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Cold-formed steel profiled decks topped with cementitious structural panels to enable fast floor construction of residential buildings

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Abstract

High efficiency floor systems satisfying structural and serviceability performance and providing ease of construction could significantly impact the quality and cost of buildings. Many of the traditional floor systems require cast-in-place concrete and most of the new floor systems are proprietary, resulting in additional costs. The FastFloor Residential project explores a new type of floor system that is non-proprietary and uses existing components to make a simple efficient design without any cast-in-place concrete. The prototype design uses two cold-formed steel profiled decks connected with self-drilling screws to form a cellular deck and topped with cementitious structural panels. Through a series of twelve four-point bending tests, the impact of fully and partially composite deck-to-structural panel connections are explored. This paper investigates how the deck and structural panel interaction impacts capacity, stiffness, and failure mode of the prototype floor system. The results have shown that using the structural panels could increase the ultimate strength up to 50%.

1. Introduction

The goal of the FastFloor Residential design, as seen in Figure 1, is to create a new floor system that is nonproprietary, lightweight, and fast to assemble. This can be achieved by using no wet concrete, and standard components: e.g., lightweight back-to-back standard 76 mm (3 in.) deep steel deck with a thickness of 1.2 mm (18 gauge) is used to create a cellular deck. The cellular deck is then topped with 19 mm (3/4 in.) thick structural cementitious panels. Everything is attached using self-drilling fasteners.

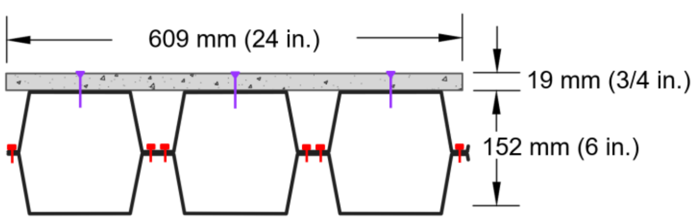

Figure 1: FastFloor Residential Prototype Cross-Section

2. Literature Review

Understanding the competitive market of residential floor systems is important for comparison to the FastFloor Residential prototype. A series of both proprietary and nonproprietary systems were examined including composite steel deck, dovetail steel deck, cold-formed steel joists, Ecospan, iSpan, and Hollow-core Plank as examples in the current market.

2.1 Composite Metal Deck

Composite metal deck [1], as shown in Figure 2 is a popular floor system. This system is nonproprietary and simple, consisting of only steel deck, shear studs, mesh reinforcement, and concrete. It provides a shallow deck profile but can provide up to a two-hour fire rating. For spans shorter than 4.25 m (14 ft), no shoring is required, making this system convenient, although, there is wet concrete needed that takes time to set on site and may involve multiple trades.

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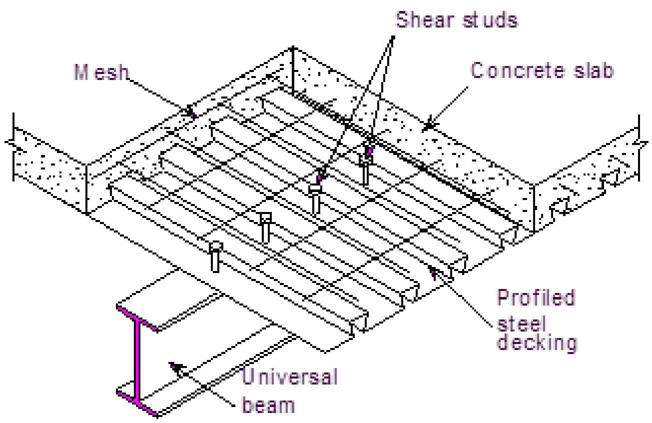

Figure 2: Composite Metal Deck [2]

2.2 Dovetail Deck

Dovetail deck [3], as shown in Figure 3, is also a simple nonproprietary floor system, deal for slightly longer spans than the composite metal deck system of up to 6 m (20 ft). Dovetail deck also provides a shallow floor system, but it commonly requires a thicker slab of at least 152 mm (6 in.) to satisfy acoustical requirements. The thicker slab still provides this system with a fire rating of up to three hours.

