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FASTFLOOR – DEVELOPMENT OF A NOVEL MODULAR STEEL FLOOR SYSTEM FOR COMMERCIAL CONSTRUCTION IN THE UNITED STATES

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Raised access floor.

Abstract

This paper describes a research program for a new prefabricated, modular, steel floor framing system being developed in the United States. Conventional steel building construction in the United States utilizes steel deck, shear studs, and poured concrete for most floor systems. Conventional floors have proven structural and non-structural performance; however, they are time consuming, labor intensive, and have high embodied carbon. In partnership with the Pankow Foundation and the American Institute of Steel Construction a modular, shop-fabricated, all-steel floor system, known as 'FastFloor' has been envisioned. Combined with a raised access floor for accommodating mechanical, electrical, and plumbing the system can be constructed at speed and with high potential performance. Research is underway to specifically address the vibration, acoustic, and structural performance of the floor system. The research program and preliminary results for this new floor system are summarized.

1 INTRODUCTION

Steel floor building construction in the United States (US) largely employs steel perimeter girders and simply connected filler beams topped with profiled steel deck, filled with poured normal or lightweight concrete, and with composite action developed through shear studs affixed through the deck to the beam flanges. The system is robust, provides desired structural and non-structural performance, and is widely adopted in the US. However, such a floor can be slow to construct, involves multiple trades, has challenging phases for safety and access during construction, and has embodied carbon challenges inherent with the use of concrete. Under the 'Need for Speed' initiative [1] of the American Institute of Steel Construction (AISC) a novel floor solution that can provide robust and resilient performance, as well as increase speed of construction, decreased total costs, and improved sustainability is sought. This new floor concept has been named 'FastFloor' and is intended to pair with 'SpeedCore' [2] and other innovations to evolve US steel building construction [1].

2 PROJECT AND FLOOR MODULE ORIGIN

The FastFloor project is a unique model for creating innovation – the system is fully intended to be non-proprietary and the primary funding for the development is from the Pankow Foundation, the Magnusson Klemencic Associates (MKA) Foundation, and AISC (see Acknowledgments for the full list of participants). The research team meets regularly with key structural engineers from MKA and AISC who are heavily invested in the development, and a broad set of professionals across the construction industry who are likely to be or support early adopters. In the language of modern software development, this academic – industry - foundation innovation model is open source with built-in beta testers.

The origin of the FastFloor module is tied to MKA's work on a building concept in 2016 and the academic team's extensive work on bare and concrete-filled steel deck floors within the Steel Diaphragm Innovation Initiative starting in 2015 [3]. MKA's 2016 concept, Figure 1, provided a lightweight all-steel floor alternative motivated in large part from ship-building practice. While lightweight – fabricators indicated that the solution would be cost prohibitive. The academic team sharpened the existing knowledge on desired floor performance and predicting demands for both gravity and seismic, as well as proposed several improvements to design processes that FastFloor aims to leverage.

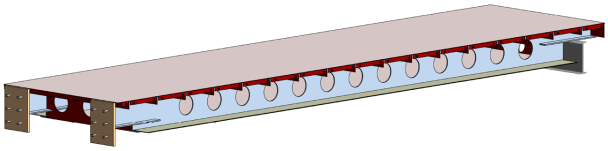

Figure 1: All-steel module from 2016 MKA concept that achieved lightweight/efficient steel detailing, but was prohibitive due to fabrication and related costs

3 INNOVATION IN FLOORS

In the development of the FastFloor a taxonomy of major areas of interest for innovation in floors was created. Though imperfect, the taxonomy spans the broad number of issues that must be addressed in developing a new floor system and includes: (1) **physical creation**: fabrication, transportation, erection, construction sequence, deconstruction; (2) **structural**: gravity performance, gravity connections, diaphragm performance, diaphragm connections (3) **non-structural**: deflection, vibration, acoustics; (4) **extreme event** performance: seismic, blast, fire; (5) **key metrics** to be monitored: weight, speed, sustainability/LCA, embodied carbon, first cost; (6) **regulatory and education**, intellectual property, codes and standards, design examples and education; (7) **systems level work**: building design feasibility, module layouts, integration with building gravity system, and building lateral system, integration with architectural systems, overall system performance; (8) **elegance and function**: architectural freedom, look, and opportunity; mechanical, electrical and plumbing (MEP) integration and opportunities; and (9) **pilot examples**: real world building projects utilizing the floor system.

