Chapter 9
Vibration Serviceability of a Modular All-Steel Floor Under Simulated Façade and Service Loads

Sahabeddin Rifai, Ahmad Rababah, Feras Abla, Mohamed Tareq Soliman, and Onur Avci

Abstract The dynamic properties and vibration serviceability of modern long-span steel floors are influenced by non-structural loads applied after construction, such as façades and service loads. This paper experimentally investigates these effects on a full-scale, 30 ft × 42 ft modular all-steel floor system. Three configurations were tested: an unloaded baseline, a 225 plf simulated façade line load, and a 12 psf simulated service area load. Modal properties were determined using shaker tests, while walking tests at a critical subharmonic frequency were performed to evaluate the vibration response, quantified by the Equivalent Sinusoidal Peak Acceleration (ESPA). The results showed that the distributed service load increased the structural damping by 40% (from 0.25% to 0.35%) and reduced the 90$^{\text{th}}$ percentile ESPA by 11%. In contrast, the façade load did not improve performance, with the 90$^{\text{th}}$ percentile ESPA slightly increasing compared to the baseline. The findings demonstrate that while all added mass reduces a floor's natural frequencies, only broadly distributed loads that also contribute to system damping may provide a tangible benefit to vibration serviceability.

Keywords Façade load · Service load · Floor vibrations · Modal analysis · Vibration serviceability

Introduction

Vibration serviceability in modern building floors has become a critical component of structural design to ensure occupant comfort [1]. Architectural trends that favor open-plan layouts with long spans and lightweight materials often produce highly flexible floor systems. A key consequence of these design choices is a reduction in inherent structural damping, which is the system's natural ability to dissipate vibrational energy. As a result, such floors can develop excessive vibrations when excited into resonant buildups by common human activities, like walking or rhythmic group exercises. This has elevated vibration serviceability from a secondary concern to primary design criterion for many structures, which is often more critical than strength requirements.

This study focuses on simulation of façade and service area loads on a full-bay FastFloor specimen. FastFloor is an innovative all-steel modular floor system composed of prefabricated components designed for faster steel-framed floor construction. Developed in response to the AISC "Need for Speed" initiative to accelerate steel construction [2]. FastFloor's lightweight and long-span characteristics make it an important case study for understanding its dynamic behavior and addressing potential serviceability issues. The development and research program of FastFloor was detailed in [3]. Prior research on FastFloor system includes initial vibration and modal testing on single modules [4, 5], finite element model updating , and serviceability assessments and predicted peak accelerations under synchronous walking [6, 7, 8]. The effect of lateral braces, called angle blocking, on modal parameters was also investigated in [9].

This study experimentally investigates the effects of simulated non-structural loads on the dynamic response of a full-scale, 30 ft × 42 ft FastFloor laboratory specimen. Two distinct load cases were evaluated against an unloaded baseline condition: a 225 plf (3.28 KN/m) line mass applied to the cantilever edge to represent a façade load, and a 12 psf (575 N/m^2) distributed area load representing a service load. The investigation focuses on quantifying changes in the floor's structural damping, and acceleration responses under human walking loads. To achieve this, experimental modal analysis

Sahabeddin Rifai · Ahmad Rababah · Feras Abla · Mohamed Tareq Soliman · Onur Avci
Department of Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506
e-mail: sr00090@mix.wvu.edu; ayr00002@mix.wvu.edu; fa00060@mix.wvu.edu; mts00029@mix.wvu.edu; onur.avci@mail.wvu.edu

Kristin B. Zimmerman, PhD (eds.), *Dynamics of Civil Structures, 2026, Vol. 2*, Conference Proceedings
of the Society for Experimental Mechanics Series, https://doi.org/10.1007/97887-438-1441-2_9

was conducted on all configurations, and free-vibration decay tests were performed to measure the damping of the baseline and service load conditions

This paper is organized as follows: Section 2 describes the full-bay FastFloor test specimen. Section 3 details the experimental setups used to simulate the façade and service loads. Section 4 presents the experimental results, including an analysis of the frequency response functions (FRFs), a quantification of the structural damping , and an evaluation of the floor's response to human walking. Finally, Section 5 summarizes the key findings and presents the conclusions of the study.

