Chapter 8
Effect of Stationary Occupants on Damping and Vibration Response of a Modular All-Steel Laboratory Floor

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

Abstract This paper presents an experimental study on a full-scale, 30 ft × 42 ft modular all-steel floor system to quantify the relationship between supplemental damping and walking-induced vibrations. Increased damping levels were simulated by introducing stationary groups of two to thirteen human occupants. Structural damping ratios for each configuration were determined using free-vibration decay tests, while the floor's performance was evaluated through walking tests conducted at the critical fourth subharmonic of the floor's fundamental frequency. The response was quantified using the Equivalent Sinusoidal Peak Acceleration (ESPA) metric. The unoccupied floor possessed a very low baseline damping of 0.34%. The presence of occupants increased this value progressively to a maximum of 4.91%. This added damping had a significant effect on the floor's performance, reducing the 90th percentile ESPA from walking by up to 81% compared to the baseline. The results suggest that a damping ratio of approximately 2.30% is required for this floor to meet the 0.50%g acceleration limit recommended by common design guides. The findings provide a clear, quantitative link between system damping and vibration serviceability, offering valuable data for the design and remediation of similar low-damping floor structures.

Keywords Floor vibrations · Vibration serviceability · Structural damping · Human-induced damping · Human-structure interaction.

Introduction

Structural damping is a critical factor governing the vibration response of floor systems. Higher damping levels are generally beneficial for floor vibration serviceability; however, achieving adequate damping can be challenging, particularly in modern commercial buildings. Current design trends favoring long, uninterrupted spans with lighter materials and fewer non-structural components often result in flexible floor systems. These characteristics lead to inherently low damping, making floors susceptible to excessive vibrations from common human activities like walking. Consequently, vibration serviceability has become a governing design criterion for many modern floors, often proving more critical than strength requirements [1, 2].

A common strategy for mitigating excessive floor vibrations is supplemental damping. In a laboratory setting, a convenient method for simulating supplemental damping is to use stationary human occupants. It is well-established that the human body acts as a good damper; people occupying a floor can absorb vibrational energy, thereby reducing the floor's response [3].

In its bare laboratory condition, the full-bay test specimen for this study exhibits inherently low damping. As a result, preliminary tests of human walking induced peak accelerations higher than those recommended by design guidelines for human comfort. The primary objective of this research was, therefore, to determine the level of damping required for this specific floor to achieve an acceptable vibration response, particularly when subjected to walking at a critical step frequency ($f_n/4$).

To achieve this goal, this study investigates the damping provided by stationary humans standing on a 30 ft × 42 ft (9.1 m × 12.8 m) full-bay FastFloor laboratory specimen. Damping levels were varied by testing the floor with groups of two to thirteen standing people. Free-vibration decay tests were performed on each configuration by exciting the floor to resonance

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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_8

and then recording the subsequent decay in vibration after excitation is stopped. Damping ratios for each case were then computed by applying a curve-fitting algorithm to the decay responses.

The tested floor system, called FastFloor, is a modular, all-steel system developed to accelerate steel construction [4]. Previous research on the FastFloor system includes the initial design and testing of single-module configurations [5, 6, 7], finite element model updating [8], and investigations into modal response and serviceability [5, 6, 7, 8, 9] with the overall research program outlined in [10].

Laboratory Floor Specimen

The floor specimen investigated in this study is a full-bay FastFloor system measuring 30 ft × 42 ft (9.1 m × 12.8 m) in plan. FastFloor is a modular, all-steel floor system developed to accelerate the steel construction of commercial buildings, consisting of prefabricated modules and infill plates that are rapidly assembled on-site with bolted connections.

As illustrated in Fig. 1, the bare floor is constructed from three prefabricated modules and nine infill plates. Its structural framing consists of two W30×108 girders and seven W24×68 beams supporting a $\frac{1}{2}$ in. (12.7 mm) thick steel plate deck. The girders and edge beams are attached to W14 columns using shear tab connections.

For this study, all tests were conducted with a raised access floor (RAF) installed over the steel deck (Fig. 2). This unoccupied configuration, supporting only its self-weight with no additional service loads, served as the baseline condition for all subsequent tests.