During Phase 1 of the work a large variety of floor systems were explored [4], with a subset summarized in Figure 2. Based on the research team's experience, MKA's 2016 experience, and on interviews with steel fabricators, erectors, and designers in the US conducted by the research team [4] several basic objectives were established: eliminate poured concrete; provide a finished working surface such as flat plate when placed; modularize the floor; keep pick weights under 7.5 US tons (desirable for cranes and shipping at least three per truck); keep width narrow enough for shipping; include a raised access floor for integrated MEP; meet all structural and non-structural objectives; keep the system details simple; and keep the module as inexpensive as possible.

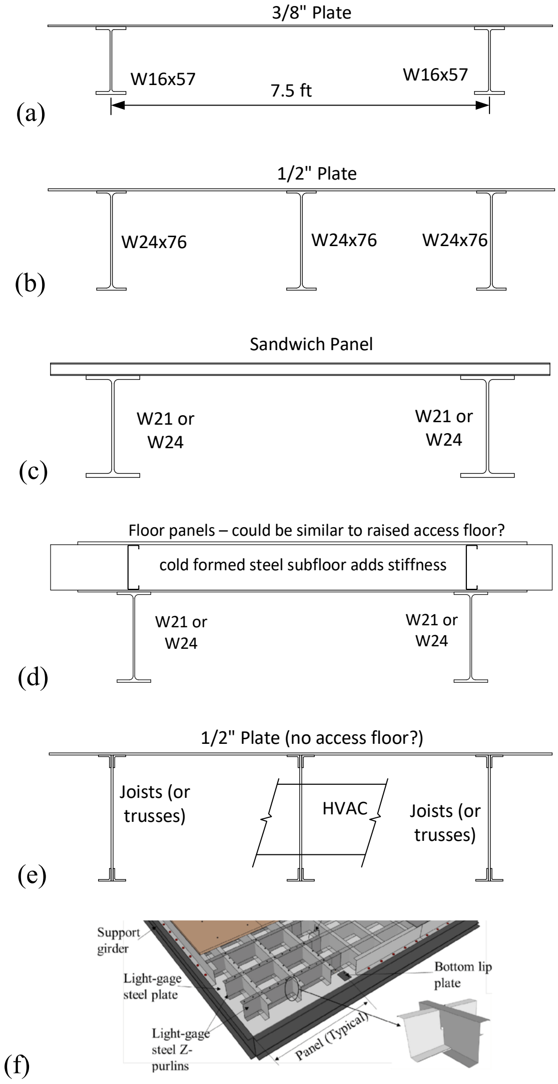

Figure 2: Examples of all-steel floor module concepts considered in Phase 1 (a) two beams and plate in double tee configuration with raised access floor (RAF) (not shown), (b) three beams and a plate with RAF, (c) two beams and a sandwich panel (or cellular panel) with RAF, (d) two beams with CFS framing instead of RAF, (e) open web steel joists with plate and no RAF, (f) two-way system of [5]

4 FLOOR MODULE CONCEPT

Considering a basic 3m (10') wide by 12.2m (40') long module, the team focused initially on the "double tee" module of Figure 2a. Industry indicated fabrication, erection, and transportation challenges with the cantilevered plate, and concerns for creating an adequate fire stop at mid-width between the beams where the two module cantilevers come together[1]. As a result of the input the system was modified to include plate edges on the beams, instead of between. Two similar options have been considered worth further exploration (a) an 'asymmetric module' with two beams and a 3 m (10') plate with a single

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[1] Industry advisory panel, https://steeli.org/?p=326

overhang (as shown in Figure 3b) or (b) a 'symmetric module' with two beams and a 1.5m (5') plate connecting the beams together and 1.5m (5') wide filler plates connecting modules together in the field. The plate is stitch welded to the beam flanges, but all field erection uses blind bolts - Shurikens[2] have been used to date. A raised access floor consisting of pedestals and tiles is added on top of the plate as depicted in Figure 3b and is supplied by Tate[3]. The depth of the beam is limited to 610mm (24in.) to maintain economical floor-to-floor heights. It is desired to minimize the weight of the beams, with current analysis showing floor vibration objectives controlling the beam, not service deflection or ultimate strength. Plate thickness is also desired to be minimized, with floor vibrations and fabrication handling concerns controlling the selection.