Tested FastFloor Specimen

The full-bay FastFloor specimen tested in this study measures 30 ft (9.1 m) wide and 42 ft (12.8 m) long. FastFloor is an innovative all-steel floor system developed to accelerate the construction of commercial buildings. It consists of prefabricated modules and infill plates that are rapidly assembled on-site with bolted connections.

A plan view of the FastFloor specimen, illustrating the location of the simulated façade load on the exterior cantilever edge, is shown in Fig. 1. The specimen is constructed from three prefabricated modules and nine infill plates. The structural framing consists of two W30×108 girders and seven W24×68 beams, all supporting a $\frac{1}{2}$ in. (12.7 mm) thick steel plate deck (Fig. 2-a). The girders and edge beams are attached to W14 columns using shear tab connections.

All tests reported in this study were conducted with a raised access floor (RAF) installed over the steel deck, as shown in Fig. 2-b. This configuration, without any additional applied loads, served as the baseline for all subsequent tests. During baseline testing, the specimen supported only self-weight.

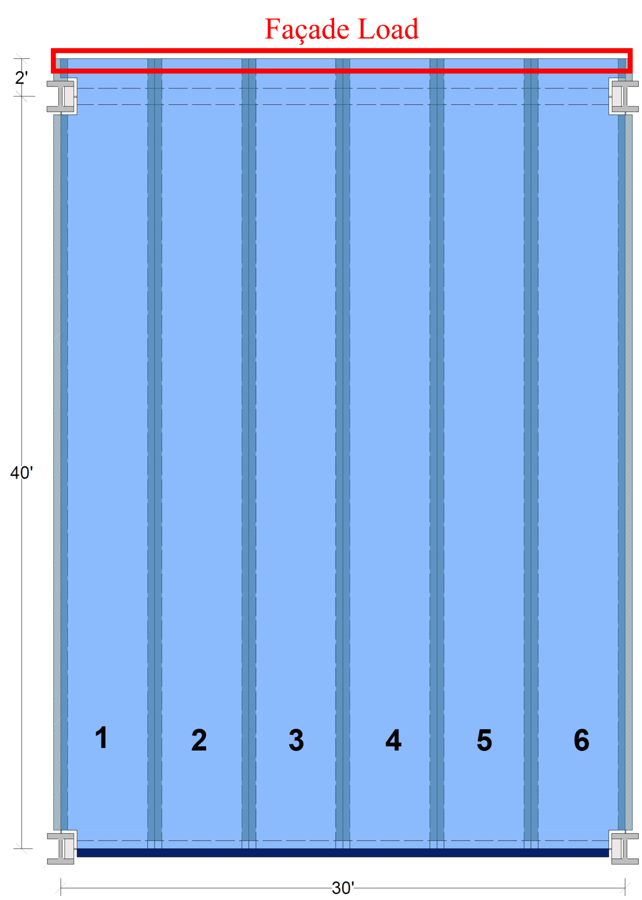
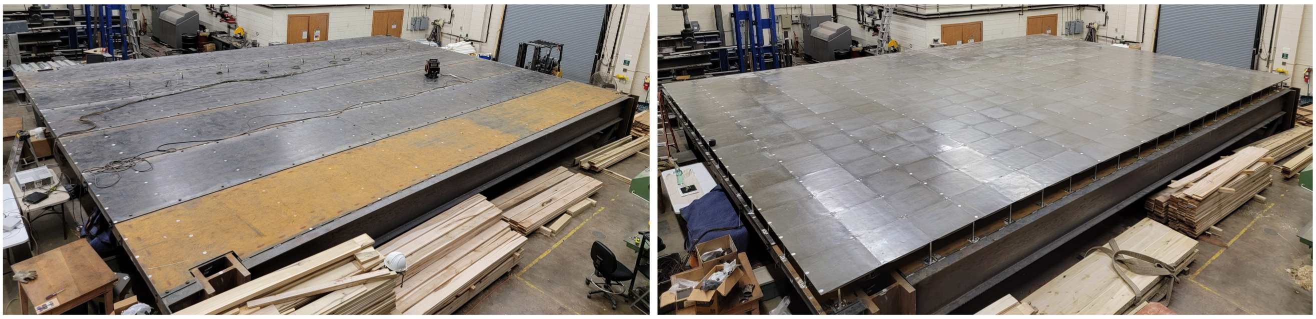