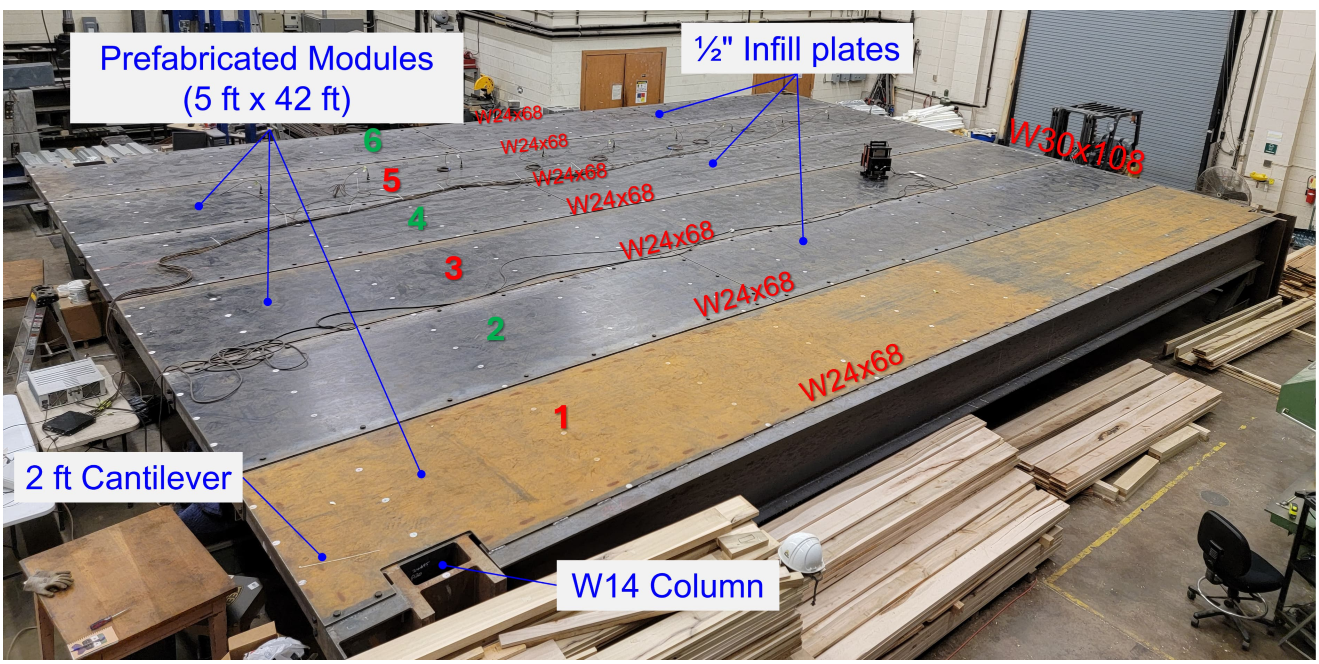

Fig. 1 The 30 ft × 42 ft all-steel FastFloor specimen in its bare condition with components annotated

Test Setups with Stationary Occupants

A series of tests were conducted with stationary human occupants to investigate the influence of supplemental damping on the floor's response. The baseline FastFloor specimen possesses inherently low damping due to its all-steel composition and isolated laboratory condition. To simulate the higher damping levels of an occupied floor, groups of people were asked to stand at specific locations close the specimen's centerline. Seven distinct configurations were tested, starting with the unoccupied baseline and incrementally adding people up to a maximum of thirteen. Table 1 details these configurations, which are ordered by an increasing number of occupants to correspond with a progressive increase in system damping.