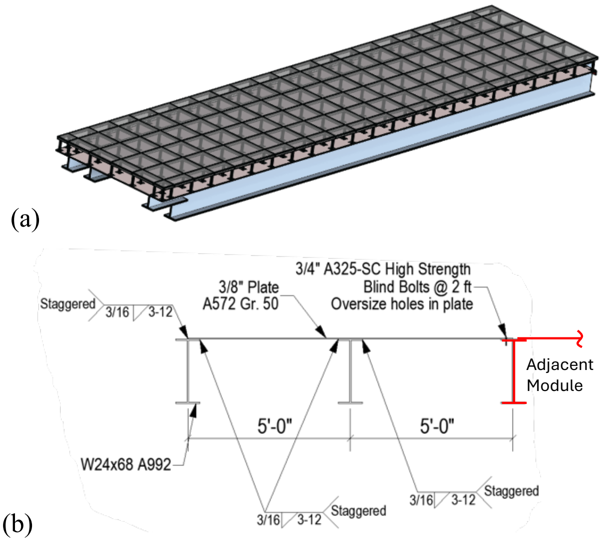

Figure 3: Current prototype module (a) isometric with raised access floor, (b) section of two beams and a plate, with asymmetric plate module shown

5 ARCHETYPE BUILDINGS

Integral to the floor development has been the design of archetype buildings that would utilize the floor modules. Two basic buildings have been designed (1) a four-story "bar" building with a 110m x 37m (360' x 120') footprint in plan, utilizing perimeter braced frames with buckling restrained braces in the high seismic archetype and ordinary concentric braces in the low seismic/wind dominated archetype, and (2) a forty-story "core" building, see Figure 4, with a 49m x 37 m (160' x 120') footprint in plan utilizing SpeedCore for the core in high seismic and ordinary concrete shear walls in the low seismic/wind case. The archetype designs help ensure realistic diaphragm and gravity loading for the floor modules, realistic erection and detailing issues, necessary information for module connection and detailing, wec. For example, erection considerations discussed with industry led to having the FastFloor beams be "on module" with the columns (for bracing) instead of an original concept that had the beams off-module and provided potential simplifications at beam-to-column interfaces that were envisioned by the team, but not by the erectors. Utilizing the forty-story core building as an example, analysis of construction time by a US contractor concluded that the FastFloor system could be installed in 2/3 of the time of a conventional (concrete-filled steel deck) floor system.

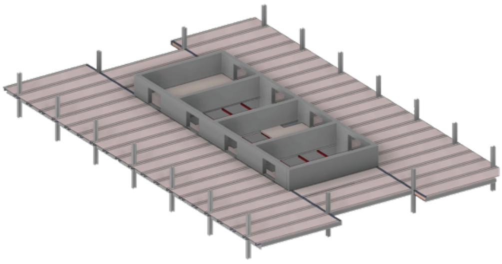

Figure 4: Floor isometric for forty-story core building archetype

6 FLOOR VIBRATION

Work to assess the vibration performance of the all-steel floor module has been extensive. Two full-scale modules were fabricated and tested as shown in Figure 5. Testing included excitations from an impact hammer, a mechanical shaker, and random and synchronous walking from a variety of people, as shown in Figure 6. Measurements were recorded at a field of high-performance accelerometers placed to capture vertical and, in some cases, horizontal accelerations, see Figure 6b and c. Frequency, mode shape, and damping were calculated from each test.

Figure 5: 12.2m x 3.0m (40' x 10') vibration specimens (a) W24x68 with 9.5mm (3/8 in). PL. and RAF (b) W24x94 with 12.7mm (½ in.) PL. and RAF

Tested configurations were extensive and included in progressive degrees of complexity: (a) the bare steel floor system (three beams and a plate), (b) with the RAF added, (c) with angle blocking across the bottom flange of the

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[2] https://www.atlastube.com/products/shuriken/

[3] https://www.tateinc.com/us/en/products/all-tate-product/access-floors/

beams at the 1/3 points added, (d) with angle plate stiffeners at the 1/3 points added, (e) with diagonal angle K-braces at the 1/3 points added, (f) with supplemental damping added in the RAF pedestal and flower head connected to the RAF tiles.