Fig. 1 Plan layout of the 30 ft × 42 ft all-steel FastFloor specimen, illustrating the location of the simulated façade load



(a) (b)

Fig. 2 The full-bay FastFloor specimen: (a) bare steel deck condition and (b) with the raised access floor (RAF) installed. The RAF configuration represents the unloaded baseline for all tests

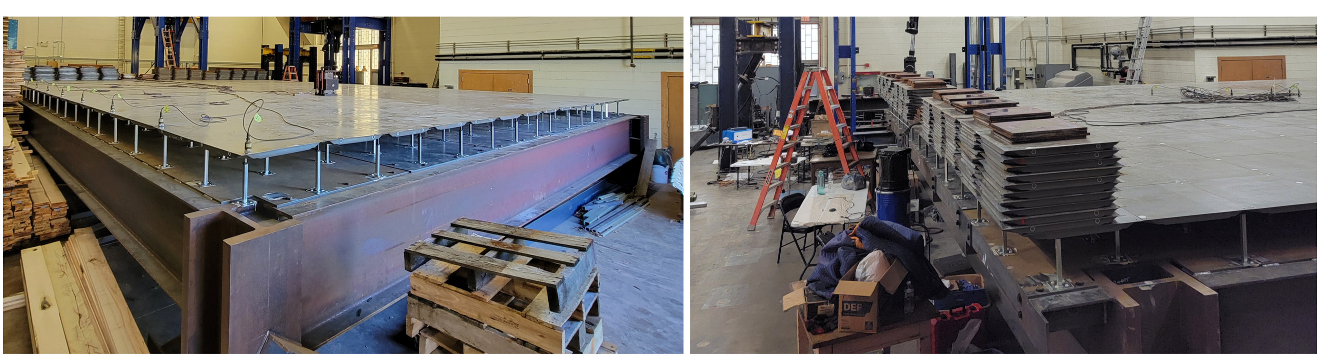
Test Setups with Façade and Service Loads

To investigate the influence of added mass, three distinct configurations were tested, as detailed in Table 1. The reference case was the Baseline (BL) configuration, representing the as-built floor with no additional loads. The second configuration with façade load (FL), simulated the weight of a façade. As shown in Fig. 3, this was achieved by placing a line mass of panels and steel plates along an exterior edge, equivalent to a 225 plf linear load.

The third configuration with service load (SL) represented a typical superimposed dead load. A distributed mass equivalent to a 12 psf area load was applied by placing materials across the floor surface, as seen in Fig. 4. Due to the large floor area, this corresponded to a total applied mass of 15.12 kips (7.56 metric tons). Small areas were left clear to accommodate the mass shaker, accelerometers, and walking spaces.

Table 1 Test configurations with notations and simulated loads

No.	Configuration	Notation	Linear Load on Exterior Edge	Area Load
1	Baseline	BL	0	0
2	Baseline with Façade Load	FL	225 plf	0
3	Baseline with Service Load	SL	0	12 psf



(a) (b)

Fig. 3 Configuration with façade load (FL) applied as a line mass of panels and plates simulating a 225 plf load on the exterior edge of the cantilever

Fig. 4 Configuration with service load (SL) applied as distributed mass simulating a 12 psf area load

Experimental Testing Results

Frequency Response Functions (FRFs)

Experimental modal analysis was performed using an electrodynamic shaker to obtain frequency response functions (FRFs) for all three test configurations. The shaker was positioned at the quarter-point along the centerline of module 3, and responses were measured at 300 points across the floor. The sensor grid was denser in the short direction to better capture plate bending modes with double curvature. Since both the input excitation and the output response were measured as acceleration, the resulting FRF magnitude is unitless. An overlay of all 300 FRFs for the baseline (BL) configuration is shown in Fig. 5.

