Chapter 7
Performance Evaluation of an Eddy Current Tuned Mass Damper on a Full-Scale Laboratory Floor

Sahabeddin Rifai, Russell A. Larsen, Robert Baxter, Joshua M. Mouras, Ronald Klemencic, and Onur Avci

Abstract This paper presents the experimental performance evaluation of a tuned mass damper (TMD) incorporating an eddy current damper on a full-scale 30 ft × 40 ft laboratory floor. The TMD was designed by Magnusson Klemencic Associates (MKA) and tested at West Virginia University (WVU). The system effectiveness was quantified through a set of dynamic tests, including shaker-induced frequency response functions (FRFs) to verify tuning, free-vibration decay tests to measure added damping, and human-walking tests to assess serviceability performance. The optimally tuned TMD suppressed the peak resonant response by 86% and increased the overall system damping by 34% to 53%, a value dependent on vibration amplitude introduced to the system as an input. Under serviceability-level human-walking tests, the TMD reduced the 90$^{\text{th}}$ percentile Equivalent Sinusoidal Peak Acceleration (ESPA) by 25%. The results validate the eddy current TMD is a promising passive control device, at the proof-of-concept stage. It offers a potential solution for mitigating excessive vibration levels in modern floor systems and other structures such as stadia. The future work on this damper will provide more information and shed more light on the potential of the proposed TMD device.

Keywords Tuned mass damper (TMD) · Eddy current damper · Floor vibrations · Vibration control

Introduction

Occupant comfort in modern buildings can be compromised by excessive floor vibrations. Architectural trends favoring open-plan layouts with long spans, combined with lightweight construction materials, create flexible floor systems with low inherent damping. These floors are easily excited into resonance by common human activities, such as walking or rhythmic group exercises. This creates significant serviceability challenges, where for many modern floor designs, the vibration serviceability limit state has become the governing design criterion rather than strength [1, 2].

Introducing supplemental damping is a remedial strategy for controlling excessive floor vibrations, often accomplished using specialized hardware like a Tuned Mass Damper (TMD). A TMD is an effective passive device for vibration control that adds damping and counteracts motion at a specific troublesome frequency without needing an external power source [3]. TMD's performance is influenced by its damping component, which is responsible for dissipating energy. Conventional dampers that rely on viscous fluids or friction can suffer from long-term performance issues like fluid leakage, temperature sensitivity, or mechanical wear [4].

To address these limitations, this paper investigates an eddy current damper as a method for vibration control. This technology operates on the principle of electromagnetic induction. When a conductive plate moves through a magnetic field, the changing magnetic flux induces circulating currents within the plate, known as eddy currents. According to Lenz's Law, these currents generate their own magnetic field that opposes the original change in flux, resulting in a Lorentz force that counteracts the motion. This phenomenon creates a stable, velocity-proportional damping force that effectively dissipates

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the structure's kinetic energy as heat [5]. Because this force is generated without physical contact, eddy current dampers are not subject to the mechanical wear, fluid leakage, or temperature sensitivity that can degrade conventional dampers

This study presents the experimental evaluation of a Tuned Mass Damper (TMD) equipped with this eddy current damper element. The TMD, designed by Magnusson Klemencic Associates (MKA), was installed on a full-scale 30 ft × 40 ft all-steel laboratory floor at West Virginia University (WVU). The primary objective is to perform a proof-of-concept study, quantify the system's effectiveness and provide a direct performance comparison to other damping technologies previously evaluated on the same structural bay.

This paper is structured as follows: Section 2 details the design of the eddy current TMD and the full-scale laboratory specimen. Section 3 describes the analytical and experimental procedures used to tune the TMD mass. Section 4 presents the results from free-vibration decay tests, quantifying the TMD's effect on system damping. Finally, Sections 5 and 6 evaluate the TMD's performance under resonant shaker excitation and simulated human-walking tests, respectively.

Eddy Current Tuned Mass Damper

The MKA-designed eddy current tuned mass damper (TMD) is illustrated in Figure 1. As shown in the installed assembly (Fig. 1-a), the TMD's spring element consists of steel strips, and the system's stiffness can be adjusted by changing the number of these strips. The mass is composed of a base plate with additional tuning plates, allowing for precise mass adjustment. The eddy current damper element (Fig. 1-b) comprises a conductive copper plate and a 3D-printed holder containing an array of disc magnets.

The installation process begins by welding support angles to the beam webs and attaching a steel channel section to the bottom beam flanges. The steel spring strips are then bolted to the support angles. Finally, the eddy current damper element is installed between the mass plate and the bottom channel section. It is connected using a hinged linkage designed to permit the necessary rotational for the vertical movement of the copper plate as it moves through the magnetic field. The linkage additionally amplifies the velocity of the conductive copper plate and amplifies the resulting resistive force applied to the TMD mass plate.