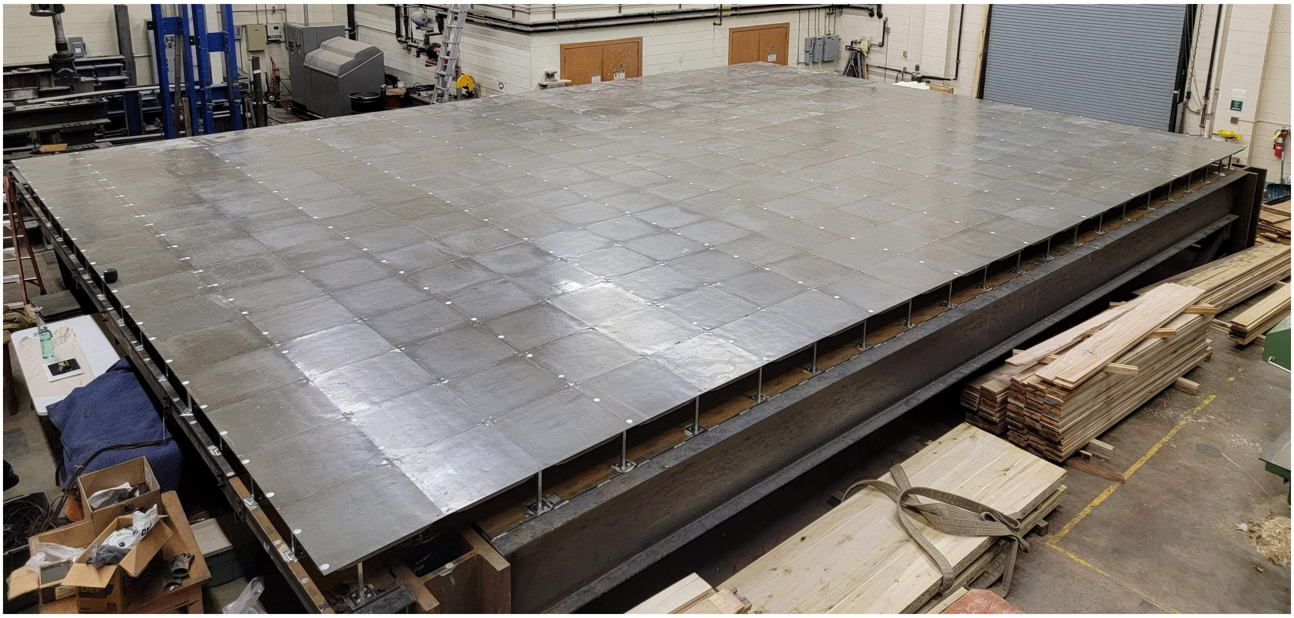

Fig. 2 The full-bay FastFloor specimen with the raised access floor (RAF) installed and no other load on the floor, representing the baseline test configuration

Table 1 Test configurations with notations and number of people standing

No.	Notation	Total Standers	Standers (Left of floor CL)	Standers (Right of floor CL)
0	Baseline	0	0	0
1	L1-R1	2	1	1
2	L2-R2	4	2	2
3	L3-R3	6	3	3
4	L4-R4	8	4	4
5	L11-R0	11	11	0
6	L7-R6	13	7	6

Four of the occupied test configurations are illustrated in Fig. 3. In these configurations, the ”left” (L) and ”right” (R) designations correspond to the specimen’s layout, with module 1 defining the far-left side and module 6 defining the far-right. The figure shows several symmetric arrangements, such as the two-person (L1-R1) and six-person (L3-R3) cases, as well as an asymmetric configuration with eleven occupants on the left side (L11-R0).

Experimental Testing Results

Frequency Response Functions (FRFs)

Experimental modal analysis was performed using an electrodynamic shaker to obtain frequency response functions (FRFs) for all seven test configurations. The shaker was positioned at the quarter-point along the centerline of module 3, and responses were measured at several points, including the center of that same module.

The FRFs measured at the center of module 3 are shown on a logarithmic scale in Fig. 4. The baseline FRF (unoccupied floor) is characterized by clean, distinct peaks with the highest amplitudes. As human occupants are added, two primary effects are observed. First, the FRF magnitudes decrease progressively with an increasing number of people. Second, the FRF curves become noisy, particularly around the first mode. This noise is attributed to minor, involuntary movements of the occupants, creating complex floor-structured interaction, even though they were instructed to remain as still as possible.