Observations and work are reported in [6]-[11], but broadly speaking are as follows. The frequency response of the floor modules is more complicated than conventional construction, ten or more modes are observed with meaningful frequency content under 20 Hz. If beam torsional buckling is mitigated through the bottom flange angle blocking, then the dominant vibration mode increases substantially, and typically is greater than 10 Hz. The floor specimens utilize either a 9.5mm (3/8 in.) or 12.7 mm (½ in.) plate – the frequency response of the thicker plate is much more favorable. The RAF improves observed damping, but overall damping is low between 0.1 and 1.5%. The heavier of the two specimens, Figure 5b, has noticeably better performance and with the angle blocking in place participants qualitatively observed that the system had minimal vibrations, and quantitatively the single module in this configuration had measured equivalent sinusoidal peak accelerations between 0.2% and 1.4% g, depending on the walker.

Figure 6: Example excitations on vibration specimens
(a) impact hammer (b) shaker (c) walking

The testing is accompanied by an extensive calculation and computational effort. Simulations have been performed in SAP2000 and ABAQUS. Shell finite elements are required to accurately capture the torsional modes of the beam and the vibration modes of the plate (and their interactions). With care taken in the beam to plate connections and the beam end conditions good agreement has been found between vibration mode shapes and frequencies between the simulations and the testing. Ongoing simulations are exploring optimal combinations of beam, plate, and blocking; direct modelling of walking excitations; and estimating the vibration performance of a larger 12.2m x 9.1m (40’ x 30’) floor with three full modules in place. Predicted accelerations in the larger floor indicate improved performance, and fabrication of the three module floor, see Figure 7, for further vibration testing is underway. Calculations have also been completed that demonstrate the expected levels of damping for in-service conditions that lead to acceptable vibrations. The testing and simulations indicate that despite the increased complexity acceptable vibration performance is possible in the system without major modifications.

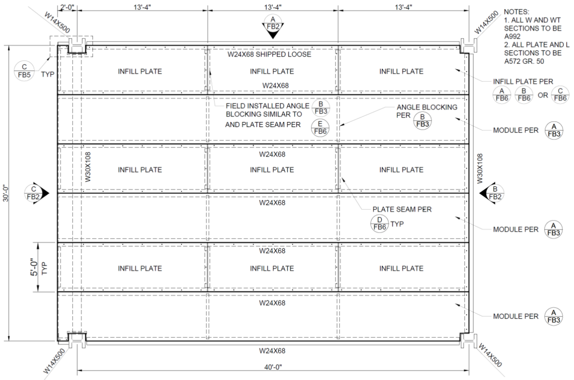


Figure 7: 12.2m x 9.1m (40’ x 30’) floor vibration specimen, currently under fabrication, to be tested in the coming year

7 ACOUSTICS

Acoustical performance of the all-steel floor system is anticipated to be different than conventional construction. As a result, an experimental chamber, as shown in Figure 8, was constructed. The floor in the upper story of the chamber utilizes the all-steel floor module.

Figure 8: Enclosure for acoustics testing, FastFloor prototype at mid-height of specimen, testing conducted on floor

Acoustical testing was conducted per ASTM E90 for airborne sound transmission and ASTM E989 for tapping (impact) tests. The tested configurations included (a) the bare steel floor, (b) the steel floor with RAF included, (c) an augmentation of neoprene washers in the RAF pedestals, (d) the addition of Pliteq GenieMat on the top of the RAF, and (e) the addition of Pliteq GenieMat cut into squares to match the RAF tiles. Testing was conducted by Cerami, an acoustical consultant. The results indicate that the steel floor with RAF meets current commercial standards in the US for sound isolation, but not for impact/tapping isolation. If the GenieMat is added as a roll or as tiles, both sound transmission and impact/tapping isolation exceed current US commercial standards. The testing did not include finished ceilings, flooring, etc. that could further improve the final performance. The testing demonstrates a clear path for acceptable acoustical performance of the system.