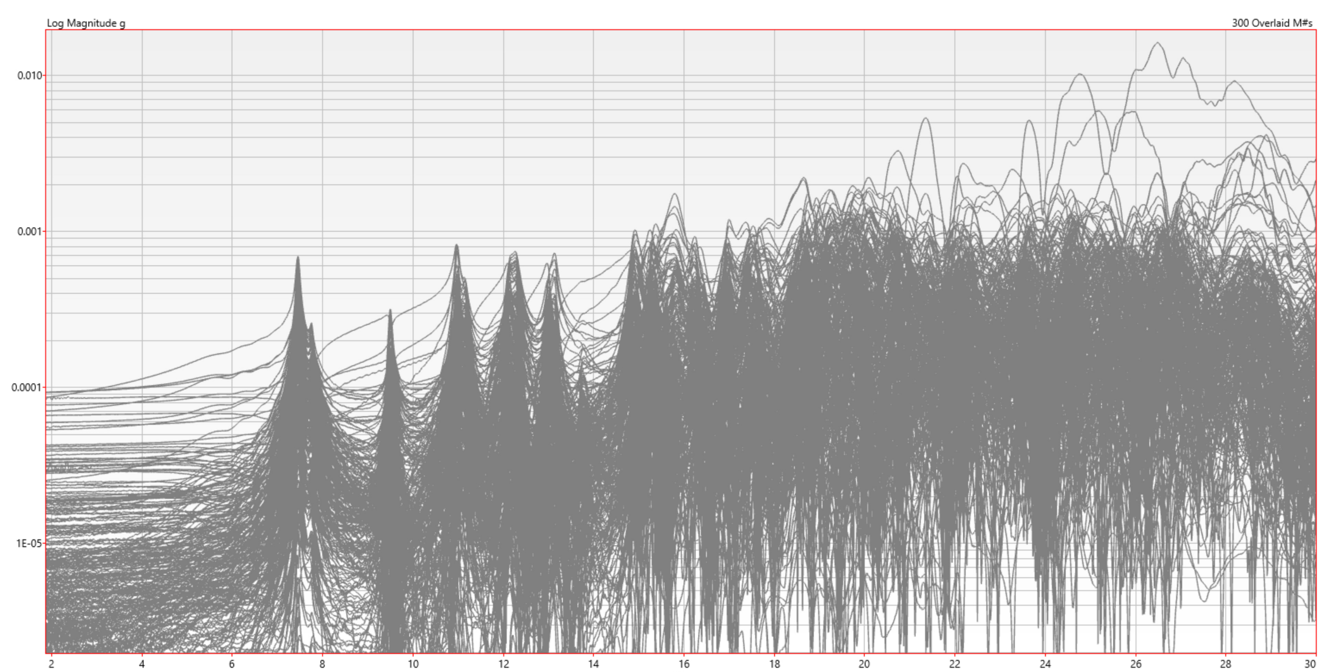


Fig. 5 Overlaid frequency response functions (FRFs) from 300 measurement points on the baseline (BL) configuration

To compare the effects of the added loads, the FRFs from a single point (the center of Module 3) are overlaid on a logarithmic scale in Fig. 6. This location captures responses from both beam and plate bending modes. The baseline (BL) FRF is characterized by the highest peak amplitudes at frequencies below 14 Hz. As expected, the added mass from the façade (FL) and service (SL) loads causes the FRF peaks to shift to lower frequencies. The frequency shift is more pronounced for the SL configuration due to its greater total mass.