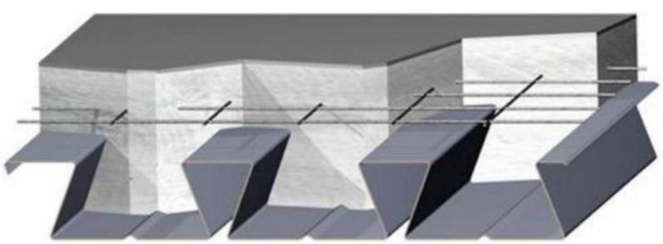

Figure 3: Dovetail Deck Rendering [4]

2.3 Cold-Formed Steel Joists

Cold-formed steel joists [5], as seen in Figure 4, is another nonproprietary floor ideal for spans around 6 m (20 ft) but has a different layout. It does not require any wet concrete allowing for quick construction, but is a deeper system, commonly greater than 203 mm (8 in.), with joists typically spaced between 305 mm (12 in.) and 610 mm (24 in.). The joists are topped with, oriented strand board, or structural panels and final detailing controls whether the system has a one-hour or two-hour fire rating. To prevent torsion in the joists, blocking against the webs is sometimes required.

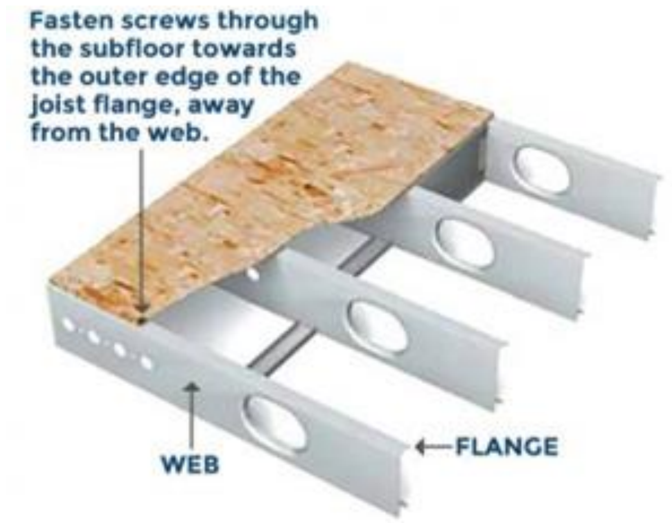

Figure 4: Cold-Formed Steel Joists Rendering [6]

2.4 Ecospan

Ecospan [7], as seen in Figure 5, is a longer span proprietary system by Vulcraft. This system is a more complex system that has a depth between 254 mm (10 in.) and 762 mm (30 in.). The open web steel joists are spaced up to 1.5 m (60 in.) apart. This system uses a composite deck in addition to the joists. Rather than conventional shear studs this system uses proprietary Shearflex screws to improve the composite action between the concrete and steel deck. This system has up to a three-hour fire rating.

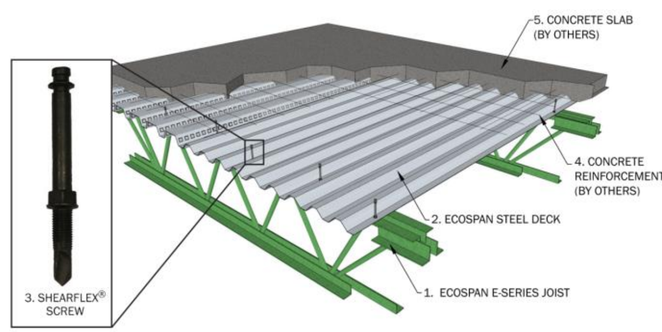

Figure 5: Ecospan Rendering [7]

2.5 iSpan

iSpan [8], as seen in Figure 6, is a proprietary version of cold-formed steel joists for fast floor assembly. These joists are also spaced between 305 mm (12 in.) and 610 mm (24 in.), but the system can achieve larger spans of up to 8.5 m (28 ft). This system uses joists with an I-shaped cross-section and longitudinal stiffeners rather than standard C-sections. This system with common detailing has a fire rating of one-hour.

