Name of Innovation:
High-Performance Steel Fiber Reinforced Concrete for Improving Constructability and Damage Tolerance of Structural Wall Systems in Earthquake-Prone Regions

This innovation consists of the use of a highly ductile fiber reinforced concrete in critical regions of earthquake-resistant wall systems (i.e., link beams and wall plastic hinge regions) in order to simplify their construction and improve their behavior during strong earthquakes. The fiber reinforced concrete material used exhibits a post-cracking hardening behavior under direct tension. In compression, it behaves like well-confined concrete. Because of their excellent tensile ductility, these materials are referred to as *high-performance fiber reinforced concrete (HPFRC)*. The tensile and compression behavior of HPFRCs allows a substantial reduction in reinforcement used for shear resistance and confinement, which facilitates construction and reduces costs. In the case of link beams (or coupling beams) connecting structural walls, the use of this fiber reinforced concrete leads to reductions in diagonal reinforcement used for shear resistance between 60% and 100% depending on the beam span-to-depth ratio. In wall plastic hinge regions, increases in transverse reinforcement spacing on the order of 2 are possible.

For several decades, researchers and structural engineers have struggled to develop a design for link beams in earthquake-resistant wall systems that leads to adequate seismic behavior while being easy to construct. Options investigated include alternative reinforcing bar detailing and steel coupling beams. Current design practice for link beams includes heavy amounts of diagonal and transverse reinforcement, which makes these beams nearly impossible to build. Further, the construction of these beams often controls the construction schedule for coupled wall systems. With the development of high-performance fiber reinforced concrete link beams, structural engineers and contractors now have the option to use link beams that are more economical and easy to construct, while exhibiting excellent behavior during earthquakes. Given the advantages of HPFRC link beams over traditional diagonally reinforced concrete link beams, these new beams are already being incorporated in the design of a few high-rise core-wall structures on the west coast, including a 40-story tower that will start construction this year in the Seattle area.

Research on the development of HPFRC link or coupling beams, led by Professors Gustavo J. Parra-Montesinos and James K. Wight from the University of Michigan, started in 2000 through funding provided by the U.S. National Science Foundation. For the following ten years, and with additional support from the National Science Foundation as well as industry, research activities focused primarily on fiber selection, reinforcement detailing, and constructability. This led to the development of a precast link beam design that includes a 1.5% volume fraction of high-strength hooked steel fibers, little or no diagonal reinforcement depending on the beam aspect ratio, and no special confinement reinforcement except for the beam ends. Further, an innovative design was developed for connecting the precast link beams with structural walls that greatly facilitates construction by allowing all reinforcing bars to exit the link beam horizontally. In current practice, diagonal bars extend several feet into the wall above and below the link beam. This requires the link beam reinforcement to be in place prior to casting of the wall underneath the link beam. With the new link beam design, the precast beam can be put in place after the concrete in the wall below has been cast to the bottom of the beam. Also, since the precast portion of the beam extends only into the wall cover, interference with the wall reinforcement is avoided, which is a major drawback of steel link beams.

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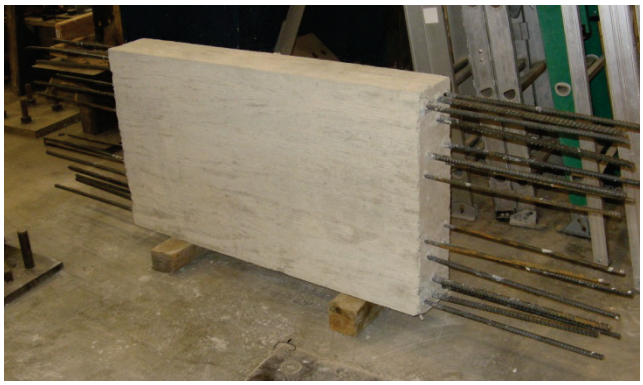
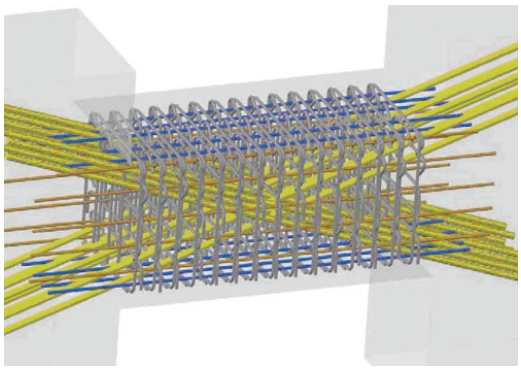
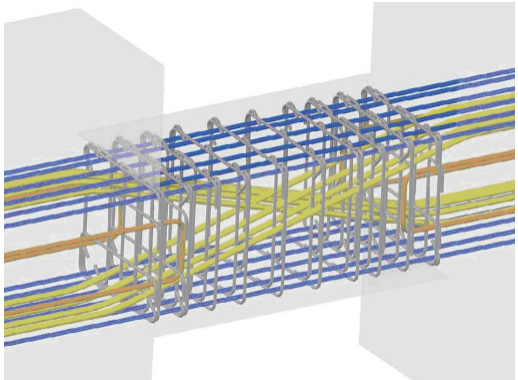
Current coupling beam design practice (Courtesy of Rémy Lequesne)



Precast HPFRC coupling beam (note that reinforcement exits the beam horizontally)



Regular concrete link beam



HPFRC link beam

Comparison of reinforcement detailing for link beams with equal strength (Courtesy of Cary Kopczynski & Co.)

Damage in link beams after being subjected to earthquake-type loading. Top: regular concrete link beam; Bottom: HPFRC link beam