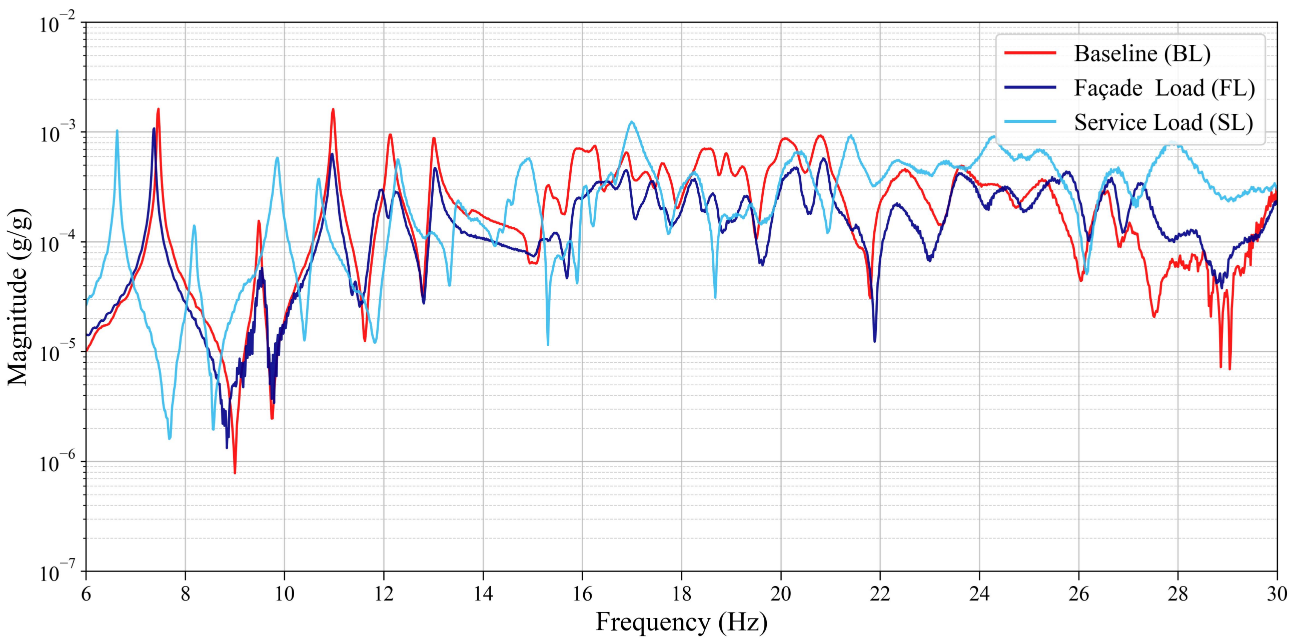


Fig. 6 Comparison of FRFs for all three configurations, measured at the center of module 3 (logarithmic scale)

Since the first (fundamental) mode has the highest mass participation and typically dominates the floor's vertical vibration response, it is examined more closely. The shape of this primary bending mode is shown in Fig. 7. A detailed view of the FRFs near the fundamental mode is presented on a linear scale in Fig. 8. Compared to the baseline, the peak magnitudes for both the FL and SL configurations are reduced. Both loaded configurations show a similar reduction in the first peak's magnitude, which is approximately 30% lower than that of the baseline.

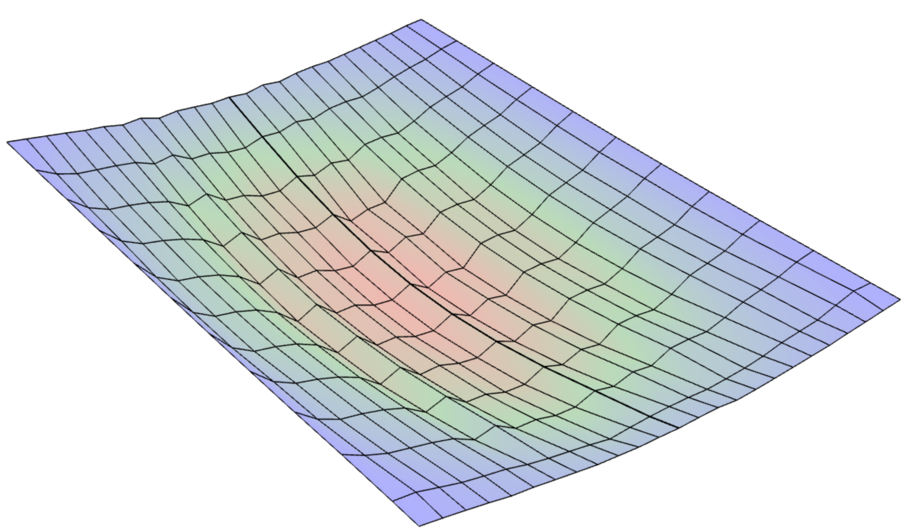


Fig. 7 The first (fundamental) mode shape, showing the major bending behavior of the floor