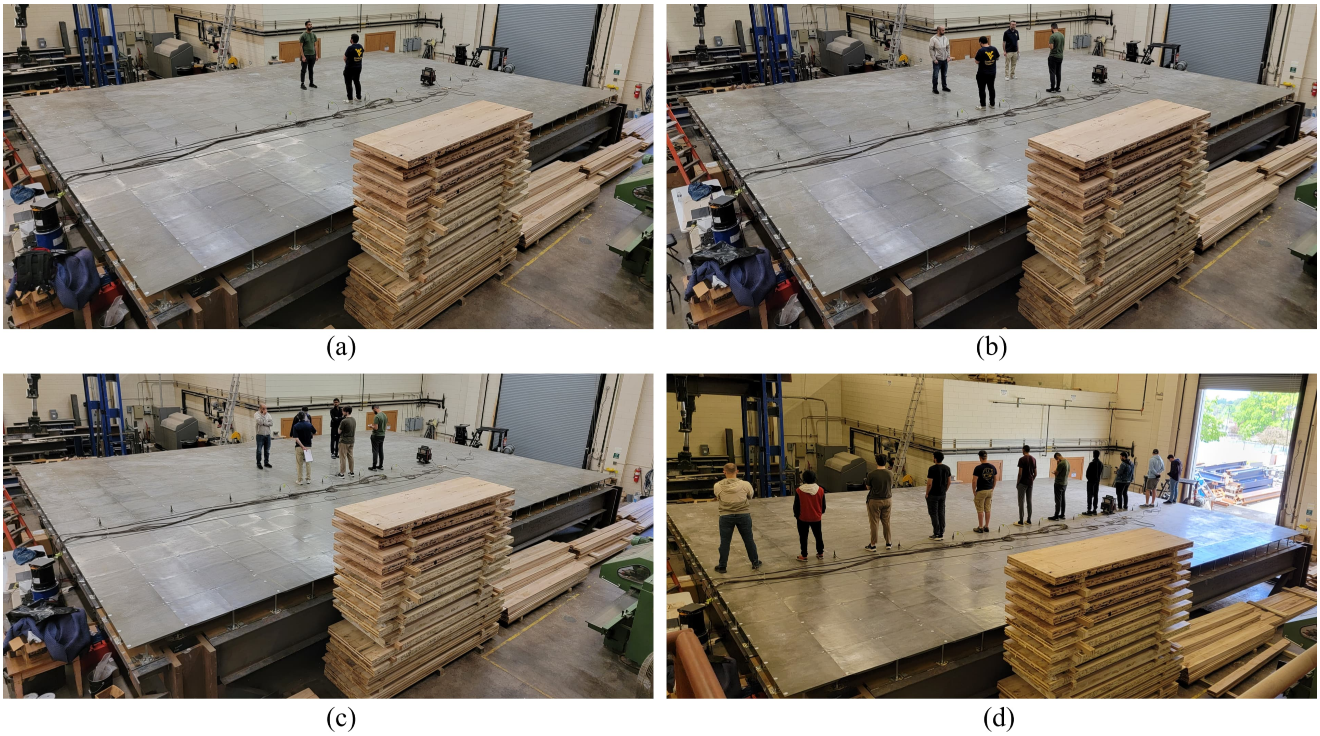

Fig. 3 Four configurations with people standing on the FastFloor specimen to simulate higher damping levels: (a) L1-R1, (b) L2-R2, (c) L3-R3, and (d) L11-R0

