Steel Fibers in Link Beams

Seattle's The Martin tower is first to implement new technology

by Sheila Bacon Cain

After more than a decade of research, review, and code implementation, structural engineers can now offer an alternate design for concrete link beams in high-rise towers, significantly reducing congestion and dramatically improving constructibility. Deliverance lies in steel fibers mixed into the concrete placed in beams above the doorways and mechanical openings in concrete shear walls—areas where seismic strength and ductility are critical. Inch-long steel fibers can now take the place of the diagonal bars required in conventional designs, providing comparable strength and eliminating the headaches contractors experience in placing the bars and concrete in what are traditionally highly congested zones.

The Martin, currently under construction in the Belltown neighborhood of Seattle, WA, is the first tower with seismic link beams with steel fiber reinforcing. The project team building the 240 ft (73 m) tall, 24-story apartment building reports that the new approach has the potential for significant savings in time and costs. "The big push in the industry is lean construction," said Andrew Clapham, Senior Director of Design and Construction for Seattle's Vulcan Inc., the developer of The Martin. "If this is a tool we can put in our toolbox for future projects, it will be very useful for us."

Improving Construction

Shear walls provide lateral stability to a building. The strength and stiffness of a wall are compromised, however, by penetrations required for doorways and mechanical openings. The remaining elements above the openings become very highly stressed "link" beams, often requiring diagonal bars that must be anchored in the walls. Threading the diagonal bars through the congested vertical and horizontal bars in the walls' boundary elements can be very difficult and time-consuming. The time spent placing the bars, placing the concrete, and ensuring it's consolidated in the heavily congested beams and boundary elements can negatively impact the construction schedule.

By using concrete mixed with steel fibers, the strength and ductility of link beams is greatly increased, and a significant quantity of reinforcing steel—including the unwieldy diagonal bars—can be eliminated. The Martin's structural engineering firm, Bellevue, WA-based Cary Kopczynski & Company (CKC), has been at the forefront of the effort to integrate steel fibers in seismic link beams in the Pacific Northwest. "We believe this could revolutionize the construction of shear wall link beams in high seismic areas," said Joe Ferzli, CKC Principal.

The Fibers

The Dramix® steel fibers used in The Martin's link beams are manufactured by Bekaert. The fibers are produced from 0.015 in. (0.38 mm) cold-drawn steel wire. Each fiber is 1.18 in. (30 mm) in length and has hooked ends for anchorage. They can be mixed into the concrete at the batch plant or at the job site. Fibers are delivered to the producer in groups of 30, bonded with a water-soluble glue that dissolves when the groups are mixed into the concrete, allowing the fibers to separate and disperse throughout the mixture. The fiber dosage for The Martin project is 200 lb/yd^3 (120 kg/m^3) of concrete.

Opportunities

While steel fibers are commonly used in applications where high toughness is required, such as dams, tunnel linings, and industrial floors, fiber applications in building

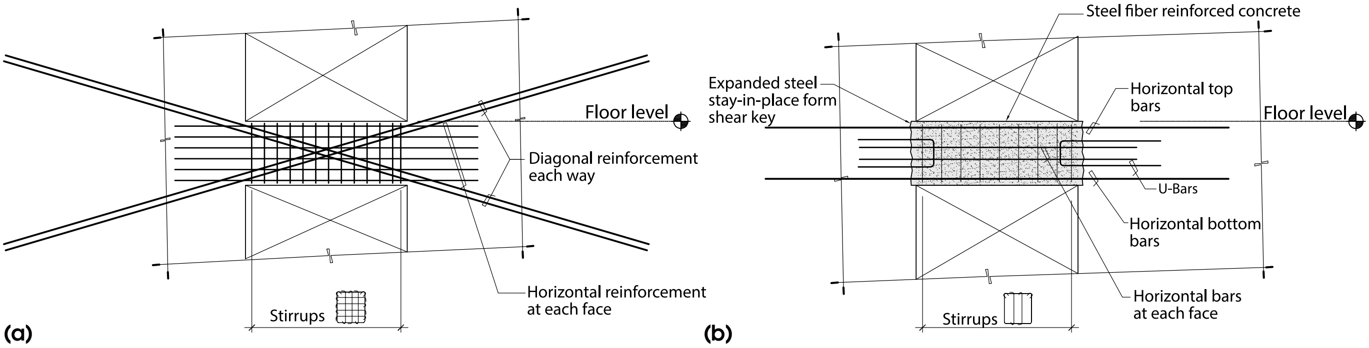

Fig. 1: Schematics of link beams: (a) conventional reinforced concrete; and (b) fiber-reinforced concrete. A conventional link beam is typically highly congested and the extensions of the diagonal reinforcing bars will conflict with the adjacent wall reinforcing (yet to be placed). Fiber-reinforced concrete helps to eliminate much of the reinforcing needed in the beam, alleviating the congestion. In many cases, fiber-reinforced concrete will also help eliminate the diagonal extensions

Fig. 2: Construction of a fiber-reinforced concrete link beam in The Martin: (a) reinforcing bars and expanded steel stay-in-place forms are positioned between a column and a wall; (b) a worker consolidates the fiber-reinforced concrete with a spud vibrator as he directs the concrete into the form; and (c) vibration is continued as the concrete is topped off

structures have heretofore been limited. Vulcan is leading the construction industry with its decision to use this innovation on one of its high-profile projects. The flexibility and willingness of the entire project team—from the concrete suppliers and contractors to on-site laborers—has helped get the technology to the field. "As industry leaders, we are constantly on the lookout for innovative ways to improve our projects," said Vulcan's Clapham. "We believe a better product is possible if we challenge ourselves to think outside the box."

