Strength Test of Timber and Concrete Composite Successful

At the connection edge between individual panels, the layers of cross-laminated timber are stepped down, and the 2.25 in. concrete overlay is increased to 9 in.

AS A BUILDING material, wood offers many benefits: it is an inexpensive, renewable resource, and its use can significantly reduce the embodied carbon footprint of a construction project, a characteristic of growing importance in the 21st century. However, wood has certain limitations: its strength is finite and its flammability must be managed. But would it in fact be possible to design a 42-story building using mass timber instead of concrete? Such was the task that researchers led by Benton Johnson, P.E., S.E., an associate in the Chicago office of Skidmore, Owings & Merrill LLP (SOM), took on in 2013. Their solution—a timber frame system with concrete joints—relies on mass timber structural elements with supplementary reinforced concrete at connecting joints.

A final, full-scale test this summer validated the research expectations of the timber and concrete composite design, providing evidence that the system developed by the team could both meet building code requirements and compete economically with such traditional construction materials as steel and concrete. Indeed, the 37.5 ft long, 8 ft wide, and 9 in. thick panel of timber and concrete used in the full-scale test was able to carry an ultimate load of 82,000 lb—eight times what is required under the design load, according to SOM.

"Our work in 2013 was researching ways not only to make mass timber possible in high-rise buildings but also to make it competitive with conventional materials," Johnson notes. "We determined that timber-concrete composites are the most effective way to reach these goals," he says. "Concrete [is] used to create a rigid connection between timber elements," Johnson says. "This enhance[s] the performance of a timber system by a factor of 5, which is far better than using more materials or higher-strength materials to achieve the same goal."

The team also determined that the gravity framing structure of a building—that is, its floors, beams, and gravity columns—is responsible for the majority of materials consumed in a building, according to Johnson. Because of this, the team members initially focused on such systems.

The physical testing program for the panels of timber and concrete was developed by Oregon State University in conjunction with SOM. Andre Barbosa, Ph.D., an assistant professor of civil and construction engineering in the university's College of Engineering, led the testing, which covered vertical and gravity loading, along with Christopher Higgins, Ph.D., the Cecil and Sally Drinkward Professor in the College of Engineering.

The composite panel system designed by SOM begins with a base of cross-laminated timber (CLT), which is formed by first gluing strips of wood together to form layers and then gluing the layers together in a crosshatch pattern to create panels. Each layer lies at a 90-degree angle to the layers that are immediately below and immediately above, making the panels "dimensionally stable" so that they only minimally shrink or swell in the plane, according to Johnson.

To create the composite of timber and concrete that was used in the full-scale test, a five-layer base of CLT was topped with a layer of concrete of regular strength. Though added for acoustic and fire performance needs, the concrete also enhances the structural performance of the system. To join the concrete to the CLT base, self-tapping screws were sunk into the CLT in a grid pattern in such a way that the screws protruded at 45-degree angles in opposing directions. Between 2.25 and 9 in. of concrete was then placed atop the CLT and screws.

The 37.5 ft long test specimen was modeled on a 24 ft bay and two 6.75 ft sections of adjacent bays. In this way the concrete connection between two panels atop an underlying beam could be tested as well. The concrete thickness was increased to 9 in. at the connection edge between the individual deck panels to ensure that the floor panels could be designed to span between the necessary beams with relatively thin cross sections, according to material on SOM's website. The concrete layer was always poured level, and the extra thickness was made possible by stepping down the CLT layers at the beams, according to Johnson. "The concrete slab both stiffens the CLT floor plank and makes it a continuous beam with the CLT plank on the opposite bay," Johnson says.

The full-size specimen tested this past August was loaded with a hydraulic actuator, and 48 sensors recorded its behavior during the two-hour test. "The structure performed well, exceeding our stiffness requirements by 30 percent," Johnson says. "The strength was well beyond code requirements and does not govern the design." The excess strength demonstrated by the system is expected to provide the necessary three-hour fire rating: as the wood chars during that period, enough strength will remain to exceed building requirements.

