conference preview

CORE SOLUTION

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A new composite assembly is positioned to set the pace for future high-rise buildings and elevate steel to dominance in core construction.

FOR THE LAST 20 TO 30 YEARS, high-rise office building construction has been dominated by a single structural system: reinforced concrete core walls surrounded by structural steel composite floor framing.

The reasons for this are many. Concrete walls situated around elevator shafts, exit stairs, restrooms and mechanical/electrical services offer the benefits of geometry—all while satisfying the owner's and architect's programmatic requirements. Plus, fire and acoustical separations, which are easily achieved, and adequate structural stiffness and strength can be readily provided via this solution.

Inherent to concrete core wall construction is the cycle time required to set formwork, install reinforcing steel, place embedded plates, install sleeves and block-outs and place and cure concrete before the next level of the core can be constructed. While cycle times vary based on core geometry, reinforcing steel congestion and the skills of the contractors in the geographic location, a common time frame required to construct each core level for a typical tower is three to five days per floor.

On the other hand, erecting the surrounding steel floor framing can occur at a much more rapid pace. Two tiers (four floors) of steel erection per week are possible in many markets, allowing the steel erection to proceed at roughly twice the pace of concrete core construction. This cycle time disparity often delays the start of steel erection. Timed perfectly, the final steel beams are erected just after the concrete core walls are completed. But consider that for high-rise projects, the difference in pace between the two materials can add up to several months of extra time required to complete the tower. For owners and developers, this can equate to substantial additional costs in construction loans and contractor general conditions and a delay in collecting rent from building occupants, potentially totaling millions of missed dollars.

A New Approach

Luckily, a new approach to core construction has emerged. And in fact, it's currently being implemented as part of the Rainier Square Redevelopment project in downtown Seattle. This approach, a concrete-filled composite plate shear wall (CF-CPSW) core system, is commonly referred to as a "sandwich panel wall system" and directly addresses the cycle time disparity. In the case of Rainier Square, a schedule savings of three to four months is anticipated as the entire superstructure can be erected in sequence without the timing restrictions of concrete core construction. The core wall arrangement is identical to a traditional concrete core, providing similar benefits to owners and architects.

Here's how it works: The system includes prefabricated wall panels and boundary elements comprised of steel face plates, typically ½ in. thick, separated by 1-in.-diameter cross-connecting tie rods spaced 12 in. on center, both horizontally and vertically, with an overall wall assembly thickness varying from 21 in. to 45 in. These panels, which include integrally detailed composite (concrete-filled) coupling beams, are rapidly erected at the same pace as the balance of the steel erection. They are designed with adequate strength and stability

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➤ The Rainier Square Redevelopment project in downtown Seattle, currently under construction.

to support up to four floors of steel floor beams and metal decking prior to being filled with concrete, where the face plates serve as permanent formwork for the infill concrete.

The role of the cross-connecting tie rods is critical to the overall performance of the system. The rods serve multiple purposes and provide:

- Strength and stability of the un-concreted wall panel to support erection loads
- Lateral resistance and face plate bracing during the concrete infill operation
- Mechanical connectivity between the steel plates and in-fill concrete for composite action leading to enhanced axial and shear strength
- Confined pressure for the concrete for superior seismic performance under ultimate demands
- Prevention of delamination modes through the plain concrete infill
- Out-of-plane shear strength
- Reduced slenderness of the steel plates

Once the panels are erected and the panel-to-panel connections are made, a self-consolidating concrete mix is placed in the space between the two plates. The concrete, combined with the steel plates, provides the ultimate strength and stiffness for the core wall assembly as a composite section. Shannon Testa, project manager for the project's general contractor, Lease Crutcher Lewis, highlighted another benefit of the system, saying, "The construction tolerances we typically struggle with between concrete construction and steel construction are eliminated."

Technical Beginnings

Before we discuss the Rainier Square project further, let's take a brief look back at the sandwich panel system's history. The system saw its beginnings with a product called Bi-Steel, which was originally developed by Corus in the United Kingdom. The product included a patented welding procedure to affix interconnecting tie rods between two steel plates. The technical advantages of this system were many, but it did not enjoy widespread application, with only a few modest-size apartment buildings in London being constructed.

