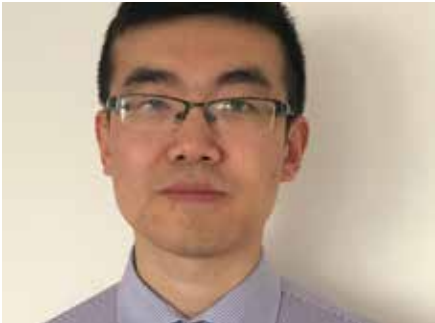


Double Impact

BY KARA D. PETERMAN, PHD, LIZHONG WANG,
MARK D. WEBSTER, PE, JAMES A. D'ALOISIO,
PE, AND JEROME F. HAJJAR, PE, PHD



Kara D. Peterman (kdpeterman@umass.edu) is an assistant professor in the Department of Civil and Environmental Engineering at the University of Massachusetts Amherst.

Lizhong Wang (wang.l@husky.neu.edu) is a PhD student in the Department of Civil and Environmental Engineering at Northeastern University. **Mark D. Webster** (markw@ckcps.com) is Senior Staff II with Simpson Gumpertz and Heger, Inc.

BUILDINGS ACCOUNT FOR NEARLY 40% of U.S. energy consumption and greenhouse gas emissions.

The materials required to construct a building all require energy to manufacture, fabricate, deliver and erect. Once it is operational and in use, the building itself is heated and cooled. And when it has reached the end of its lifespan, energy is required to disassemble and demolish the building.

When it comes to framing systems, structural engineers can take a leading role in developing new structural systems that are more sustainable. The good news for structural steel is that, in addition to other green attributes, it is largely produced from recycled materials. And work is currently underway in the form of systemic innovations that can take steel-framed buildings to the next level of sustainability.

Two projects at Northeastern University, in collaboration with Simpson Gumpertz and Heger (SGH) and other partners—both funded in part by AISC—are exploring improvements to common structural steel systems that can help reduce their environmental impacts.

Both projects take a closer look at the contributions of the structural system to the energy consumed in building construction and use. The first project explores strategies for adding thermal breaks to cladding details to reduce building heating and cooling demands while maintaining the structural efficacy of the details. The second project addresses a composite structural floor system developed to facilitate deconstruction, in which the structural systems are designed to be taken apart and reused in other structures. Both projects highlight testing conducted at Northeastern's Laboratory for Structural Testing of Resilient and Sustainable Systems (STReSS Laboratory) which was established in 2011.

Thermal Break Strategies

When a structural element spans the building envelope, it can act as a thermal bridge that allows energy to flow between the building's exterior and interior. Steel, for all its strength and ductility, is also thermally conductive. Conductive cladding details combined with large differences in interior and exterior temperatures are not only appropriate conditions for energy loss, but also condensation. A thermal break may be used to mitigate this thermal bridge.

Together with the Charles Pankow Foundation, the American Composites Manufacturing Association (ACMA) and the Pultrusion Industry Council (PIC), AISC partnered with a team from Northeastern University, SGH and Klepper, Hahn and Hyatt (KHH) to design and validate a suite of thermal break strategies. While many steel elements can become thermal bridges, this work focused on slab-supported shelf angles, roof posts (for supporting mechanical units and other rooftop structures) and canopy beams.

As an effective thermal break involves improved thermal performance in addition to adequate structural performance, stainless steel and fiber reinforced polymers (FRP) were natural candidates, both as shims inserted in the building envelope and as full or partial replacement of the structural member. Based on the expertise of the SGH and KHH engineers along with the project's Industrial

Two research projects at Northeastern University’s STReSS lab shed some light on opportunities to make steel construction more sustainable.

Advisory Panel—which included representatives from AISC, ACMA, PIC and a number of companies—viable solutions were developed using these materials, then validated using 3D thermal modeling software to determine the effectiveness of the proposed breaks. Structurally promising solutions were then tested at full-scale as subsystems in the STReSS Laboratory. In addition to these subsystems—which included shelf angles, roof posts and canopy beams—double-lap-splice steel-bolted connections with FRP fills of varying thicknesses and flatwise creep testing of the FRP materials subjected to through-thickness compression was also conducted. Finite element modeling was used to substantiate the results from the experimental testing.