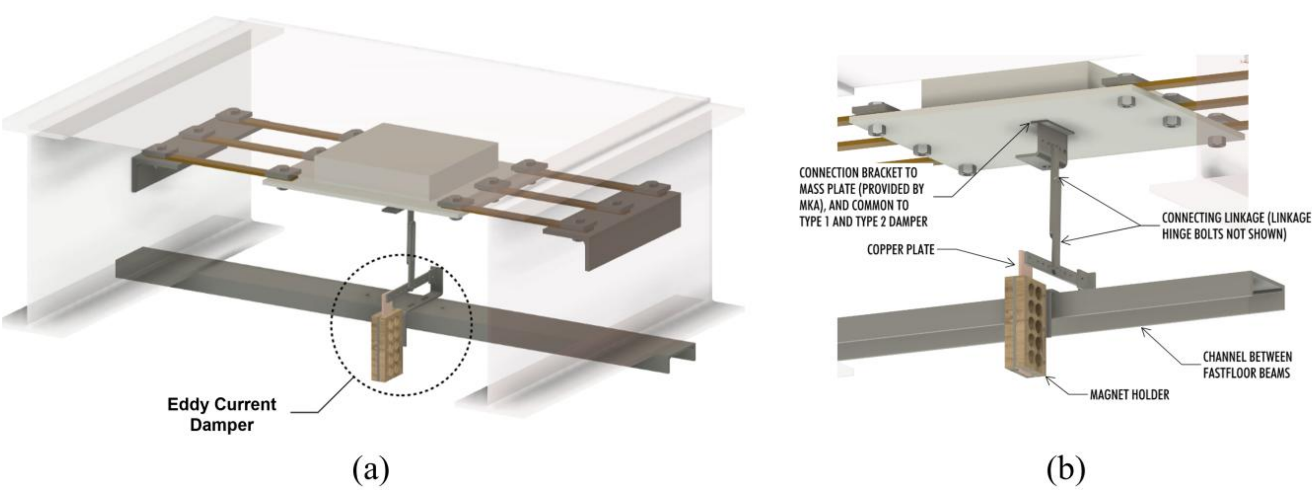
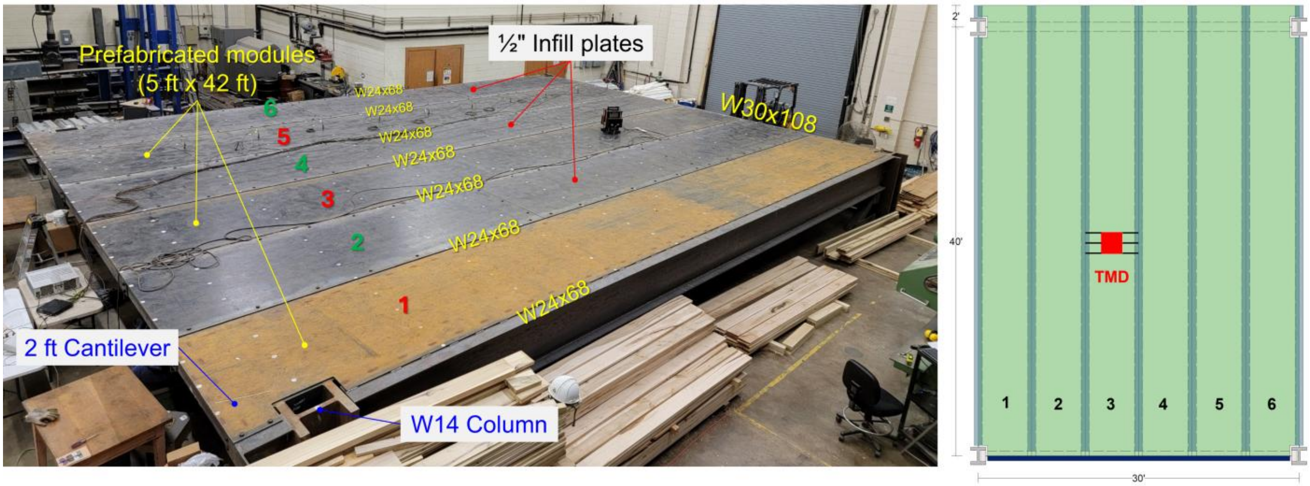


Fig. 1 Schematic of the eddy current TMD design by MKA. (a) View of the TMD assembly. (b) A view of the eddy current damper element with part names

The eddy current TMD was installed and tested on a 30 ft × 40 ft FastFloor laboratory specimen, a modular all-steel system designed to accelerate commercial building construction using prefabricated components. The full-bay specimen consisted of six modules supported by two W30×108 girders. Three of these modules were prefabricated units made from W24×68 steel beams and $\frac{1}{2}$ in. thick plates, while the remaining three were formed by connecting infill plates on-site. The modules were attached to the girders using bolted shear connections. Fig. 2-a shows the specimen in its bare condition. Fig. 2-b provides a plan layout, indicating the TMD location at the center of module 3. For all tests, a raised access floor (RAF) was installed over the steel plates (Fig. 3).