However, the system has been used extensively in the third generation of nuclear power facilities in the United States and around the world. In this facility type, it is employed as the shield building to provide aircraft impact resistance and also in


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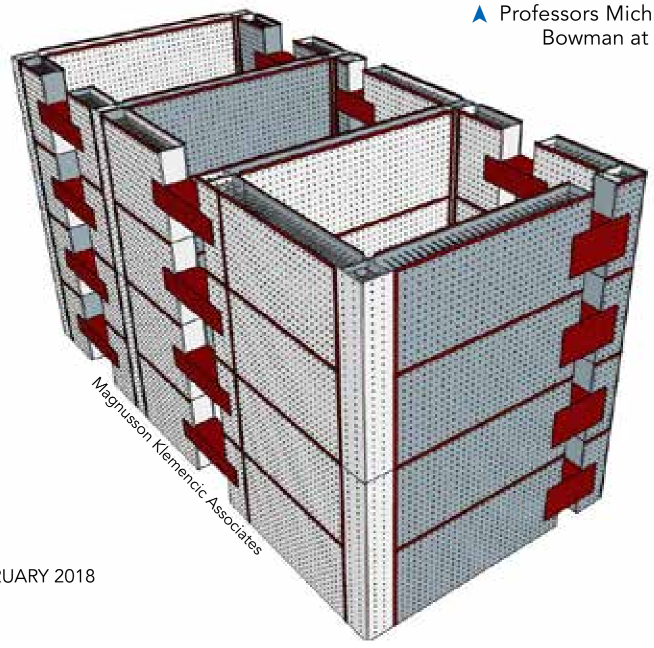
Professor Amit Varma and his research assistants at Purdue's Bowen Lab.

internal containment structures to provide adequate strength and stiffness for seismic loading and accident scenarios including impactive and impulsive loading. In fact, AISC has recently published a specification (AISC N690-2012 Supplement No. 1 *Specification for Safety-Related Steel Structures for Nuclear Facilities*) and a design guide (AISC Design Guide 32: *Design of Modular Steel-Plate Composite Walls for Safety-Related Nuclear Facilities*) for this system and associated connections in nuclear construction. (See "Nuclear Option" in the November 2017 issue, available at **www.modernsteel.com**, for more on this design guide.)

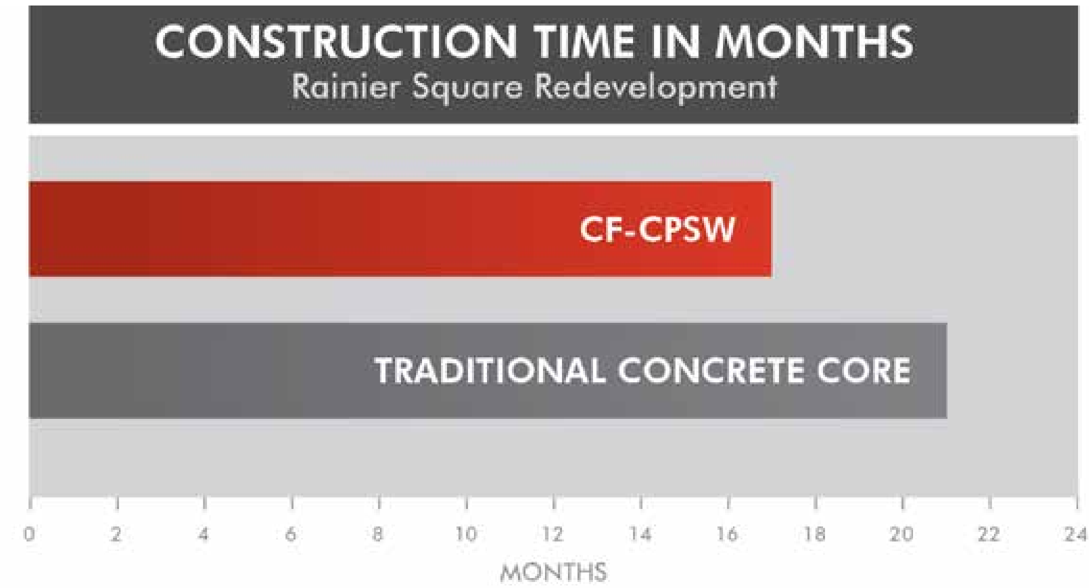
In order to extend the merits of the Bi-Steel concept to high-rise buildings in high-seismic zones, Purdue University, with funding from the Charles Pankow Foundation, began researching and testing the technology in 2006. Led by professors Mark Bowman and Mike Kreger, the research aimed to investigate a non-proprietary version of an assembly similar to Bi-Steel. Several aspects of the system were modeled numerically and physically tested, including the stability of the assembly prior to concrete placement, forces in the cross-connecting tie rods and a ⅜-scale, 5½-story T-shaped wall assembly under cyclic loading. The results of this research can be found in a Charles Pankow Foundation research report, *Behavior and Design of Earthquake-Resistant Dual-Plate Composite Shear Wall Systems*, and detailed design guidelines are presented in the report *Design Procedure for Dual-Plate Composite Shear Walls*.