The research demonstrated that FRP shims can be effective and structurally sound thermal breaks for shelf angles and roof posts, as well as for canopy beams subjected to light loads that were within the scope of this research. Figure 1 shows the setup for testing the strength of shelf angle assemblies connected to steel framing with different thermal break strategies. In the setup, the specimen is shown in green, and the loading beam representing gravity loading from cladding is shown in brown. Figure 2 shows a schematic of a roof post assembly, along with representative results through thermal modeling to show the potential impact of using thermal breaks. Compared to thermally unbroken connections, we estimated thermal transmittance reductions of up to 65% for roof posts, 30% for canopy beams and 92% for shelf angles. Creep can be managed by limiting the stress in the shims. Some of the connection configurations explored in this work, all of which used snug-tight bolts, are not compliant with the *RCSC Specification*. The project team is looking forward to expanding the work to include a greater range

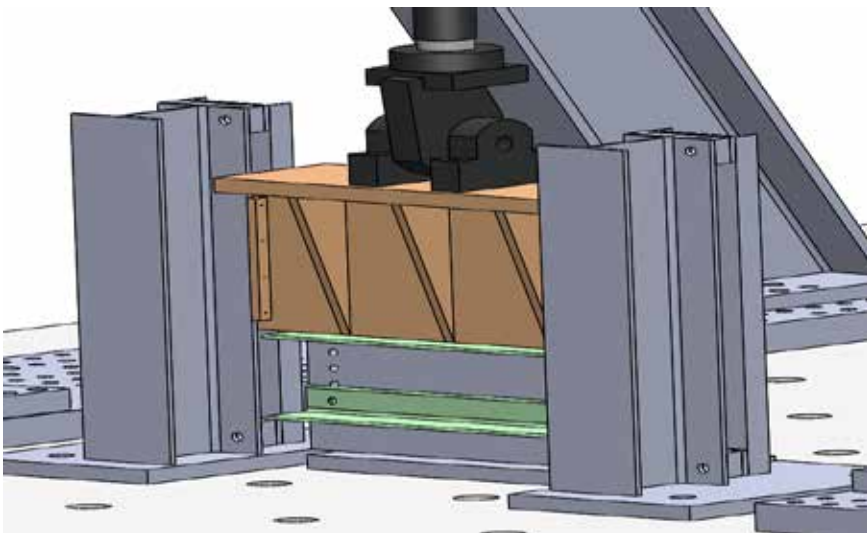


Figure 1. Test setup for shelf angle assemblies examined in the thermal breaks project.



James A. D'Aloisio (jad@khhpc.com) is a principal with Klepper, Hahn and Hyatt.

Jerome F. Hajjar (jf.hajjar@northeastern.edu) is the CDM Smith Professor and Chair in the Department of Civil and Environmental Engineering and director of the Laboratory for Structural Testing of Resilient and Sustainable Systems (STReSS Laboratory) at Northeastern University.