All told, nearly 20 tests were completed as part of the testing program implemented by Oregon State and SOM. In addition to the full-size section, the tests included smaller beam-sized (10 ft 8 in. long and 2 ft wide) panels that were used to test different types of connections between the CLT and the concrete, including self-tapping screws, steel mesh connectors, and steel plates with studs, according to Barbosa. Panels measuring 8 ft square were tested for stiffness and strength in the strong and weak directions under positive and negative bending and warping. Moreover, a beam 20 ft long and 4 ft wide was tested for deflection over a four-month period for long-duration loading under positive bending while a 13 ft 6 in. long and 4 ft wide specimen was measured under negative bending, according to Barbosa.

SOM's research has established that the carbon footprint of its timber frame with concrete joints is 60 to 75 percent lower than that of a comparable building of reinforced concrete or steel.

While wood is a renewable resource, it takes time to grow to maturity. However, a large supply of wood referred to as beetle-killed pine that could be used for mass timber manufacturing already exists in a large swath of the Pacific Northwest reaching up into Canada, according to Barbosa. "Because of climate change, global warming, and less harsh winters, beetles were able to really flourish," Barbosa explains. As a result, "there were a lot of pine trees that were killed by the beetles," he notes.

"If the wood is harvested within three to five years of it being killed by the beetles, the wood does not lose structural properties," Barbosa notes. "So [there is] a big driver and a big push to come up with new, value-added solutions [for wood construction] because the trees have to be harvested anyway."

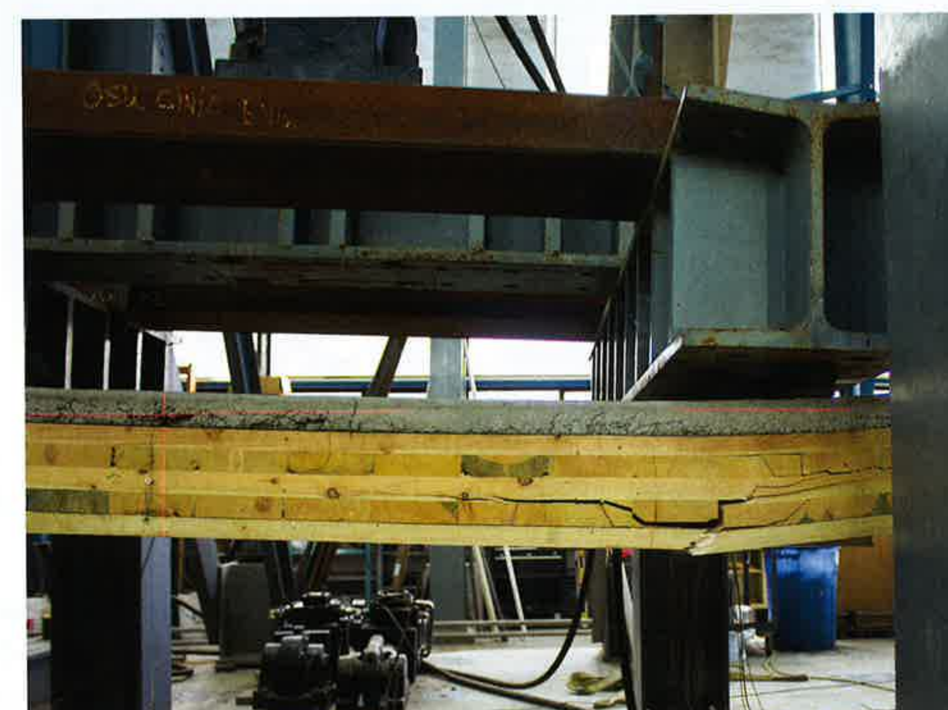
While SOM has not explored the use of beetle-killed pine per se, "we understand that it does not impact structural performance if harvested in time," Johnson says. "We have no objection to using this material, provided it meets the industry standard for CLT grading."

The physical testing carried out by Oregon State and SOM's research were funded by the Softwood Lumber Board, an industry-funded initiative based in Washington, D.C., to promote the use of softwood in construction.

The next step will be to firetest the designs.

—CATHERINE A. CARDNO, PH.D.

A full-scale test of the timber and concrete composite design was able to carry an ultimate load of 82,000 lb, eight times what is required under the design load, before cracking.



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