The installed eddy current TMD is shown in Fig. 4. The system's dynamic response was monitored using eleven accelerometers. Two sensors were mounted directly on the TMD assembly (one on the mass plate and one on the steel channel



(a) (b)

Fig. 2 30 ft × 40 ft All-Steel FastFloor specimen. (a) Laboratory specimen with components annotated. (b) Plan layout of the FastFloor specimen with module numbers and the TMD location shown

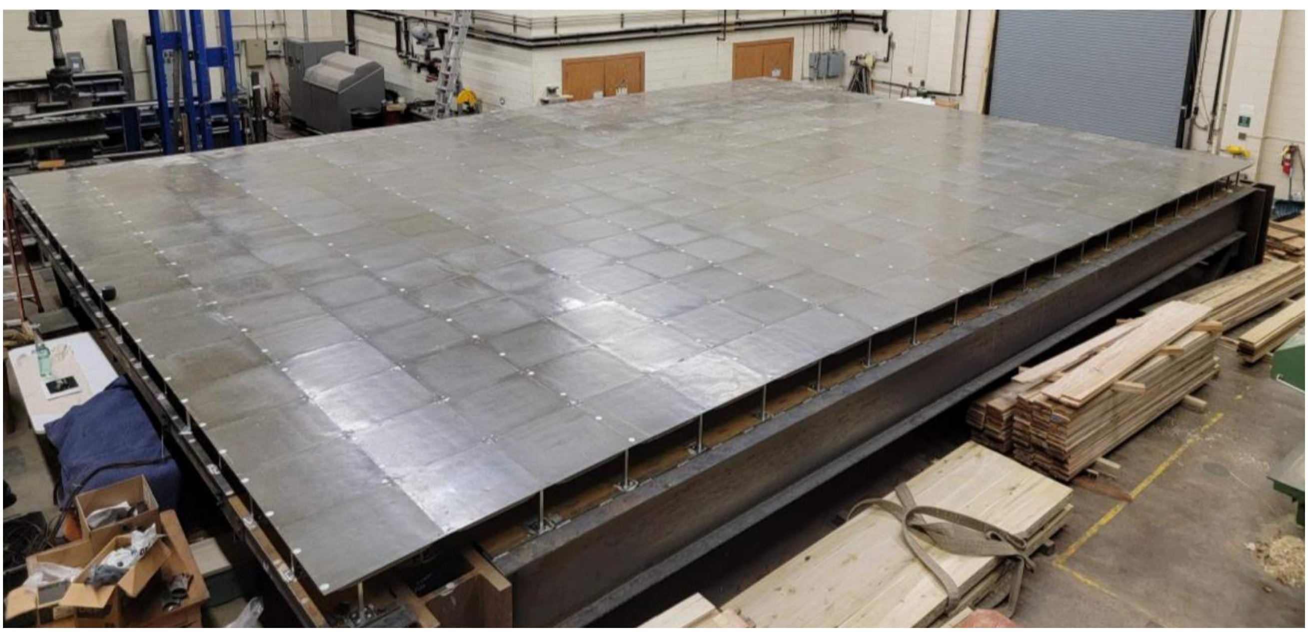


Fig. 3 The FastFloor test specimen with the raised access floor (RAF) installed

section at the bottom), and additional nine accelerometers along the centerline of the floor's third module. For modal analysis, excitation was provided by an electrodynamic shaker using a 3–30 Hz chirp frequency sweep. It is important to note that all tests, both with and without the TMD, were performed with the raised access floor (RAF) installed. The baseline configuration of the floor also included horizontal angle blocking members at L/3 and 2L/3 distances on modules 1, 3, 5, and 6.

Tuning the Damper System

The primary goal of the tuning process was to align the TMD's natural frequency with the floor's fundamental frequency, which was measured at 7.46 Hz. This mode was selected as the target because it exhibits the highest mass participation and

Fig. 4 The eddy current TMD assembly after installation on module 3: (a) view of the assembly with four spring strips and tuning mass plates; (b) the eddy current damper element with the copper plate and magnetss

therefore dominates the floor's dynamic response. As shown in Fig. 5, this mode shape is characterized by the entire floor bay bending in a single curvature. The optimization procedure involved systematically adjusting the TMD's mass by adding or removing steel tuning plates. Concurrently, the eddy current damper's configuration was verified under resonant excitation to ensure it provided an effective level of energy dissipation.