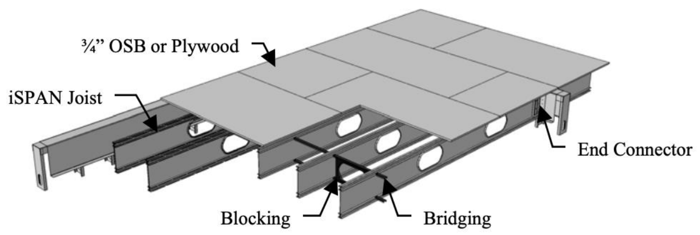

Figure 6: iSpan Rendering [8]

2.6 Hollow-Core Plank

Hollow-Core Plank [9], as seen in Figure 7, is a shallow proprietary concrete modular floor system for spans between 3.4 m (11 ft) to 14 m (46 ft). This system has more concrete than the other systems investigated which makes this system heavier, but also able to provide a fire rating of up to four-hours. This system is precast meaning that no wet concrete is required on site, but grout to fill voids between panels is required. A cast in place topping can be added to improve capacity and acoustics. (Which may also be done with many of the other systems detailed here as well).

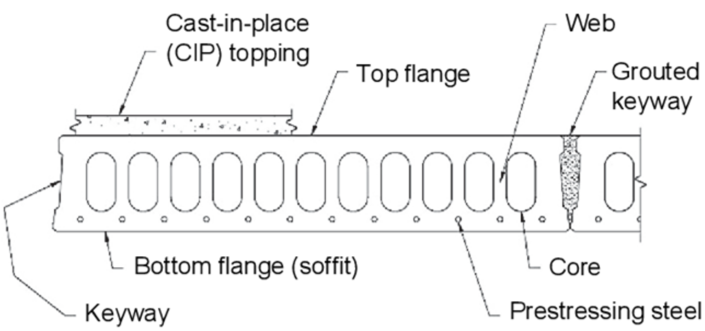

Figure 7: Hollow-Core Plank Section [10]

3. Physical Testing

To determine the capacity of the FastFloor Residential prototype system, a series of four point bending tests were conducted, as seen in Figure 8.

Figure 8: Four-point bending test

3.1 Test Matrix

The testing for this study includes 12 total specimens made up of pairs of 6 unique assemblies, as provided in Table 1. The design was tested both with and without the cementitious structural panel. USG's ¾ in. structocrete was employed for the panel. Two spacings of #8 structural panel fastener were compared, to determine the impact of partially and fully composite structural panels on the capacity of the system. Additionally, two spacings of #12 deck-to-deck fasteners were also compared.

Table 1: Design Matrix

Name	Deck Fastener Spacing, mm	Panel Fastener Spacing, mm	Quantity, #
FC[a] Bare Deck	102	--	2
FC Deck + PC[b] Panel	102	305	2
FC Deck + FC Panel	102	152	2
PC Bare Deck	203	--	2
PC Deck + PC Panel	203	305	2
PC Deck + FC Panel	203	152	2

[a] Fully Composite
[b] Partially Composite

3.2 Lab Setup

The four-point bending rig consisted of two end supports spaced 4.88 m (16 ft) that provided pin-roller end conditions, as seen in figure 9. The rollers on the load beam were spaced at 1.52 m (5 ft) with HSS spreader beams to distribute the load. Ten position transducers were used to record test data, as shown in Figure 10. The specimen deflection at the midspan and load points were measured as well as the slip between the two pieces of deck and between the structural panel and steel deck. Stiffeners were placed inside the specimen at the load points to prevent web crippling at those locations, as seen in Figure 11.