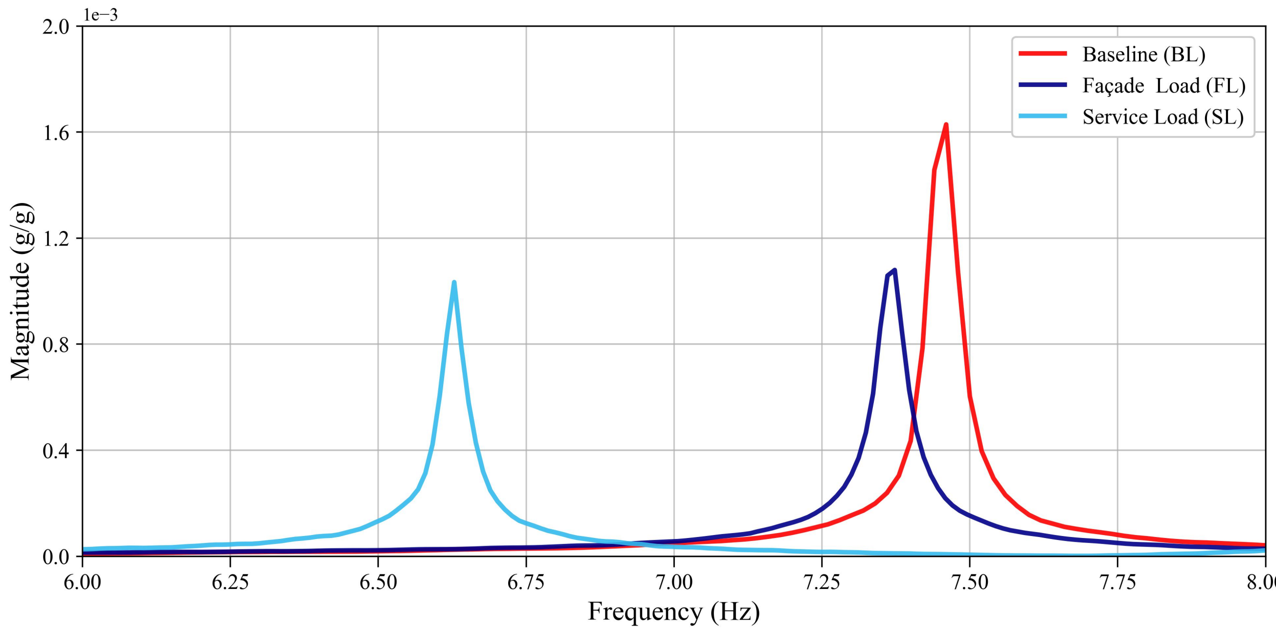


Fig. 8 Linear-scale FRFs showing the detailed response near the fundamental mode for all three configurations

Structural Damping

The effect of the added service load on the floor's overall structural damping ratio (β) was quantified using free-vibration decay tests. These tests were conducted for the baseline (BL) and service load (SL) configurations only. The procedure involved exciting the floor to a steady-state resonance at its fundamental frequency using low-amplitude shaker inputs. The excitation was then abruptly stopped, and the subsequent decay was recorded. The acceleration signals were pre-processed by detrending and applying a Butterworth filter, after which the damping ratio (β) was extracted by fitting an exponential function to the decaying peaks.

The results, illustrated by the decay curves in Fig. 9, show that the addition of the 12 psf service load increased the floor's structural damping. Under low-amplitude excitation, the damping ratio for the baseline configuration was found to be 0.25%. For the SL configuration, the damping increased to 0.35%, representing a 40% increase due to the presence of the service load.