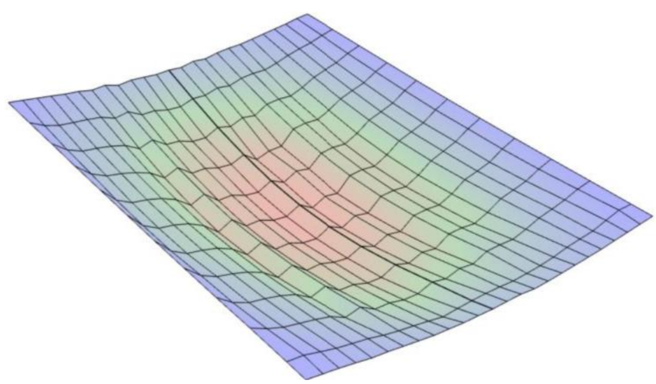


Fig. 5 Experimentally identified fundamental mode shape of the full-bay floor specimen

Mass Tuning: Analytical and Experimental

The initial tuning of the TMD was guided by analytical calculations from the designers at MKA, which suggested a configuration of four spring strips and five mass plates to target the floor's 7.4 Hz fundamental frequency. A key consideration in these calculations is the slight decrease in the floor's natural frequency that occurs after the TMD is installed due to its self-weight. The five-plate configuration resulted in a mass ratio of approximately 1.2%, which is the ratio of the TMD's total mass to the effective modal mass of the floor.

To experimentally verify the initial tuning calculations, modal tests were conducted using five distinct TMD mass configurations (0, 2, 4, 5, and 6 tuning plates). For each configuration, low-amplitude shaker excitations were used to generate a Frequency Response Function (FRF), and the results are compared in Fig. 6. It should be noted that these mass optimization tests were performed using another damper element. The primary goal of this experimental sweep was to identify the number of mass plates that resulted in the greatest suppression of the FRF peak near the 7.4 Hz target frequency.

FRFs from the mass tuning tests are presented on a logarithmic scale in Fig. 6, with a detailed view of the target frequency range shown in Fig. 7. The results confirmed that the five-plate mass configuration was optimal, reducing the peak FRF magnitude by approximately 87% compared to the baseline floor, which aligned well with the initial analytical predictions. It was observed that the peak reductions for the other mass configurations did not follow a simple linear trend. This can be attributed to known challenges in testing large, flexible floor structures, where nonlinear behavior and complex shaker-structure interactions can cause slight variations in measured resonant peaks [6].

With the optimal five-plate mass configuration determined, the eddy current damper element was installed to complete the TMD assembly. A modal analysis was then performed, and the resulting FRF is compared to the baseline (no TMD) case in Fig. 7. The results are shown on both a logarithmic scale over a broad frequency range (Fig. 7-a) and a linear scale focused on the fundamental mode (Fig. 7-b). The comparison shows the TMD's effectiveness, reducing the peak resonant response by 86%. A slight reduction in the floor's fundamental frequency was also observed with the TMD installed.

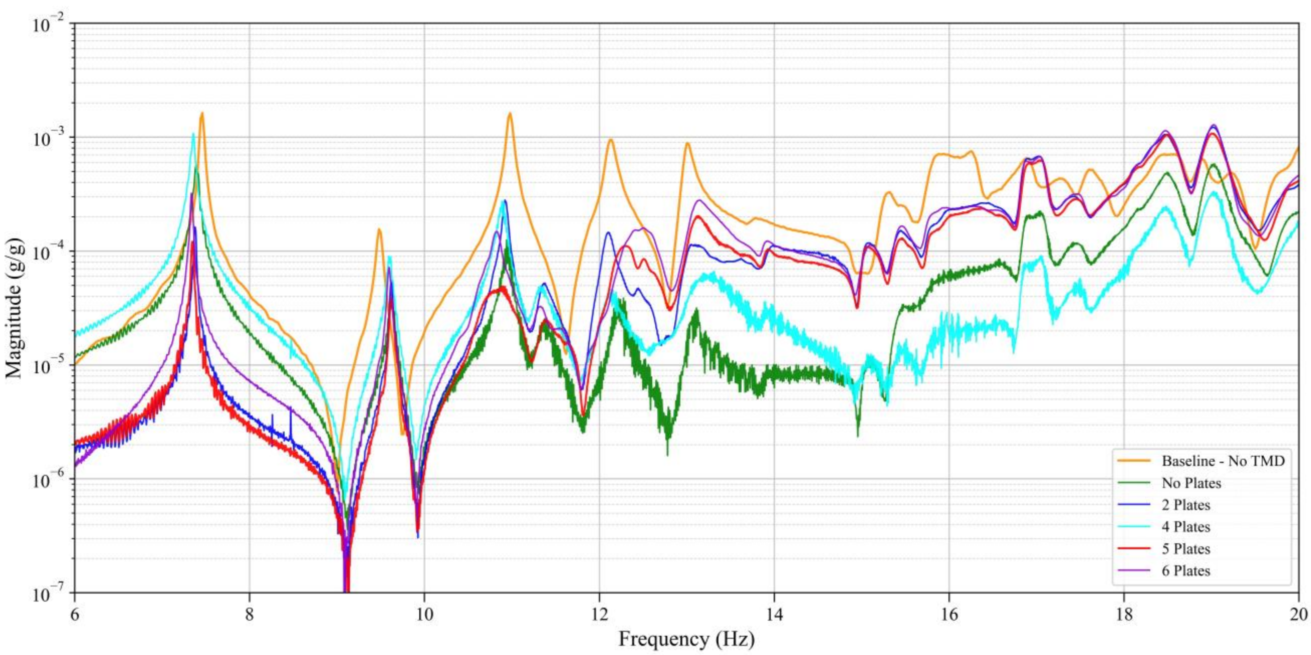


Fig. 6 Frequency response functions (FRFs) measured at the center of module 3 for different TMD mass configurations, generated using shaker excitation (logarithmic scale)