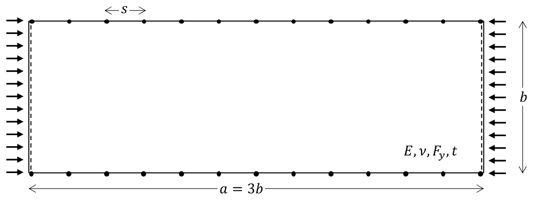
8 GRAVITY STRENGTH

The flexural strength of the FastFloor module must address steel flexural member limit states: yielding, web and flange local buckling, and lateral-torsional buckling (LTB). The attachment of the top plate to the I-beams potentially provides in-plane shear diaphragm translational bracing against LTB, and additional composite strength to the flexural assembly. However, the top plate is locally slender and only intermittently connected (by stitch welds or bolts) so the stiffness and strength available from the top plate must be determined. In addition, while it may be adequate for strength if the top plate is only partially effective under load, it is less clear what the impact of local buckling deformations may be on serviceability considerations for the surface of the RAF attached to the plate.

As part of the project fundamental work has been completed addressing the local plate buckling and compressive strength with intermittently spaced connections on its longitudinal edges [12]. As shown in Figure 8c, if the fasteners are spaced too far apart the plate buckles between the fasteners, and little to no post-buckling strength can be developed. As reported in [12] if the normalized spacing is limited to

$$\frac{s}{b} \le \frac{0.3}{\sqrt{\lambda_w}} < 0.33 \qquad (1)$$

then the full plate buckling strength can be developed; where s is the longitudinal spacing of the intermittent connector, b is the plate width, λ_w is the plate slenderness defined as $\sqrt{F_y/F_{cr\ell}}$ where F_y is the yield stress of the plate, and $F_{cr\ell}$ is the local buckling stress of the plate. In addition, when assessing the flexural strength, the top plate undergoes longitudinal strains in excess of the yield strain if the beams are to develop their plastic capacity; therefore, traditional local buckling assessments (e.g. Winter's effective width equation) must be modified for the effective width at higher levels of longitudinal strain. Work is also currently ongoing to develop guidance for the in-plane plate shear stiffness and strength to address the LTB bracing and shear diaphragm behavior.



(a) Figure 4. Basic setup and variables for studied plate

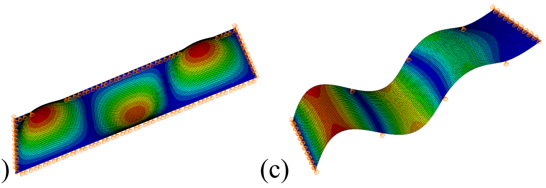


Figure 8: Stability studies on top plate intermittently fastened (a) basic setup (b) buckling mode when fasteners close enough to create local plate buckling (c) buckling mode when fasteners are two far apart and Euler buckling between fasteners occurs

Flexural testing of the floor assembly will be conducted in the next phase of the project. The preliminary test assembly and related nonlinear finite element collapse simulations are provided in Figure 9. Preliminary assessment indicates that the plate accompanied with bottom flange angle blocking at the 1/3 points of the span are sufficient to mitigate against LTB up to and past peak flexural capacity.

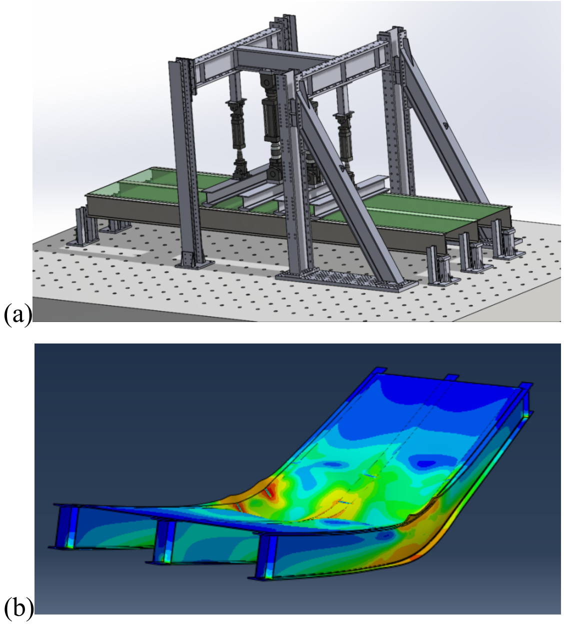


Figure 9: Gravity performance of module (a) test setup to date (b) simulation of flexural strength

9 DIAPHRAGM STRENGTH

The premise of the diaphragm performance for FastFloor is that the flat plates form the field of the diaphragm and the welded or bolted connections at the perimeter of the floor resolve the forces into the chords and collectors. The interior of the diaphragm also utilizes welds and bolts to transfer the in-plane shear from plate to plate through the interior beam flanges. The in-plane shear strength and stiffness of the floor plate, for the plate thicknesses currently under consideration, significantly exceed the perimeter fastener stiffness and strength at common spacings necessary for gravity strength. As a result, the realized diaphragm stiffness and strength is more of a design choice (i.e., number and spacing of welds and bolts controls the results) than is typical in conventional concrete-filled steel deck diaphragms. The significance of this design freedom has not yet been fully explored by the team.