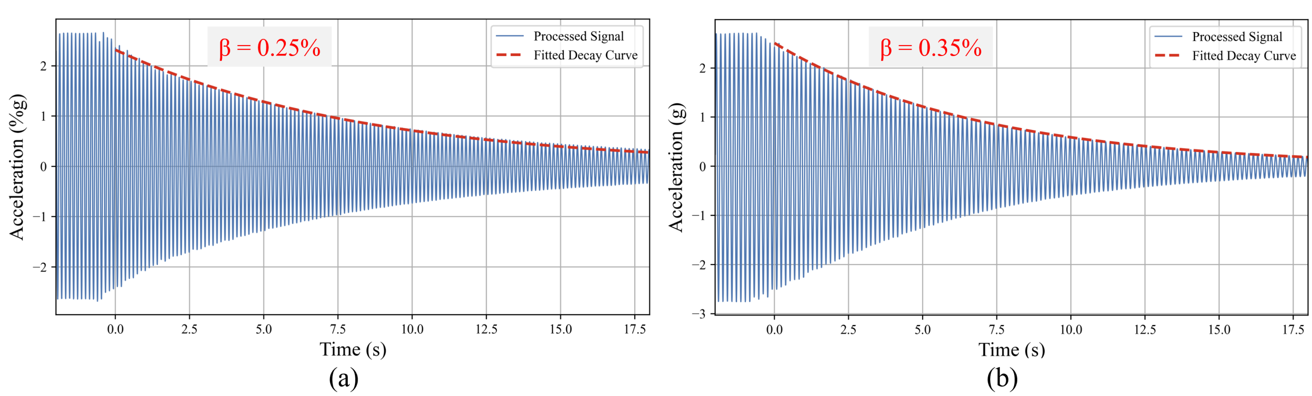


Fig. 9 Comparison of free-vibration decay curves for the (a) baseline (BL) and (b) service load (SL) configurations, showing the increase in damping under low-amplitude excitations

Response to Human Walking

To measure the response under footfalls, a series of walking tests was performed on each floor configuration. During these tests, four individuals walked along the centerline of module 4. A metronome was used to maintain a consistent step frequency equal to the fourth subharmonic of the floor's fundamental frequency (f_n /4). This pacing is known to be effective for exciting a resonant buildup in such structures. The resulting vibrations were recorded by an accelerometer at the center of module 3.

The recorded acceleration data was then processed using the Equivalent Sinusoidal Peak Acceleration (ESPA) method to evaluate the floor against established human comfort criteria. In accordance with procedures from AISC Design Guide 11 and SCI P354, the ESPA for each test was calculated by identifying the maximum one-second root-mean-square (RMS) value from the filtered acceleration signal and multiplying it by $\sqrt{2}$ [1, 10].

To account for the inherent variability in human footfalls over multiple trials, the 90^{th} percentile ESPA was used as the final, representative metric for comparison. This statistical approach provides a robust value that is less influenced by outlier measurements, which is particularly important for low-damping systems where response data can be more scattered.

The results of the walking tests, summarized in Table 2, show that the two load types had different effects on the floor's vibration response. The simulated façade load (FL) did not improve the floor's performance. In fact, the mean, maximum, and 90^{th} percentile ESPA values all increased slightly compared to the baseline. This outcome is likely attributed to the fact that the concentrated line load did not significantly increase the overall system damping. In contrast, the service load (SL) led to a reduction in the vibration response. The 90^{th} percentile ESPA decreased from 1.79 %g to 1.59 %g, an 11% decrease. This reduction is a direct result of the added structural damping provided by the distributed mass. The findings suggest that while edge mass may not benefit serviceability, broadly distributed service loads can provide a modest but helpful improvement in vibration performance.