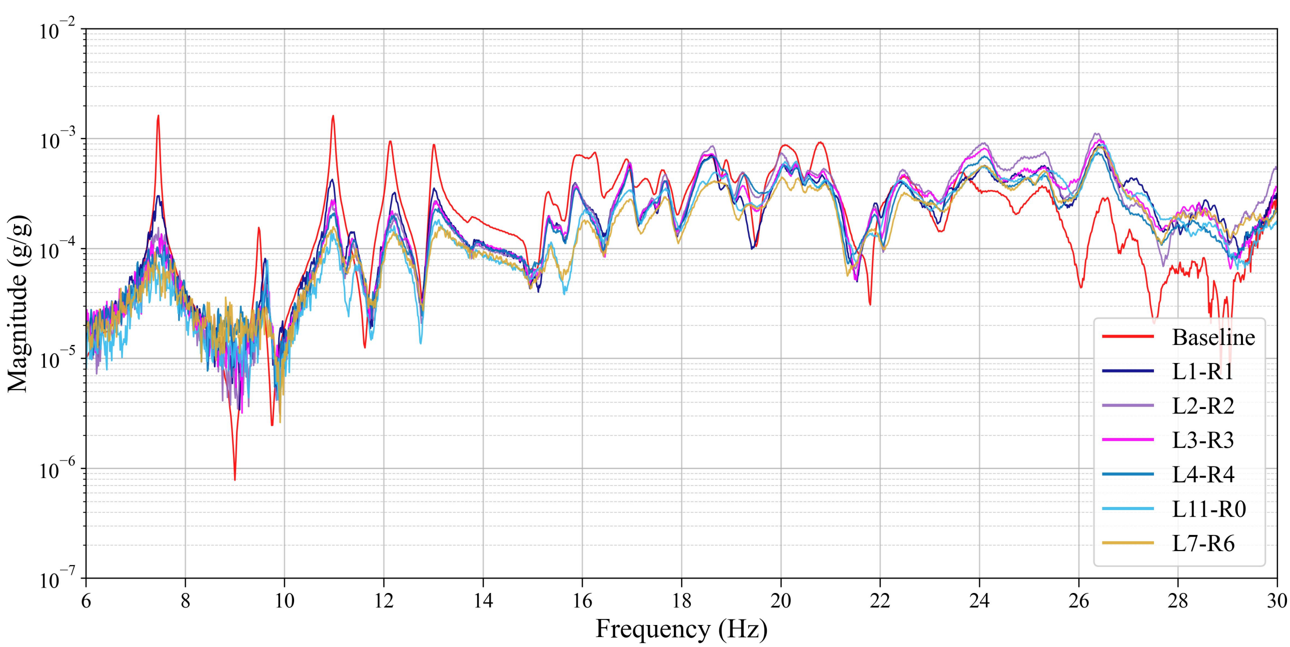

Fig. 4 Frequency response functions (FRFs) measured at the center of module 3 for all configurations, generated using shaker excitation (logarithmic scale)

Since the first (fundamental) mode has the highest mass participation in the vertical direction and typically dominates the floor's vibration response, it is examined more closely. Fig. 5 shows the FRFs on a linear scale, focused on a narrow frequency band around the fundamental mode. Despite the noise in the occupied test cases, the FRF magnitudes show a significant reduction, confirming the damping effect provided by the occupants. The reduction in the peak FRF magnitude at the first mode ranged from approximately 80% for the two-person (L1-R1) case to 95% for the eleven- and thirteen-person (L11-R0 and L7-R6) cases.

While the reduction in FRF amplitude provides a clear indication of increased damping, a more direct analysis of the damping ratios and floor performance under walking excitation is necessary. The following sections, therefore, present the calculated structural damping ratios and the measured floor response under human walking at a subharmonic of fundamental frequency (f_n/h).

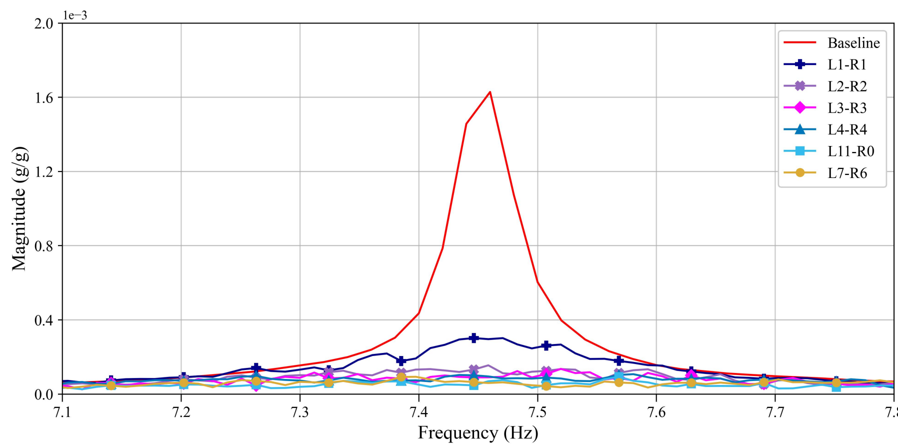

Fig. 5 Linear-scale FRFs measured at the center of module 3 for all configurations, showing the response near the fundamental mode

Effect on Structural Damping

This section presents the effect of the human occupants on the floor's overall structural damping ratio (β). For each configuration, the damping ratio was obtained from free-vibration decay tests. These tests involved exciting the floor to a steady-state resonance at its fundamental frequency, after which the excitation was suddenly stopped to record the decay. High-amplitude excitations were used, as the resulting decay curves are more clearly defined for curve-fitting. It is noted that excitation amplitude affects modal parameters; higher amplitudes tend to correspond to higher damping and slightly lower natural frequencies [11]. Prior to analysis, the recorded acceleration signals were pre-processed by detrending and applying a Butterworth filter to remove high-frequency noise. The damping ratio (β) was then extracted by fitting an exponential function to the decaying peaks of the filtered signal.