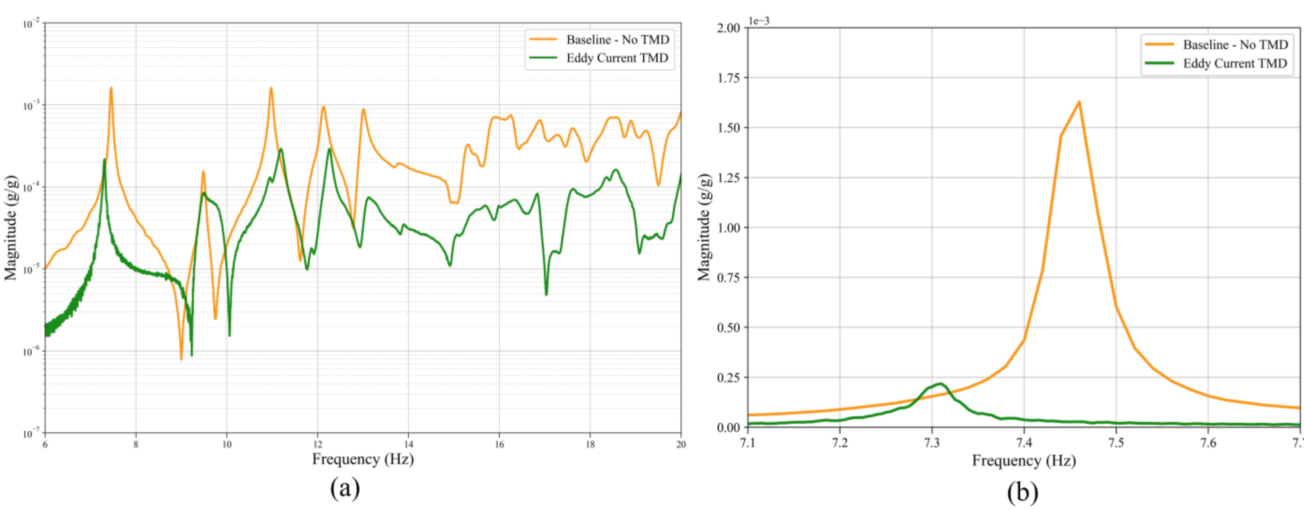


Fig. 7 FRFs measured at module 3 center for the baseline and TMD configurations: (a) Logarithmic-scale plot of the FRFs over the 6–20 Hz range; (b) Linear-scale plot of the FRFs near the fundamental mod

Effect of the TMD on Structural Damping

The structural damping of the floor system was quantified using the free-vibration decay method. This procedure involved exciting the floor to a steady-state resonance at its fundamental frequency, after which the shaker excitation was abruptly ceased. The resulting decay in acceleration was recorded, and the test was repeated across various excitation amplitudes to investigate the system's amplitude dependence. Prior to analysis, the raw acceleration signals were pre-processed by detrending and applying a Butterworth filter to eliminate high-frequency noise. The damping ratio (β) was then extracted by applying a curve fit of the signal's decaying peaks to an exponential function.

Damping Analysis

The damping of the baseline floor (without the TMD) was established first, with the decay curves shown in Fig. 8. The floor exhibited amplitude-dependent behavior, with the measured damping ratio (β) increasing from 0.29% at low-level excitations to 0.36% at high-level excitations.

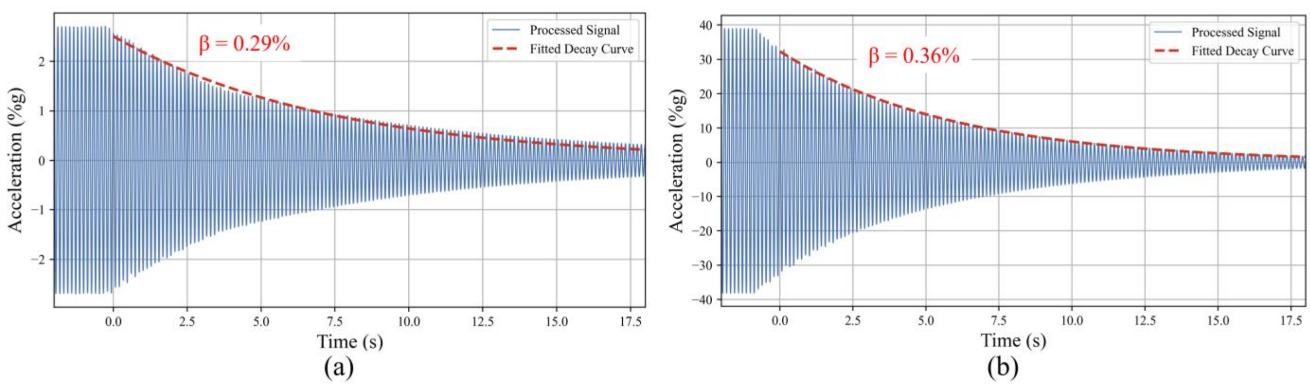


Fig. 8 Comparison of free-vibration decay curves for the baseline specimen at (a) low and (b) high excitation amplitude