10 FUTURE AND ONGOING WORK

The FastFloor research and development effort was originally envisioned in four phases across five years, and the second phase is nearing completion. Significant experimental work on floor vibrations in a full bay, component and module flexural strength, and connection testing remain. Modeling of the FastFloor modules in vibration, and collapse simulations of the modules under gravity and diaphragm demands are ongoing. Nonlinear modeling of full building archetypes, particularly under seismic demands, with nonlinear phenomenological models for the FastFloor modules based on the experiments and collapse simulations will also be completed. The scope of work to address innovations in floors is considerable (see the taxonomy in Section s), but excellent progress has been made to date and the system is on track for consideration in real building consideration (pilot projects) in the near future. It is worth noting that a short span FastFloor system also is under development – this system uses non-proprietary cellular deck and screw attached cementitious panels and is more appropriate for spans between 3m (10’) and 6m (~20’) [13].

11 CONCLUSIONS

Floor systems in conventional steel building construction in the United States (US) are slow to construct and use a significant amount of (high embodied carbon) concrete. A non-proprietary, all-steel, modular floor system is being developed as an industry-academic-foundation collaboration in the US to address these shortcomings. The system, known as FastFloor, aims to be as simple and inexpensive as possible for fabrication and erection, but still hit a robust set of structural and non-structural performance targets. Work to date has selected and fine-tuned the basic layout of the floor module, and specifically addressed floor vibration and acoustic performance. Assessment of gravity and lateral structural performance at the component, connection, and full building level are all ongoing. The research team has nearly completed two of an anticipated four phases of research, with a desired outcome of utilizing the developed floor module in a pilot building project.

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REFERENCES

[1] AISC (2024) Need for Speed Initiative.

[2] Huber, D. and Varma, A. (2021) “Core Value”. Modern Steel Construction, March 2021, p. 30-37.

[3] Eatherton, M.E. et al. (2020). “Steel Diaphragm Innovation Initiative: Year 5 Final Report”. https://steeli.org/?p=293

[4] Mercado, M.A. (2023) “Vibration Serviceability Assessment of a Steel Modular Floor System.” M.S. Thesis, Virginia Tech.

[5] Boadi-Danquah, E., et al. (2017). Lightweight modular steel floor system for rapidly constructible and reconfigurable buildings. *IJCMEM, 5*(4), 562–573. DOI

[6] Avci, O. et al. (2023). “Vibration Serviceability Evaluation of a Modular Steel Plate Floor Assembly.” SEM IMAC. pp. 269-275.

[7] Avci, O. et al. (2024). “Vibration Testing of an All-Steel Modular Floor Assembly.” SEM IMAC. pp. 17-23

[8] Rifai, S. et al. (2025) “Effect of Bottom Flange Angle Blocking on the Dynamic Response of Two All-Steel Laboratory Floors.” SEM IMAC 2025.

[9] Rifai, S. et al. (2025). “Modal Testing and Finite Element Model Updating of a FastFloor Specimen: A Modular All-Steel Floor System.” SEM IMAC 2025.

[10] Rifai, S. et al. (2025). “Vibration Serviceability Evaluation of an All-Steel Floor System using the High-Frequency Floor Procedure.” SEM IMAC 2025.

[11] Kumar, R.C.M. et al. (2023). “Efficient stability and vibration analysis of an all-steel modular floor assembly.” SSRC Conf. Proc., presentation.

[12] Kumar, R.C.M. et al. (2024). “Effect of intermittent edge support on in-plane plate compressive strength.” SSRC Conf. Proc.

[13] Caswell, H.L. et al. (2022). “FastFloor Residential Testing Report”. CFSRC-22-03.