The baseline damping of the unoccupied floor was first established using the acceleration decay measured at the center of module 3 (Fig. 6). The structural damping ratio (β) was calculated to be 0.34%. This low value is characteristic of an unloaded, all-steel structure in a laboratory setting and serves as the reference for all subsequent occupied floor configurations.

The addition of human occupants immediately and significantly increased the floor's damping. For the first occupied case with two people (L1-R1), the damping ratio was found to be 1.12%, a 229% increase over the baseline, as illustrated by the decay curve in Fig. 7-a. When the number of occupants was doubled to four (L2-R2), the damping ratio more than doubled to 2.14%, representing a 529% increase from the baseline (Fig. 7-b).

As more occupants were added, the trend of increasing damping continued. The configuration with six people (L3-R3) yielded a damping ratio of 2.33% (a 585% increase), while the eight-person case (L4-R4) resulted in a damping ratio of 3.38% (an 894% increase). The corresponding decay curves in Fig. 8 show a visibly higher rate of decay compared to the previous configurations, indicating that vibrational energy was dissipating much more rapidly.

The most heavily occupied configurations produced the highest damping values recorded in the study. The asymmetric eleven-person case (L11-R0) resulted in a damping ratio of 3.01% (Fig. 9-a). The maximum damping was achieved with thirteen occupants (L7-R6), which raised the damping ratio to 4.91%. This represents a remarkable 1344% increase compared to the unoccupied floor (Fig. 9-b).