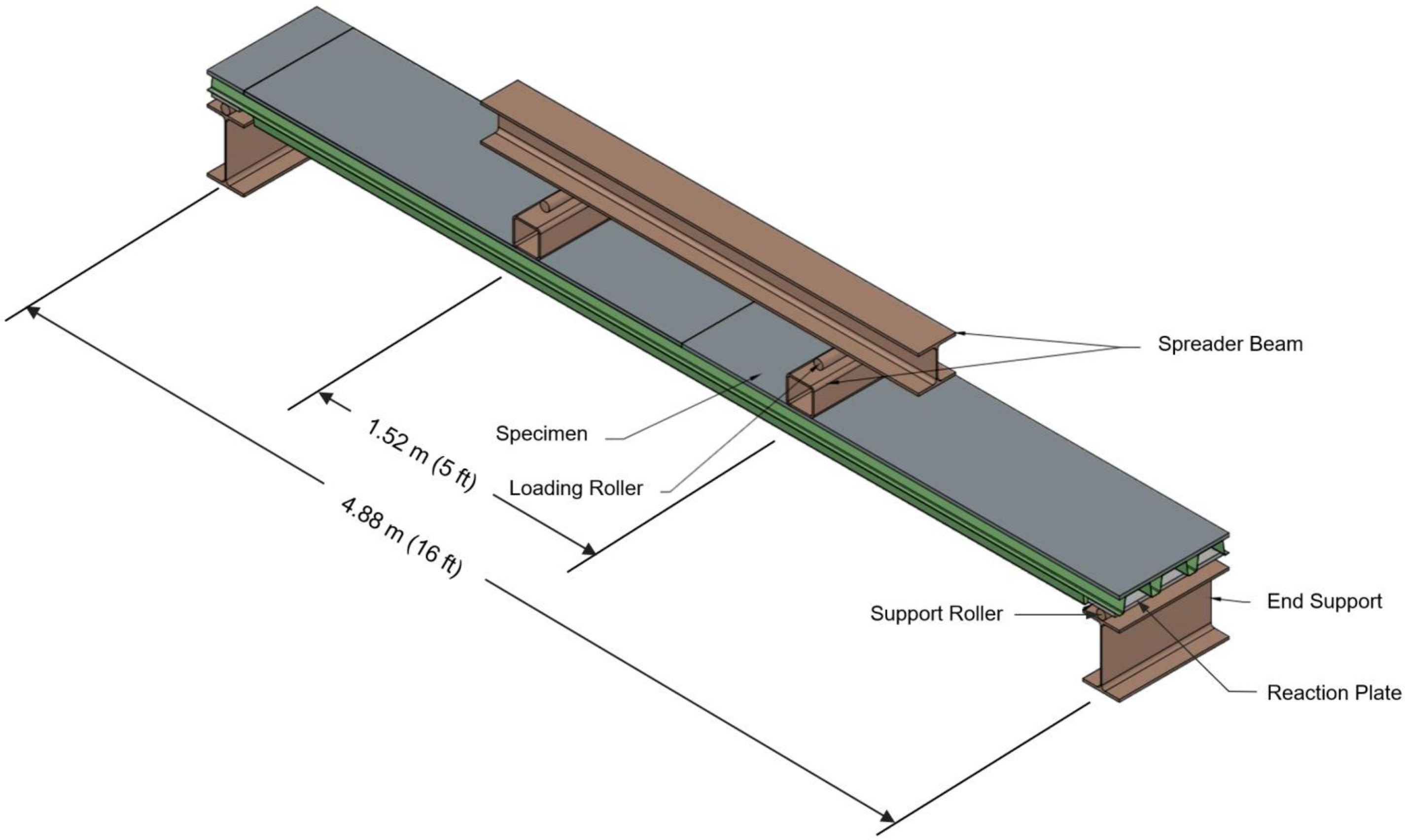

Figure 9: Lab Setup

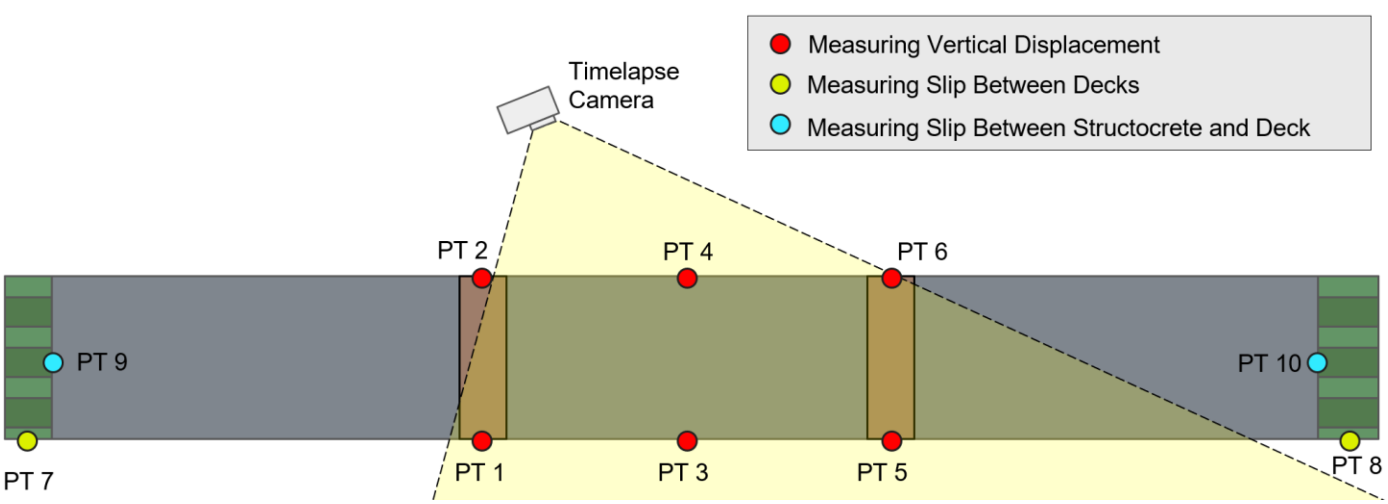

Figure 10: Position Transducer Setup

Figure 11: Stiffeners being placed inside the specimen during construction

4. Results

The spacing of the deck-to-deck fasteners had little effect on the capacity, while the structural panel and its fastener spacing had a significant impact on capacity, as summarized in Table 2.

Table 2: Specimen Capacity

Name	Capacity[a], kN (kips)
FC[b] Bare Deck	26.8 (6.03)
FC Deck + PC[c] Panel	35.9 (8.07)
FC Deck + FC Panel	43.1 (9.69)
PC Bare Deck	27.2 (6.11)
PC Deck + PC Panel	36.4 (8.17)
PC Deck + FC Panel	43.0 (9.66)