Table 2 Statistical summary of damping and ESPA values from the human walking tests

			Equivalent Sinusoidal Peak Accelerations (ESPAs) [%g]				
Configuration	**# of Walking Tests**	**Step Frequency (steps/min)**	**Mean (μ)**	**Min**	**Max**	**STD (σ)**	**90^{th} Percentile (μ+1.28σ)**
BL	28	112	1.46	1.09	1.92	0.26	1.79
FL	28	111	1.49	1.07	2.13	0.26	1.82
SL	28	99	1.30	0.93	1.87	0.23	1.59

Conclusions

This paper presented an experimental investigation into the effects of simulated façade and service loads on the vibration response of a full-bay modular all-steel floor. The study compared an unloaded baseline configuration with two loaded cases: a concentrated line load representing a façade and a distributed area load representing a service load. The key findings are as follows:

1. The addition of mass from both the façade and service loads reduced the floor's natural frequencies, with the service load causing a more significant reduction due to its greater total mass.
2. The distributed service load (SL) provided a measurable benefit to the floor's performance. It increased the overall structural damping ratio by 40% (from 0.25% to 0.35%) and consequently reduced the 90^{th} percentile walking-induced vibration response (ESPA) by 11%.
3. In contrast, the façade load (FL) did not improve the vibration serviceability. The 90^{th} percentile ESPA increased slightly compared to the baseline, which is attributed to the line load not contributing significantly to the system's overall damping.

These findings demonstrate that while all superimposed dead loads reduce a floor's natural frequency, only broadly distributed loads that also contribute to system damping may provide a tangible benefit to its vibration serviceability. The location and type of non-structural mass are therefore critical considerations in the vibration analysis of modern floor systems.

Acknowledgments This work was sponsored by the Charles Pankow Foundation, American Institute of Steel Construction (AISC), MKA Foundation, Nucor, Schuff Steel, Herrick Steel, Cives Steel, Zekelman Industries (Atlas Tube/Shuriken), and Metals Fabrication. In-kind support was provided by Cerami, Sherwin-Williams, Cooper Steel, Clark Construction, and Hensel Phelps. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the sponsors and supporters.

References

1. T. M. Murray, D. E. Allen, E. E. Ungar, and D. B. Davis, "Design Guide 11: Vibrations of Steel-Framed Structural Systems Due to Human Activity (Second Ed.) | American Institute of Steel Construction."
2. FastFloor – The Need for Speed – Session 1 [N24] 2024 | AISC. [Online Video]. Available: https://learning.aisc.org/local/catalog/view/product.php?productid=2508
3. B. Schafer, O. Avci, W. S. Easterling, M. R. Eatherton, and J. Hajjar, "FastFloor – Development of A Novel Modular Steel Floor System for Commercial Construction in The United States," Dec. 02, 2024, Engineering Archive. doi: 10.31224/4183.
4. O. Avci et al., "Vibration Testing of an All-Steel Modular Floor Assembly," in Dynamics of Civil Structures, Vol. 2, M. Whelan, P. S. Harvey, and F. Moreu, Eds., Cham: Springer Nature Switzerland, 2025, pp. 17–23. doi: 10.1007/978-3-031-68889-8_3.
5. S. Rifai et al., "Modal Testing and Finite Element Model Updating of a FastFloor Specimen: A Modular All-Steel Floor System," in Dynamics of Civil Structures, Vol. 2, River Publishers, 2025. doi: 10.13052/rp-9788743801597A004.
6. O. Avci and M. A. M. Celin, "Vibration Serviceability Evaluation of a Modular Steel Plate Floor Assembly," in Dynamics of Civil Structures, Volume 2, Springer.
7. M. A. Mercado Celin, "Vibration Serviceability Assessment of a Steel Modular Floor System," Virginia Tech, 2023.
8. S. Rifai, Abla, Feras, A. Rababah, R. C. M. Kumar, B. W. Schafer, and M. R. Eatherton, "Vibration Serviceability Evaluation of an All-Steel Floor System using the High-Frequency Floor Procedure," in Dynamics of Civil Structures, Vol. 2, River Publishers, 2025. doi: 10.13052/rp-9788743801597A010.
9. S. Rifai et al., "Effect of Bottom Flange Angle Blocking on the Dynamic Re- sponse of Two All-Steel Laboratory Floors," in Dynamics of Civil Structures, Vol. 2, River Publishers, 2025. doi: 10.13052/rp-9788743801597A003.
10. A. L. Smith, S. J. Hicks, and P. Devine, Design of Floors for Vibration: A New Approach (2009).