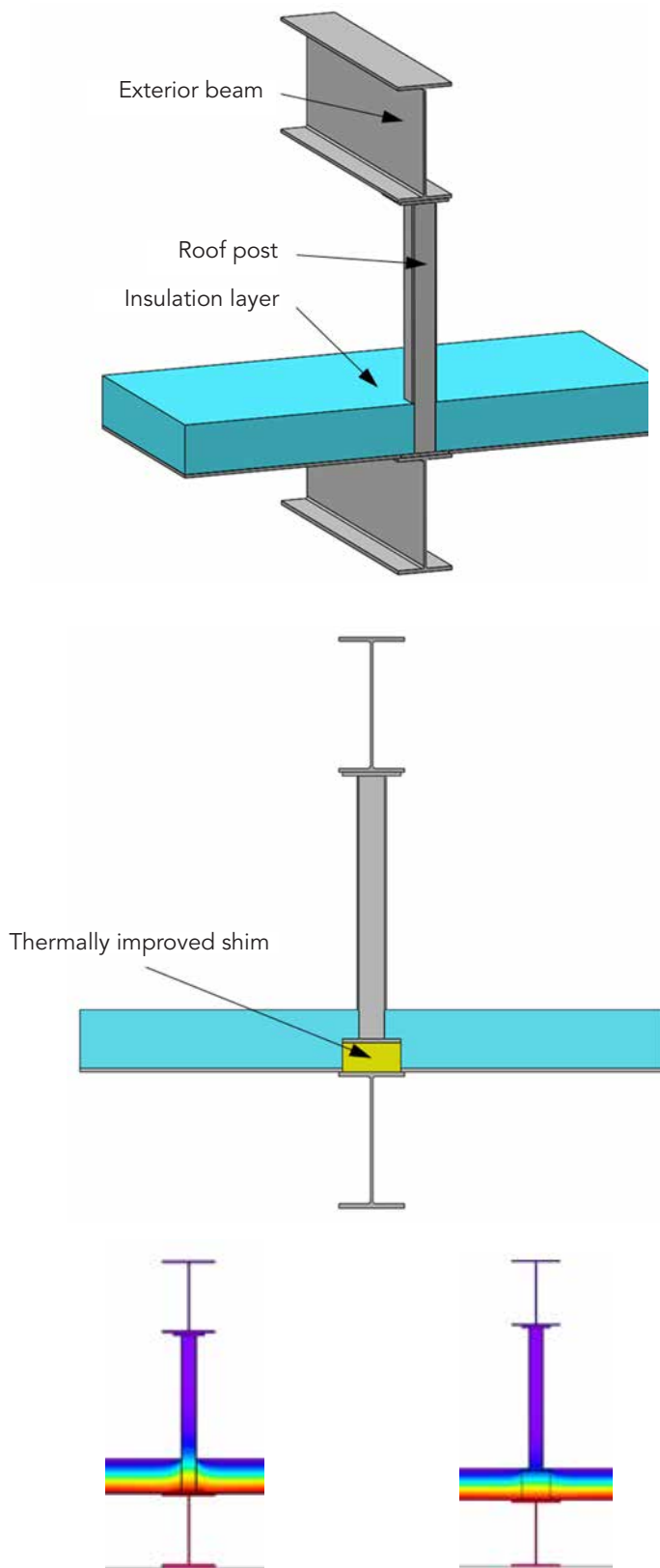


Figure 2. The top detail shows an initial design concept for a thermal break at a roof, the middle detail shows the design with an improved shim incorporated and the bottom image shows thermal imaging/efficacy of the assembly without (left) and with (right) the shim.

of structural design provisions, structural loads, mitigation techniques and involvement from industry.

A hallmark of this work was the continued and enthusiastic involvement of AISC, practicing engineers and representatives of the numerous funding agencies and participating companies. As the recommended mitigation strategies must ultimately be designed and implemented by engineers, guidance throughout the research process ensured that the results have been meaningful for structural steel design.

Design for Deconstruction

A deconstructable structural system provides a new paradigm for construction in which the structural system can be taken apart at the end of its useful life and its components reused in other structures, assuming there has been minimal to no damage to the system. Often, buildings are demolished not due to structural deficiency but rather because their styling or floor plan has fallen out of favor, or due to development trends in the building's neighborhood. Even if a building reaches its design service life and needs to be demolished, the steel and concrete components, which are protected from the environment within the envelope, are normally free of corrosion and deterioration and can thus potentially be reclaimed from the demolished building and reused in a new project—provided that the structural system can be readily deconstructed. To achieve this goal, a deconstructable structural system should embody key features that include: having modular components dry-assembled on site; independence of various systems; application of parallel instead of sequential assembly/disassembly; use of mechanical connectors; and related features.

A traditional composite steel-concrete floor system does not integrate future deconstruction into the design and construction process. For several decades, composite steel-concrete floor systems incorporating steel deck, shear studs and cast-in-place concrete slabs have been the most ubiquitous type of structural steel framing for commercial and institutional buildings. This cost-effective solution, however, is also a highly integrated design, which removes the possibility of deconstructing and reusing the structural system at the end of its service life. The steel beams and shear studs are generally extracted from the demolition debris and recycled, while the concrete slabs may be broken up and sent to landfills or crushed to make aggregate for fill or new concrete.