[a] Average Capacity of two tests
[b] Fully Composite
[c] Partially Composite

The specimens acted essentially elastic until the steel deformed in local buckling starting with the top steel deck and then moving to the bottom steel deck as shown in Figures 12 and 13.

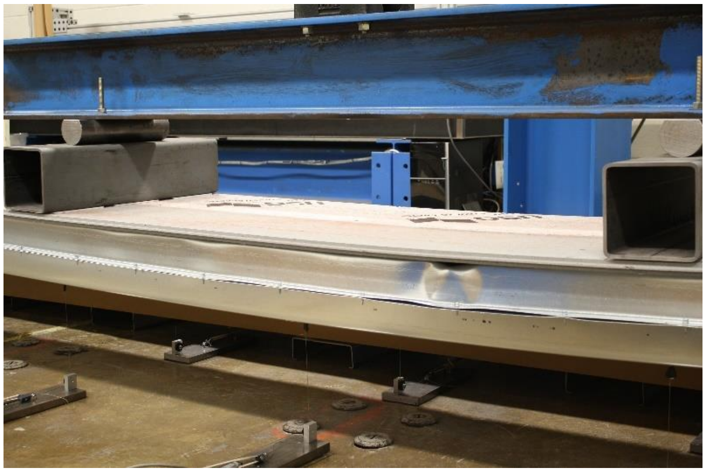

Figure 12: Local buckling and plastic mechanism in the top deck

Figure 13: Local buckling and plastic mechanisms in the bottom and top deck

The specimens continued to act ductility until screws started shearing off, as shown in Figure 14. This shearing of the screws at large deformation leads to large drops in load, as shown in Figure 15.