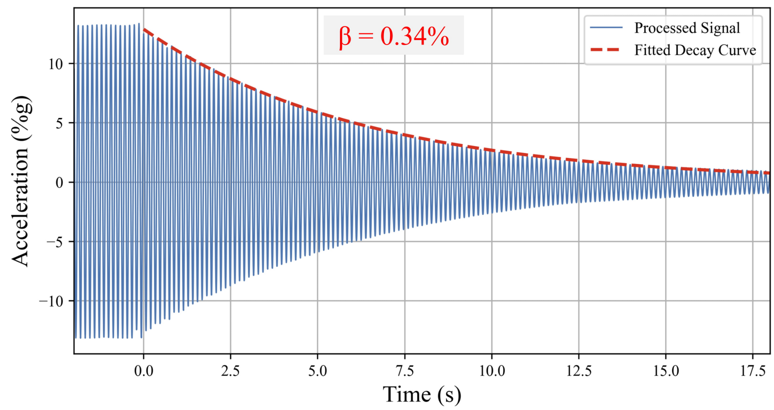

Fig. 6 Free-vibration decay curve for the baseline configuration

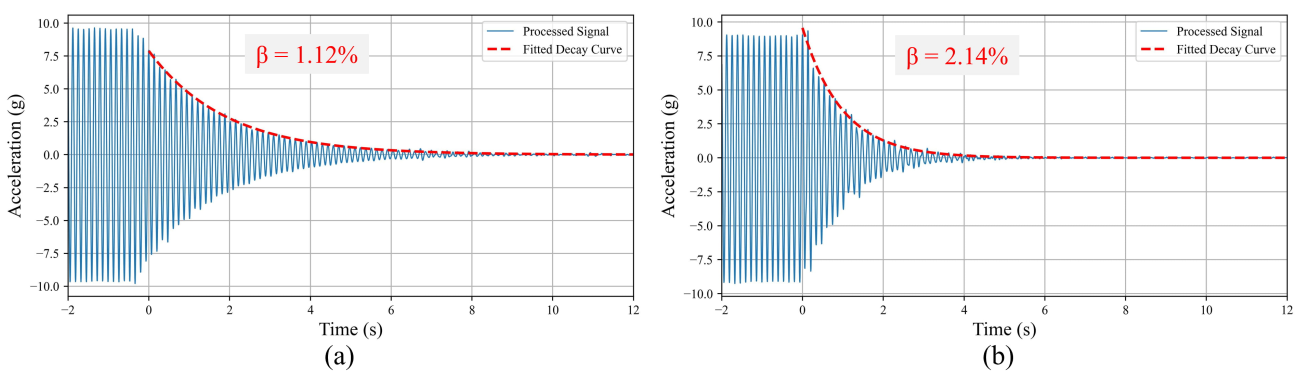

Fig. 7 Free-vibration decay curves for (a) L1-R1 and (b) L2-R2 configurations

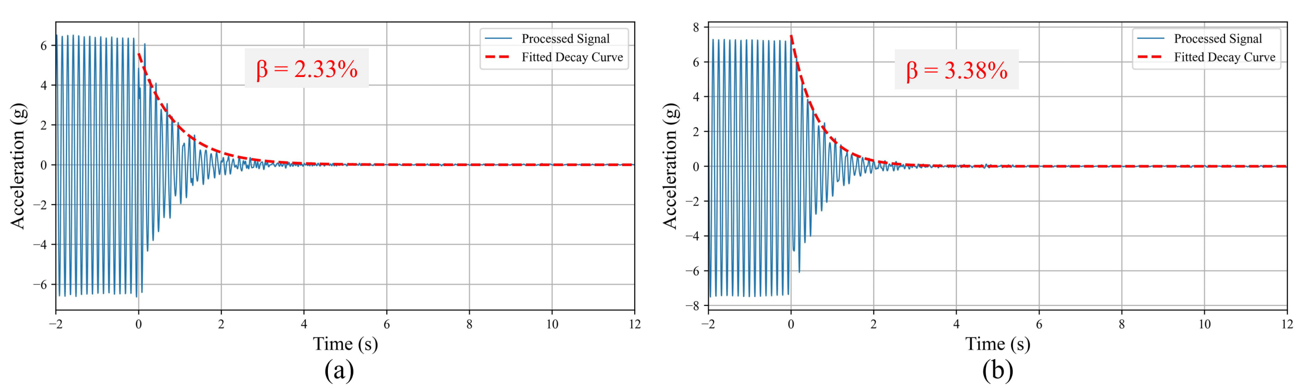

Fig. 8 Free-vibration decay curves for (a) L3-R3 and (b) L4-R4 configurations

Table 2 provides a comprehensive summary of the damping ratios and their corresponding percentage increases for all seven configurations, clearly documenting the relationship between the number of occupants and the measured structural damping.

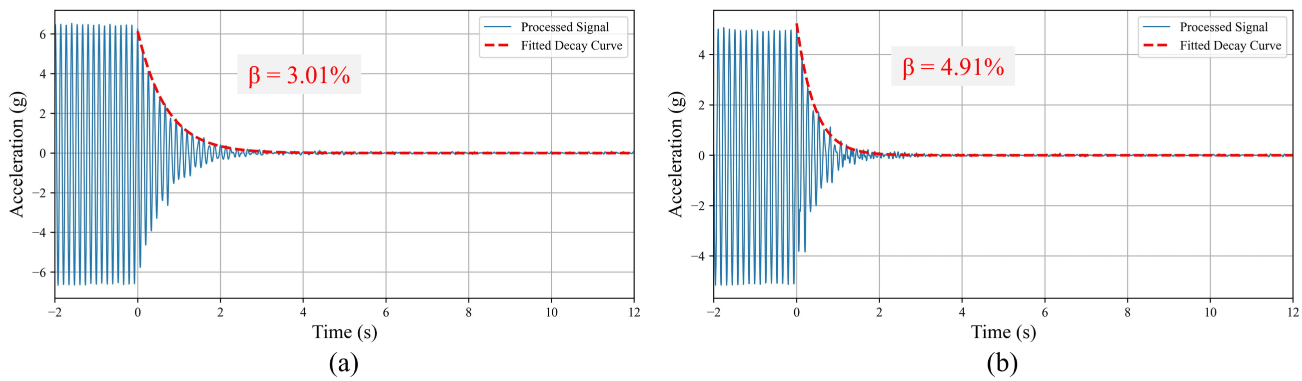

Fig. 9 Free-vibration decay curves for (a) L11-R0 and (b) L7-R6 configurations

Table 2 Summary of damping ratios and increase percentages relative to the baseline

Configuration	Damping Ratio (β)	Increase in β (%)
Baseline	0.34	-
L1-R1	1.12	229
L2-R2	2.14	529
L3-R3	2.33	585
L4-R4	3.38	894
L11-R0	3.01	785
L7-R6	4.91	1344

Response to Human Walking

To evaluate the floor's performance under realistic service conditions, a series of human walking tests was conducted for each damping configuration. These tests were designed to measure the floor's response to footfall vibrations. A few individuals walked along the centerline of module 4 at a controlled pace, maintained by a metronome. The step frequency was set to the fourth subharmonic of the floor's fundamental frequency (f_n/4), a pace known to be critical for inducing resonant response in floors of this type. The resulting acceleration was measured at the center of module 3.