Our design for deconstruction (DFD) research project, funded by the National Science Foundation (NSF) and AISC, developed a deconstructable composite floor system to maintain the benefits offered by composite construction while enabling deconstruction and reuse of the structural components, thereby reducing demolition waste from old projects and raw material consumption in new projects (Figure 3). The system consists of precast concrete planks and steel beams joined with clamping connectors. The clamping connectors use friction at the steel-concrete interface to resist required shear flow and achieve compos-

ite action. Channels are cast into the concrete to provide flexibility for where the beam intersects the plank and to allow for different beam widths. Tongue-and-groove joints at the concrete plank edge ensure vertical load transfer between adjacent planks and offer a level and well-matched finished floor surface.

To transfer in-plane diaphragm forces, the precast concrete planks are staggered and connected using un-bonded threaded rods before being attached to the steel beams (Figure 4). Friction, developed by pretensioning the rods, provides the resistance against joint sliding due to diaphragm shear and joint opening due to diaphragm flexure.

By untightening the bolts and rods, the precast concrete planks and steel beams can be disassembled and reconfigured in future projects. This type of construction also facilitates adaptation for renovations. Preliminary plank dimensions are 20 ft by 2 ft by 6 in. This size is small enough to facilitate transportation and handling and promote reconfiguration in future structures, but large enough to have structural integrity and reduce labor for construction and deconstruction. Ideally, the planks would be stocked in different sizes and concrete strengths for ready use, comparable to how steel is currently stocked at service centers.

The experimental program of this project consisted of push-out tests and composite beam tests, all conducted at full scale. In the push-out tests (Figure 5) the clamping connectors were subjected to direct shear, and the characteristics of the clamping connectors were quantified, including load-slip curves, strength, stiffness and slip capacity. The push-out test results show that the peak strength of a clamp using a 24-mm bolt is close to that of a 3/4-in. (19-mm) diameter shear stud, but the clamps possess much greater initial stiffness, ductility and slip capacity than a stud.

We then tested four 30-ft-long deconstructable composite beams using W14x38 and W14x26 W-shapes and 6-in.-thick planks (Figures 6a and 6b). All the beams exhibited very ductile behavior even at a beam deflection of over 14 in., well past service load deflections. The beam test results confirmed the clamp strengths obtained from the push-out tests and demonstrated that AISC design provisions for

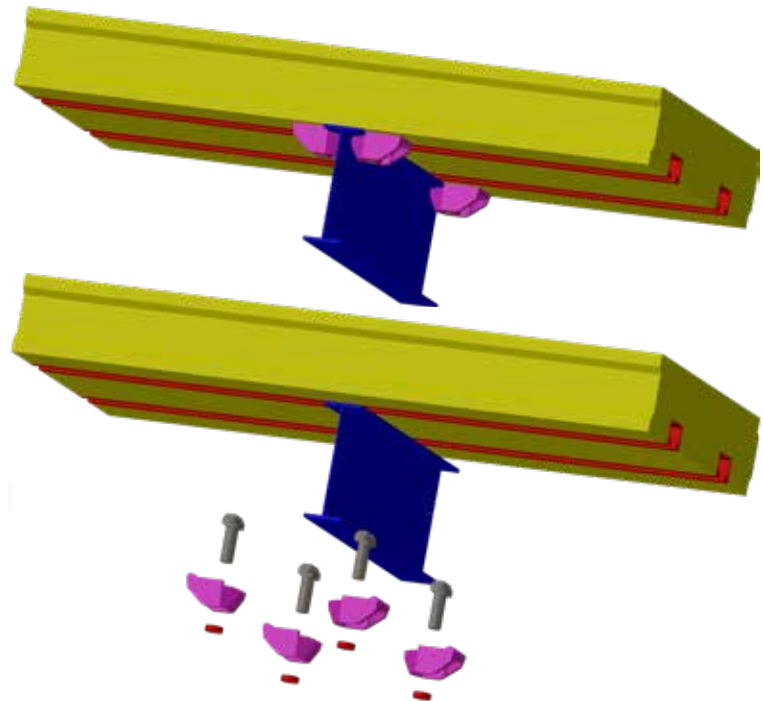


Figure 3. A deconstructable composite beam prototype, including concrete plank, steel beam, cast-in channels, tongue-in-groove joints, bolts and clamps.