The ongoing research at Purdue University under professor Amit Varma, as well as at the University at Buffalo under professor Michel Bruneau, is investigating

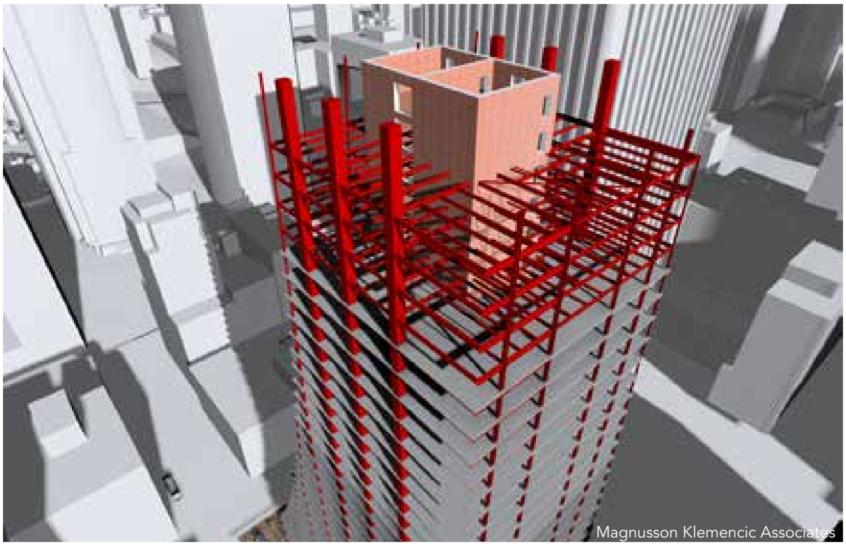
Professors Michael Kreger and Mark Bowman at Purdue's Bowen Lab.



A diagram of a building core constructed with sandwich panels.



▲ Sandwich panel core construction vs. concrete core construction.



➤ Sandwich panel core being constructed concurrently with steel floor framing.

the performance of: planar sections under varied axial load with alternate cross-connecting tie rod arrangements supplemented by headed studs; more complex wall assemblies including C-Shapes and T-Shapes; coupling beam detailing and performance; and R-factors for seismic design using the FEMA P695 approach. This extensive research program is being funded by AISC and the Charles Pankow Foundation, with in-kind support provided by the Supreme Group.

The test set-up and assembly at Purdue's Bowen Laboratory are being used to test composite walls to combined axial load and cyclic lateral loading up to failure. The parameters included in the experimental investigations are the axial load level (10% to 30% of concrete axial load capacity) and tie rod spacing achieving plate slenderness ratios of 24 to 48. The specimens are ½- to ⅜-scale models

➤ A stack of sandwich panels.


Purdue University Research Team

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of the prototype walls designed for theme structures located in non-seismic and seismic regions. One emphasis of the project is to develop design details for both non-seismic (governed by wind) and seismic regions, which will become part of the AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360) and *Seismic Provisions for Structural Steel Buildings* (ANSI/AISC 341), respectively (both are available at **www.aisc.org/specifications**). Results from initial tests are favorable and will ultimately provide guidance to practitioners in the form of improved design guidelines and acceptance in the AISC *Specification*.

