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A retrofitted beam in the Coolidge Roundhouse gym is fully encased with a carbon-fiber covering.

Civil Engineering Research Aids High School Gym

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A structural engineering solution devised by UA civil engineers has allowed the Coolidge School District to add elevated bleacher seating to its Roundhouse Gymnasium at minimal cost and disruption to school activities.

The technology involves strengthening ceiling beams with Fiber Reinforced Polymers (FRPs) that are similar to fiberglass and Kevlar.

QuakeWarp, Inc., a company formed by UA Civil Engineering Professor Mohammad Ehsani, has employed FRPs in the past to strengthen concrete beams and columns, reinforce masonry walls, and retrofit large pipes.

The process has been used in California to help masonry structures resist earthquakes, and in Arizona to strengthen floors in local hospitals and to line pipes for the Central Arizona Project.

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Related Web sites
QuakeWrap, Inc.
Mohammad Ehsani's Homepage

New Bleachers Create A Problem

In Coolidge, Ariz., the school district wanted to create elevated bleacher seating above the locker rooms that are next to the gym floor. This would allow them to move sports fans off the gym floor and to provide them with a better view.

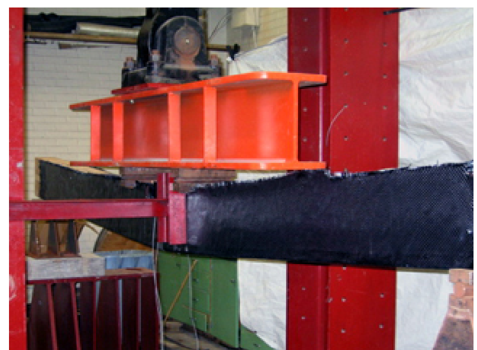
Unfortunately, placing this kind of load on top of the locker rooms wasn't anticipated when the gym was built in the 1960s. School officials found that the second floor wouldn't support the bleachers and spectators without being reinforced.

One possible solution involved placing vertical columns under the floor, but this would have severely restricted space in the locker rooms. Another solution would have added additional horizontal beams below the floor, but these would have been costly and difficult to install.

So Paragon Structural Design, Inc., of Phoenix, Ariz., which was in charge of structural engineering on the project, contacted Ehsani about using FRPs to do the job. Mark Larsen, president of Paragon, was familiar with the process as an alumnus of UA Civil Engineering.

Problem Sends Ehsani Into the Lab

Larsen's question sent Ehsani into the lab to test glue laminated (glulam) wooden beams similar to those used in the Roundhouse gym. Ehsani worked on this research with civil engineering master's student Nathan Palmer, who was very familiar with the Roundhouse, having played on the Coolidge basketball team just a few years before.


A retrofitted test beam nears failure in UA's Structural Engineering Laboratory.

Ehsani and Palmer tested wooden beams similar to those used in the Coolidge gym, and used strain gauges to measure forces. The gauges were mounted on an unmodified beam and on a second beam reinforced with FRP materials. They found that the reinforced beam was 67 percent stronger than the unmodified one.

With this data in hand, work began on the Roundhouse gym.

Carbon-fiber plates were epoxied to the top and bottom of the wooden ceiling beams to increase their strength in both tension and compression. Carbon fabric was then wrapped around the beams to anchor the carbon plates and to provide increased shear strength by confining the laminated wood.

Adding the carbon-fiber plates to the tops of the beams was a problem because the beams were flush with the floor above and not accessible.

Novel Idea Solves the Problem

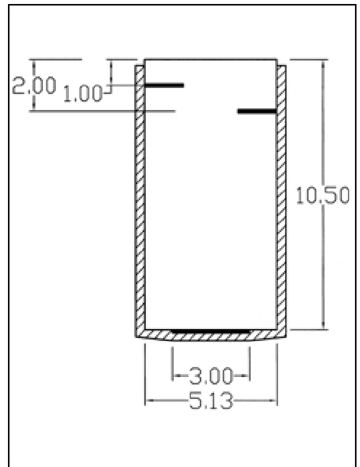
Ehsani and Palmer solved this problem by cutting 1/8-inch-wide slots 1 5/8ths inches deep into the beam near the top. The slots were slightly offset to prevent weakening the beam. Then 1.5-inch-wide strips of carbon plate were coated on both sides with thixotropic epoxy and pushed into the grooves.

A 40-mil-thick layer of thixotropic epoxy was then applied to the beams, and carbon fabric, which had been saturated with epoxy resin, was wrapped around three faces of the beam.

The beams were retrofitted in less than two weeks — while the locker rooms remained in use — at a cost of $8.50 per square foot.

"This was a very inexpensive solution," Ehsani said. "Sometimes floor tiles used as floor covering can be more expensive."

The Roundhouse floors, which originally were designed for loads up to 40 pounds per square foot, can now handle loads up to 60 pounds per square foot.



This cross-sectional drawing of a glulam beam shows how the carbon-fiber plates (solid lines) and carbon sheeting (hatched lines) were added to the glulam beams.

Pioneering the Technology Pays Off

"The greatest pleasure for one's professional career is to have dreamt of some solution and pioneered the field and then be lucky enough to be alive to see that it gets used." Ehsani said. "It's just a real joy when I drive by some building and I see that we actually strengthened it with something that came out of our lab."

Ehsani and UA Civil Engineering Professor Hamid Saadatmanesh pioneered the use of FRPs in construction beginning with a 1986 exploratory research grant from NSF.

"For the first six or seven years, people thought this was a really crazy idea," Ehsani said. "We were funded under an exploratory research grant because the idea of using FRPs to retrofit and strengthen structures was considered very far out at that time."

But Ehsani and Saadatmanesh proved the skeptics wrong and that first grant led to a patent on the process. When the researchers wanted to take the results from their lab to the field for further testing, Ehsani formed QuakeWarp for liability reasons.

Working at the interface of research and application has proven beneficial both to research and teaching, Ehsani said.

"I wouldn't have delved into this mini research project on glulam beam strengthening, for instance, if it were not for this project in Coolidge High School," he said. "This is something we had not looked at before. And we tested it and found out that it works and now we are publishing papers on it and have solved the problem for the client."

By working closely with practicing engineers, Ehsani said he has gained a deeper understanding of factors that are important in industry, but may not be important in the lab.

"Oftentimes for contractors, the aesthetics — the smell, how much dust is generated and similar issues — are critical," he said. "So is the ability to quickly complete the job and move out. In the lab, these things often aren't important. But they've now become critical factors in our research and they're real-world engineering concepts that I include when teaching my classes."

"It's been very gratifying to me to see the fruits of our research being applied and benefiting people," he added. "It's much better than just having your research end up in a publication that's sitting on somebody's shelf."