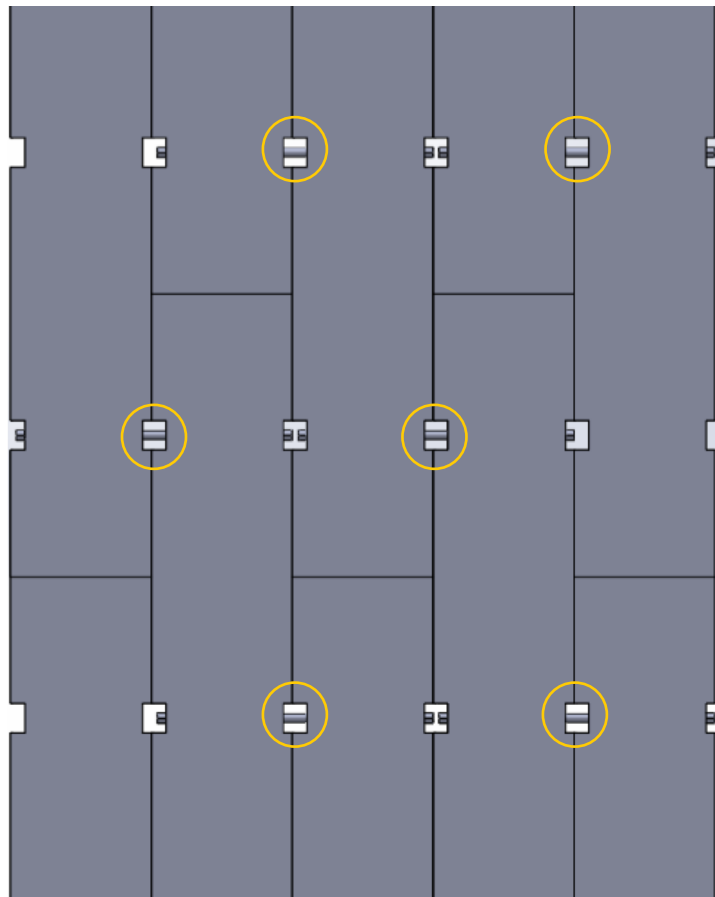


Figure 4. Precast concrete plank in-plane connections. Threaded rods are indicated with yellow circles.



Figure 5. Push-out test specimen.



Figure 6a. Beam test specimen.



Figure 6b. Beam test specimen.

conventional composite beams are applicable to the deconstructable composite beams. This research shows that using clamped connectors at the steel-concrete interface can effectively achieve composite action in sustainable composite beams, and these tests confirm a potentially transformative approach for nearly damage-free transfer of force in appropriate applications.

Design for deconstruction of buildings still requires additional work before being fully accepted, such as building code guidance on evaluating and designing with reused materials; coordination between material demand and supply, including time for deconstruction in project schedules; and consideration of possible costs or potential savings from this approach. However, this research highlights the viability of a key structural system to enable the reduction of energy required in construction.

This research highlights new strategies for reducing the environmental impacts of construction and creates clear opportunities for sustainable structural steel design. Researchers and practitioners should collaborate and embrace these new opportunities to ensure that research not only expands the frontiers of structural engineering but also produces pragmatic design outcomes. ■

Acknowledgments

This material is based upon work supported in part by the National Science Foundation under Grant Nos. CMMI-0654176 and CMMI-1200820, Charles Pan-kow Foundation, AISC, the American Composites Manufacturers Association, the ACMA-Pultrusion Industry Council, Simpson Gumpertz and Heger, Inc., Klepper Hahn and Hyatt and Northeastern University. In-kind support was provided by Armadillo NV, Bedford Reinforced Plastics, Benevento Companies, Capone Iron Corporation, Creative Pultrusions, Fabreeka, Fastenal, Halfen, Infra-Metals, Lehigh Cement Company, Lindapter, Meadow Burke, S&F Concrete, Souza Concrete and Strongwell. Any opinions, findings, and conclusions expressed in this material are those of the authors and do not necessarily reflect the views of the sponsors.