On The Martin project, the steel fibers were mixed into the concrete at the batch plant. "This was the first time we had used this," said Brian Foster, Superintendent with Exxel Pacific, a Bellingham, WA-based concrete contractor. "When the first mix showed up at the job site for test pours, it didn't move." While an 8 to 10 in. (200 to 250 mm) slump was needed, the fibers had brought the slump down to less than 2 in. (50 mm). The mixture was modified with chemical admixtures to improve flowability.

After a workable mixture was developed, crews quickly learned they had to wear thick work gloves for protection against the fibers. Concrete placement required only a little extra time, as a tower crane and bucket were used to deliver the link beam concrete rather than the pump used to deliver the shear wall concrete. Link beam placements on The Martin were finished in December 2012, and overall construction on the tower is expected to reach completion in the fall of 2013.

Fig. 3: The completed fiber-reinforced concrete link beam

In The Beginning...

The study of the use of steel fibers in seismic link beams started at the University of Michigan with researchers Gustavo J. Parra-Montesinos and James K. Wight and the financial support of the National Science Foundation through a 3-year grant awarded in 2000. In 2004, Parra-Montesinos presented results from this and other structural applications of fiber-reinforced concrete to an ACI 318 Subcommittee, where members were studying new materials, products, and ideas. The committee encouraged further exploration, and committee member Cary Kopczynski showed great interest in transferring this technology into practice. After the first research grant expired, further research on steel fiber-reinforced concrete coupling beams was funded by the National Science Foundation Network for Earthquake Engineering Simulation and Bekaert.

Parra-Montesinos and Wight studied substantially reducing or even eliminating diagonal reinforcement in link beams. They tested beams of varying aspect ratios—from 1.0 up to 3.3—concluding that a ratio of about 2.2 or higher would allow for the elimination of diagonal reinforcing bars in the link beams. They investigated different fiber types, eventually settling on high-strength hooked steel fibers at a 1.5% volume fraction. They also investigated various concrete mixtures, using numerous admixtures to produce workable concretes with compressive strengths of 6000 to 10,000 psi (41 to 69 MPa).

CKC proposed using fiber-reinforced link beams on a pair of high-rise residential towers in 2009, but those projects fell victim to the economic downturn. Once the building industry began to recover in 2011, CKC resurrected the steel fiber approach and proposed its use in The Martin.

But before the technology could be used in The Martin, Seattle's Department of Planning and Development required a thorough peer review. From March through June 2012, Joseph Maffei, Principal with civil and structural engineering firm Rutherford and Chekene in San Francisco, CA, and Richard Sause, Professor of Structural Engineering with Lehigh University's Department of Civil and Environmental Engineering in Bethlehem, PA, studied the findings of Parra-Montesinos, Wight, and their students; pored over computer analytical studies; and reviewed beam expected performance based on the structure's design—eventually concluding that the fiber-reinforced beams without diagonal bars would achieve comparable performance as those in the original design.

Savings

Whenever unconventional products or procedures are used for the first time, immediate cost savings are rarely realized. Such was the case with the use of steel fibers in The Martin's seismic link beams, but project team members agree that's sure to change. Once first-use issues are ironed out and the industry becomes more familiar with the process, benefits in cost, time, and constructibility—as well as improved structural performance—are certain, said CKC CEO and Senior Principal Cary Kopczynski.

"Uncertainty often plays a role in keeping costs high when a new product hits the market," said Kopczynski. "Once a product proves itself and all stakeholders have had a chance to gain experience with it, that fear diminishes and prices fall in step."

The Martin was not initially designed for the use of steel fibers in its link beams. In fact, the process wasn't implemented until Level 12, when the peer review of the innovation was completed. Had the building been designed from the start to incorporate steel fibers in the link beams, bar quantities could have been reduced elsewhere.

"I think we would have seen some cost savings in the labor as well as rebar tonnage in the core," said Foster. Clapham indicated that further cost savings could have been realized if the fiber-enhanced concrete had been specified earlier: "They were basically doing this as a change order. [Seattle concrete contractor] Conco did a great job stepping up and agreeing to use this material."

Kopczynski estimated that the innovation could result in up to 30% cost savings over traditional link beam construction. He also noted that research on the amount of steel fiber required in the link beams continues—with the likelihood of reducing it—which could further lower costs.

Expanding Use

Researchers are also soon expected to provide the results of laboratory testing to validate the use of steel fibers in entire shear walls. If approved, this would reduce horizontal, confinement, and boundary element reinforcement. Meanwhile, CKC has plans to use steel fibers in seismic link beams in several Seattle towers currently in design. Vulcan, too, is eager to follow up on The Martin's success.

"Now we have some facts and data we can call on when analyzing bids," Clapham said. "We believe there are potential savings. But if we sit back on our hands, we won't be going forward in this industry."

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Selected for reader interest by the editors.

Fig. 4: Rendering of The Martin

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