircase.

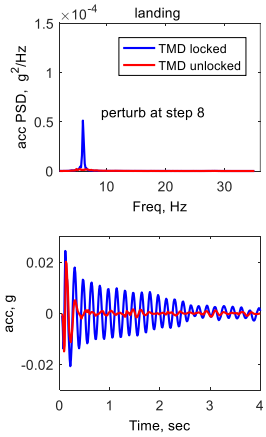


Figure 3 measured vibration with the TMD locked (blue) and unlocked (red)