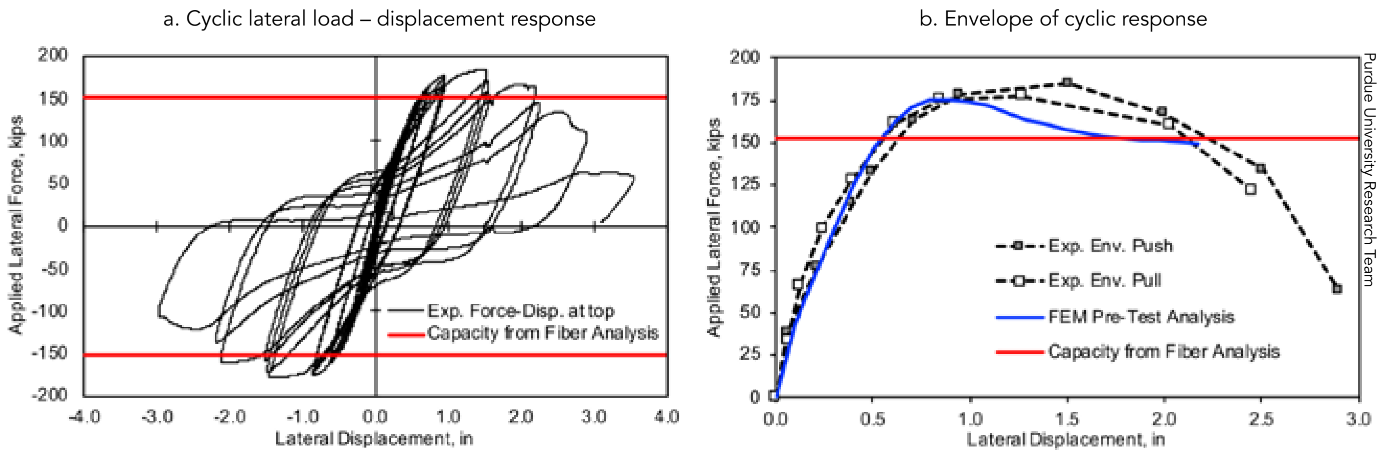
Fabrication and Erection Challenges

Back to the Rainier Square project, the wall panels, typically measuring 13 ft, 9 in. by 37 ft, are being fabricated off-site by Supreme Steel Portland (an AISC member and certified fabricator) and shipped in stacked groups. Steel erection is being handled by The Erection Company, who will direct the hoisting, placement and connection of all of the steel elements, including the sandwich panel wall system.

The panel system includes approximately 500 panels and 200 boundary elements, as well as installation of up to 240,000 cross-connecting tie rods. The fabrication sequence and the connection of the tie rods are critical to the efficient and timely fabrication of the panels, and Supreme Steel has devised a process to streamline the fabrication and ensure the quality of the cross-connecting tie-rod connections.

Panel-to-panel connections during the site erection sequence are also a critical detail of the system, specifically when subjected to the high seismic demands possible in Seattle. Welded connections are being used exclusively at the recommendation of the erector in order to ease field

A look inside two sandwich panels with different stud configurations.



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▲ Sandwich panel test results compared to analytical results.

➤ Testing a specimen at Purdue's Bowen Lab.

fit-up and speed construction. In addition, project-specific prequalified welds have been developed and are being tested to enhance the efficiency of the connections.

The final assembly will be spray fireproofed in order to satisfy the jurisdictional requirements for a three-hour assembly. However, ongoing studies are being conducted to better understand the fire performance of the system, with the goal of minimizing or eliminating the need for supplemental fire protection for some portions of the system.

The ongoing research and testing at Purdue University and University at Buffalo are aimed at identifying further efficiencies and design enhancements that the sandwich panel wall system can offer. As construction unfolds at Rainier Square in Seattle, there will most certainly be many lessons learned that will benefit future projects considering this system. And if the system is as successful as it's expected to be, it could very well change high-rise construction as we know it. ■

*This article is a preview of Session U5 "Innovative Composite Coupled Core Walls for High-Rise Construction" at NASCC: The Steel Conference, taking place April 11–13 in Baltimore. Learn more about the conference at **www.aisc.org/nascc**.*


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