The same tests were then performed with the eddy current TMD installed, and the results are shown in Fig. 9. The overall system damping was significantly higher and continued to show amplitude dependence. With the TMD, the damping ratio increased from 0.39% at low amplitudes to 0.55% at high amplitudes.

A direct comparison reveals the impact of the TMD. It increased the total system damping by 34% for low-amplitude vibrations and by 53% for high-amplitude vibrations. The TMD increases system damping by absorbing vibrational energy from the floor's resonant motion and using its eddy current damper to dissipate that energy as heat. The curve-fitted amplitude-damping curves are also shown and compared in Fig. 11.

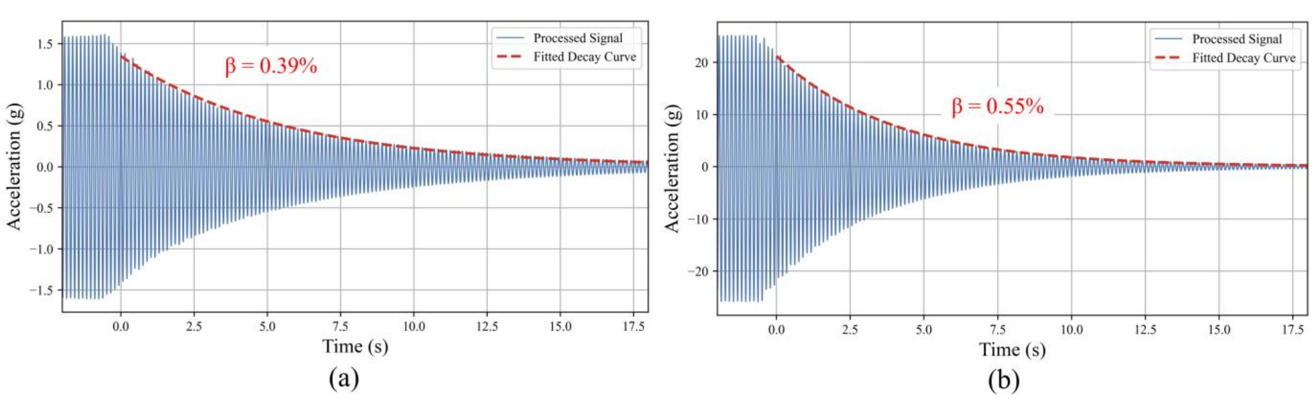


Fig. 9 Comparison of free-vibration decay curves for the TMD-equipped floor at (a) low and (b) high excitation amplitude

Amplitude-Dependent Damping

The amplitude dependence of the floor's damping was first quantified for the baseline case. As shown in **Fig. 10**, the damping ratio exhibits a clear nonlinear trend, increasing sharply for accelerations up to approximately 4% g, after which the rate of increase lessens. This phenomenon, known as the "amplitude dependence of modal parameters" [7], is attributed to inherent nonlinearities within the structural system.