The recorded acceleration signals were processed to assess the floor's performance against established human comfort criteria. This was done by calculating the Equivalent Sinusoidal Peak Acceleration (ESPA), following the procedures in AISC Design Guide 11 and SCI P354 [2, 3]. For each individual walking test, the ESPA was determined by finding the maximum one-second root-mean-square (RMS) value of the filtered acceleration signal and multiplying it by $\sqrt{2}$.

Since multiple walking tests were performed for each configuration, the 90^{th} percentile ESPA was selected as the best representative value for comparison. This statistical approach provides a robust metric that accounts for the inherent variability in footfall forces and is less sensitive to outliers, which is especially important in low-damping cases where response data is often more scattered.

The results, summarized in Table 3, demonstrate that increasing the floor's damping progressively reduces its response to walking at the critical subharmonic frequency (f_n/4). The 90^{th} percentile ESPA for the baseline configuration (0.34% damping) was 1.79 %g. The addition of just two people in the L1-R1 case (1.12% damping) reduced this response by 46% to 0.97 %g. The most significant reduction occurred in the L7-R6 configuration, where the high damping ratio of 4.91% led to a 90^{th} percentile ESPA of 0.34 %g, an 81% reduction relative to the baseline. This strong correlation between increased damping and reduced vibration highlights the effectiveness of supplemental damping in controlling floor resonance caused by synchronous human movement. The experimental results indicate that for the floor specimen in its unloaded laboratory condition, a structural damping ratio of approximately 2.3% is required to meet the 0.50%g acceleration limit recommended by AISC Design Guide 11 (DG-11).

Table 3 Statistical summary of damping ratios and ESPA results from synchronous human-walking tests

			Equivalent Sinusoidal Peak Accelerations (ESPAs) [%g]				
Configuration	**# of Walking Tests**	**Damping Ratioβ (%)**	**Mean (μ)**	**Min**	**Max**	**STD (σ)**	**90^{th} Percentile (μ+1.28σ)**
Baseline	28	0.34	1.46	1.09	1.92	0.26	1.79
L1-R1	6	1.12	0.75	0.52	0.98	0.17	0.97
L2-R2	6	2.14	0.66	0.59	0.80	0.07	0.75
L3-R3	5	2.33	0.45	0.37	0.51	0.04	0.50
L4-R4	3	3.38	0.41	0.38	0.43	0.02	0.44
L11-R0	5	3.01	0.39	0.36	0.41	0.02	0.42
L7-R6	3	4.91	0.31	0.30	0.34	0.02	0.34

Conclusions

This study investigated the effect of supplemental damping, provided by stationary human occupants, on the vibration response of a full-bay modular steel floor system. Experimental tests were conducted on the unoccupied floor and six occupied configurations with two-to-thirteen standing individuals. The following conclusions are drawn from the results:

1. The unoccupied FastFloor specimen, in its laboratory condition, exhibited a very low inherent damping ratio of 0.34%. This low damping resulted in a high vibration response to simulated human walking, with a 90^{th} percentile ESPA of 1.79%g.
2. The presence of stationary human occupants provided a significant and progressive increase in the total system damping. The damping ratio increased from 1.12% with just two people to a maximum of 4.91% with thirteen people, representing a more than 14-fold increase over the baseline.
3. This increase in damping led to a direct and substantial reduction in the floor response to walking at a critical subharmonic frequency. The 90^{th} percentile ESPA was reduced by 46% with two occupants and by as much as 81% in the most heavily damped configuration.

The findings clearly demonstrate a strong correlation between the level of human-induced damping and the improvement in vibration serviceability for this low-damping floor system. The data provides a quantitative measure of how much damping is required to control resonant vibrations caused by human activity. Based on the results, it is estimated that a structural damping ratio of approximately 2.3% is required for this specific floor system to meet the 0.50%g acceleration limit recommended by AISC Design Guide 11 [2].

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.

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