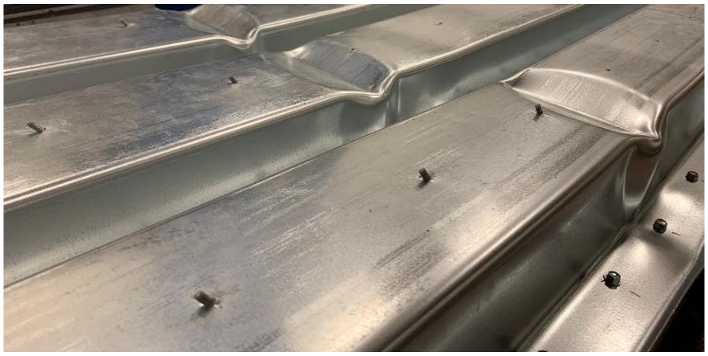

Figure 14: Post-test showing plastic mechanisms in top deck and sheared screws between panel and top flute of top deck

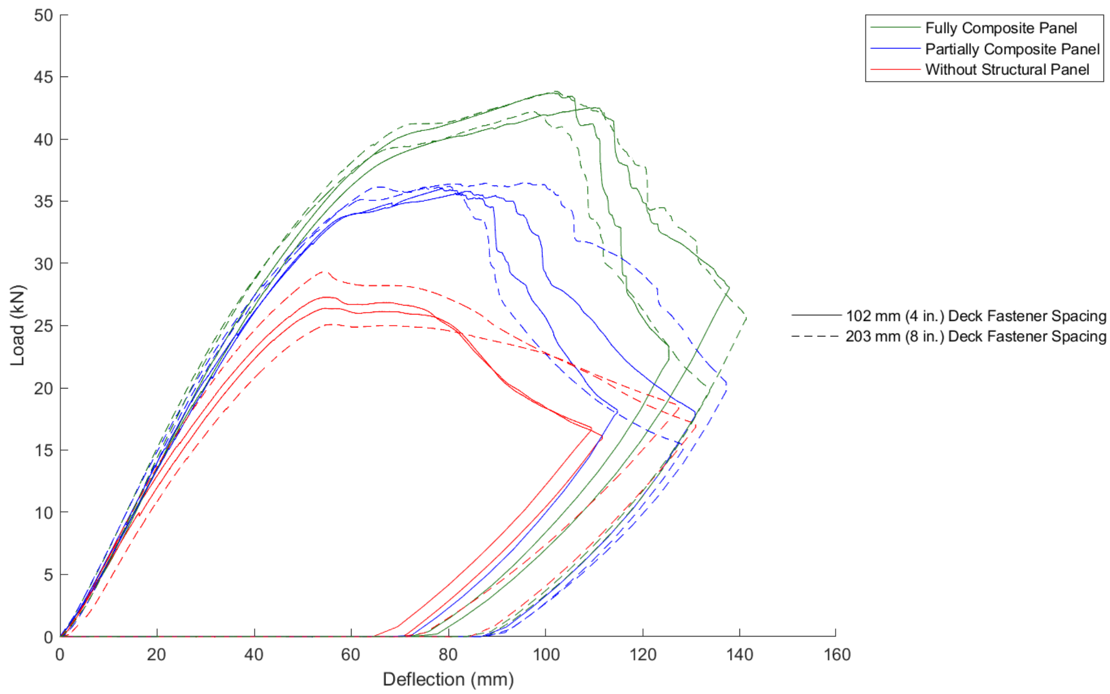

Figure 15: Load-Deflection Curve

5. Conclusions

Testing on a FastFloor Residential prototype has provided promising results. The structural panel and use of a close fastener spacing both show significant increase in capacity above steel only response. There is, however, significant analysis and testing that needs to be completed to make more significant conclusions regarding serviceability, strength, and the use of the prototype in diaphragms.

6. Acknowledgments

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This testing would not have been possible without the contributions from all these people and organizations.

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