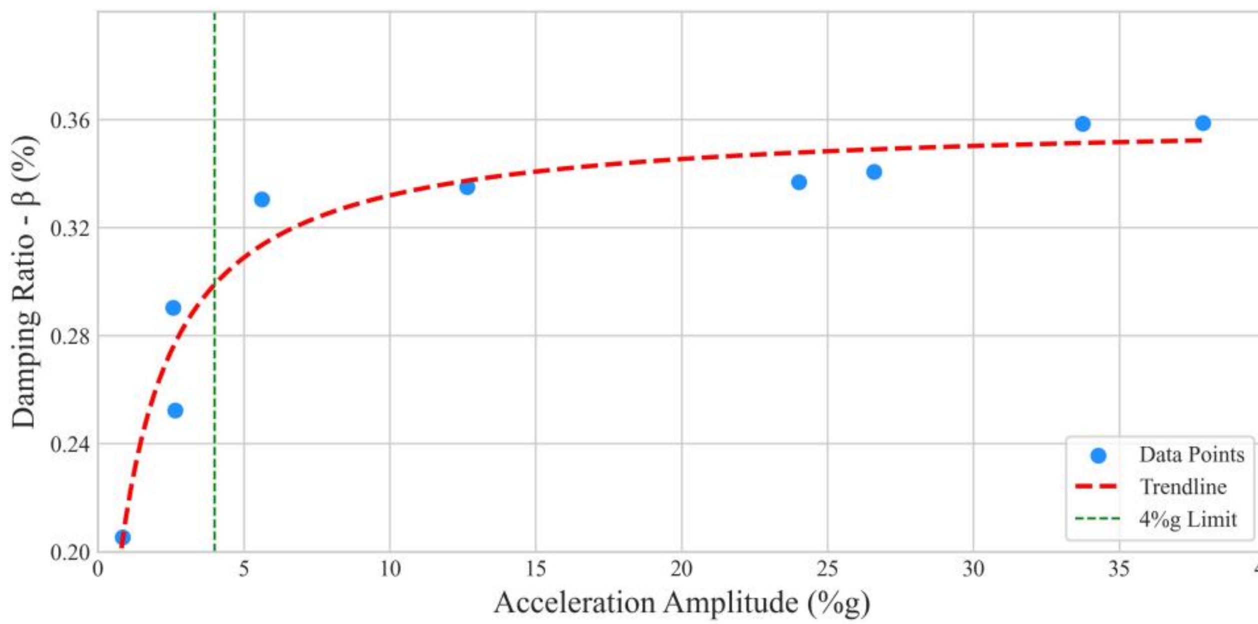


Fig. 10 Relationship between damping and acceleration amplitude for the baseline floor specimen

The same analysis was performed for the floor with the eddy current TMD installed, with the results plotted in Fig. 11. The TMD provided a significant increase in damping across all excitation levels while exhibiting a similar amplitude-

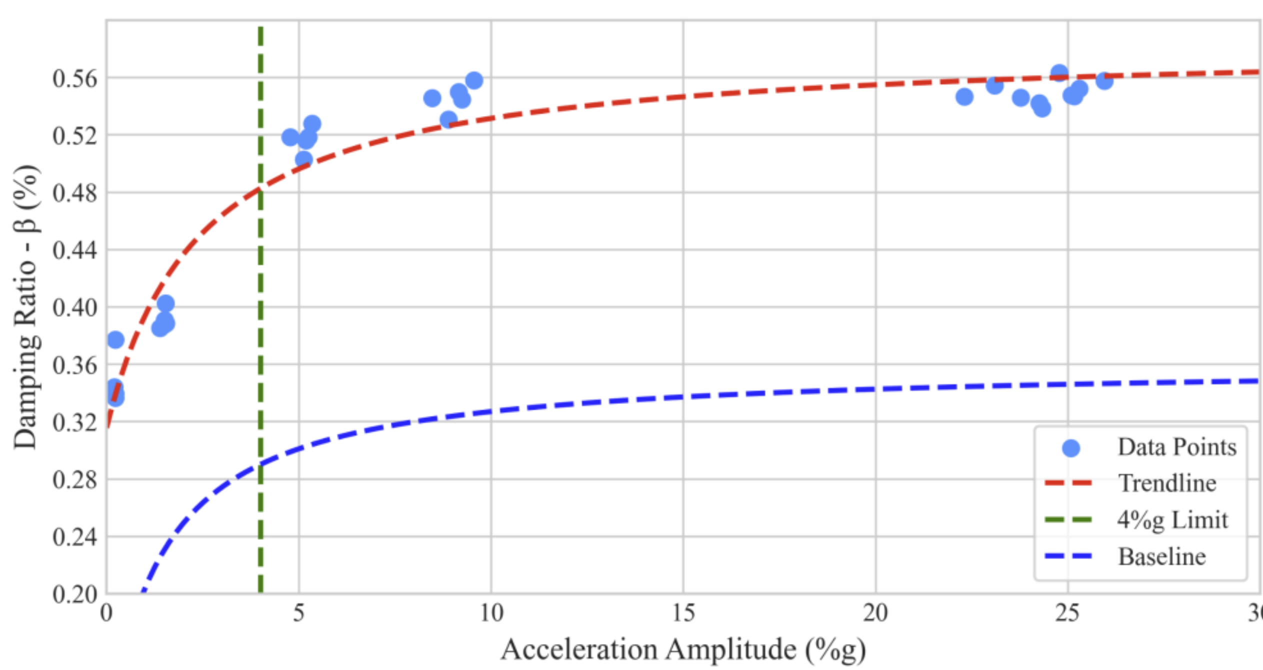


Fig. 11 Relationship between damping and acceleration amplitude for the TMD-equipped floors

dependent trend to the baseline case. The damping ratio again increased rapidly at lower amplitudes before the rate of increase began to slow.

TMD Performance Under Resonance

The TMD's effectiveness under resonant sine excitations was evaluated by comparing the acceleration of the TMD's mass to that of the floor at the center of module 3. A key performance metric is the response amplitude ratio between the TMD and the floor; a higher ratio indicates that the TMD is resonating as intended and actively dissipating energy. During resonant sine excitation, the TMD mass consistently exhibited a higher acceleration than the floor. As shown in Fig. 12, this amplitude ratio was measured to be 2.1 for both low- and high-level excitations, confirming the device was performing effectively.

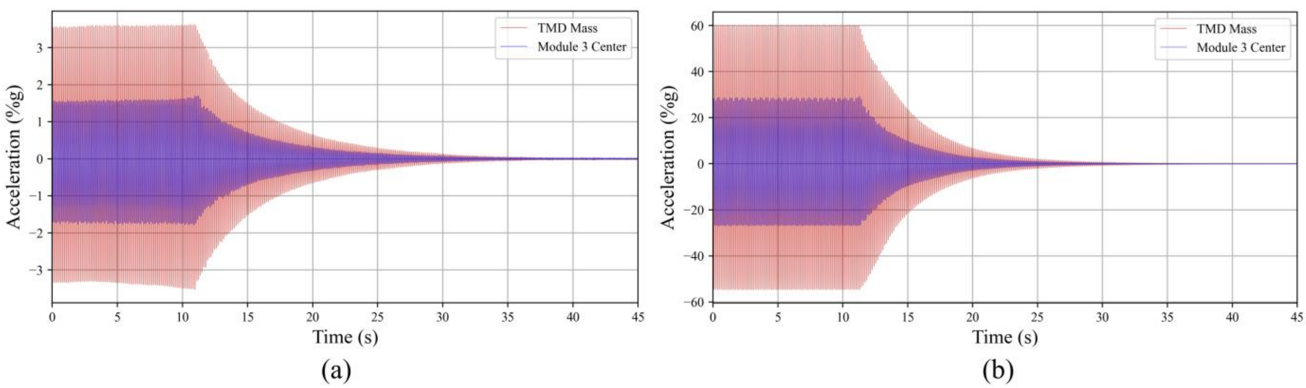


Fig. 12 Comparison of acceleration responses at the TMD mass and the module 3 center for (a) low-amplitude and (b) high-amplitude excitations

Effect of the TMD on the Floor's Response to Human Walking

To evaluate the TMD's effectiveness under realistic conditions, walking tests were conducted to simulate vibrations from human footfalls. To induce a resonant response, a walking pace corresponding to the fourth subharmonic of the floor's fundamental frequency (f_n /4) was maintained by two individuals. The tests were performed along the centerline of module 4, with a metronome used to ensure a consistent pace (Fig. 13). The resulting acceleration response was measured at the center of module 3.

From the acceleration signals, the Equivalent Sinusoidal Peak Acceleration (ESPA) was calculated. This metric is used to translate footfall vibrations for comparison against human comfort criteria. Following the procedures in AISC Design Guide 11 and SCI P354 [2, 7], the ESPA was determined by multiplying the maximum one-second root-mean-square (RMS) of the filtered signal by $\sqrt{2}$. The 90$^{\text{th}}$ percentile ESPA value was used for comparison to provide a robust statistical measure. The results, summarized in Table 1, show a significant improvement with the TMD installed: the 90$^{\text{th}}$ percentile ESPA decreased

Table 1 Statistical summary of ESPA results from human-walking tests

			Equivalent Sinusoidal Peak Accelerations (ESPAs) [%g]				
Configuration	**# of Walking Tests**	**Step Frequency (steps/min)**	**Mean (μ)**	**Min**	**Max**	**STD (σ)**	**90$^{\text{th}}$ Percentile (μ+1.28σ)**
Baseline	14	112	1.53	1.17	1.92	0.26	1.86
Eddy Current TMD	6	110	1.17	0.86	1.40	0.17	1.39

Fig. 13 Setup for the metronome-guided walking tests along the centerline of module 4, with accelerometers deployed along the centerline of module 3

by 25%, the maximum ESPA was reduced by 27%, and the mean ESPA decreased by 24%. This significant reduction demonstrates the TMD's effectiveness for the low-amplitude, subharmonic excitations typical of human walking.

Conclusion

This paper presented the experimental evaluation of a Tuned Mass Damper (TMD) that incorporates an eddy current damper. The objective of this study was to quantify the system performance in mitigating vibrations on a full-scale laboratory floor. The main conclusions of the study are as follows:

1. The TMD was successfully tuned to the floor's fundamental frequency by optimizing its mass configuration. Analysis of FRFs confirmed the TMD was working as intended, suppressing the peak resonant magnitude by 86% compared to the baseline floor.
2. Free-vibration decay tests demonstrated a significant increase in the floor's structural damping. The system damping ratio was increased by 34% at low vibration amplitudes and by 53% at high amplitudes, showing a good performance across a range of conditions.
3. Under human-walking tests, the TMD proved effective at improving the floor's response to walking-induced loads. It achieved a significant 25% reduction in the 90^{th} percentile Equivalent Sinusoidal Peak Acceleration (ESPA), demonstrating a substantial improvement in the floor's response to footfall-induced vibrations.

In conclusion, this study demonstrated the successful performance of the eddy current TMD on an isolated laboratory floor. The experimental results from this proof-of-concept study confirm that this non-contact technology is a promising method for suppressing resonant vibrations. The future work on this damper will provide more information and shed more light on the potential of the proposed TMD device on modern floor systems and other structures such as stadia.

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