Strengthening of Old Wood with New Technology

FRP Laminates and Epoxy Help Support New Loads in an Existing Wooden Gymnasium

Figure 2: Test setup showing the retrofitted beam approaching failure

By: M. Ehsani, Ph.D., S.E., M. Larsen, S.E., and N. Palmer

The retrofit of existing structures is always challenging from an engineering perspective. Constraints of accessibility, existing load capacity and project budget loom large when an older facility needs an upgrade. With existing wood structures, the options available for strengthening members are often limited. However, the growing use of Fiber Reinforced Polymers (FRP) in repair and retrofit of concrete and masonry structures has opened the door for similar applications in wood.

The advantages of FRP materials lie in their high tensile strength, low weight, and their ability to conform to varying shapes. Many carbon FRPs, for example, have tensile strengths in excess of 300 ksi while their density is less than ¼ that of steel. FRP materials have been used successfully to strengthen existing concrete columns for higher seismic loads, as well as concrete and masonry walls that lacked adequate steel reinforcement. The versatility and ease of installation make FRP retrofit solutions extremely effective.

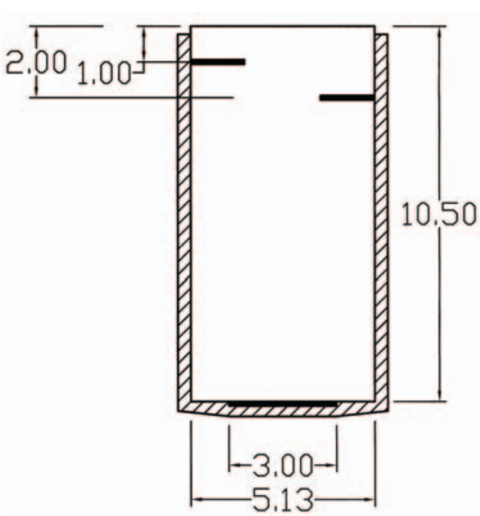

Figure 1: Beam cross section dimensions (inches)

Recently, this retrofit technique was utilized to strengthen existing glulam floor beams in a high school gymnasium in Arizona. This article summarizes the laboratory tests that demonstrated the feasibility of the strengthening system and the accompanying field application.

Laboratory Study

Experimental research has been performed to validate the applicability of FRP strengthening for wood members. The results for two specimens that are directly related to the field application are presented here. The glulam beams were 5⅛ x 10½ inch x 14 feet long (*Figure 1*). The beams were tested at the Structural Engineering Laboratory of the University of Arizona under four-point bending over a span of 150 inches (*Figure 2*). The strains of the wood and composite retrofit system were monitored using strain gages that were mounted in the critical regions of each specimen.

The first beam was tested as a control specimen without any retrofit. The maximum midspan moment resisted by the beam was 617 kip-in at a displacement of 1.94 inches. At that point, the laminate on the bottom of the beam started to fail in tension and testing was terminated at a maximum deflection of 2.2 inches (*Figure 3*).

The retrofit system utilized a 50-mil thick x 3-inch-wide carbon plate. The plate has a tensile strength of 350 ksi and a modulus of elasticity of 20,000 ksi. Because in most wooden floor systems the composite action between the deck and the beam is ignored, full benefit of the retrofit could be realized only if both the tension and compression faces of the beam could be strengthened.

To prevent buckling of the carbon plates on the compression face of the beam, it was decided to embed these elements in the beam. Two ⅛-inch thick x 1⅝-inch deep slots were cut near the top of the beam (*Figure 1*); the slots were at slightly different elevations to prevent a plane of weakness in the member. A 12-foot long piece of the 3-inch wide carbon plate was cut lengthwise into two 1.5-inch wide strips. The strips were coated with a thixotropic epoxy and were inserted into the slots, completely filling the void. On the tension face, the 3-inch wide plate was bonded to the beam surface using the same thixotropic epoxy.

For further flexural and shear enhancement, the bottom and two side faces of the beam were also wrapped in a carbon fabric. The fabric had equal amounts of fiber in the longitudinal and transverse direction, with a breaking strength of 2250 pounds per inch width in each direction. The beam surface was coated with a 40-mil thick layer of the thixotropic epoxy. This epoxy has sufficient toughness to accommodate the deformations of the glulam beams due to change in moisture. The fabric was saturated in a resin and was wrapped around the sides and bottom faces of the beam.

The retrofitted beam reached a maximum moment of 1028 kip-in. at a displacement of 2.56 inches, *representing a 67% gain in strength compared to the control specimen*. The stiffness and ductility of the beam was also improved (*Figure 3*). For comparison, the theoretical moment capacity of the beam corresponding to an allowable stress of 2400 psi is also shown.

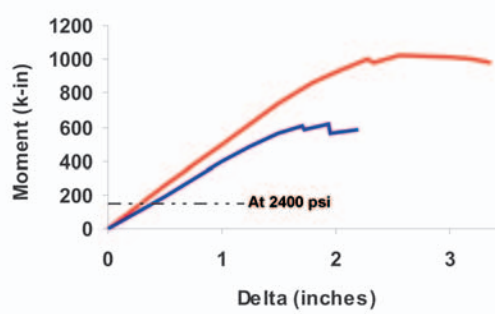

Figure 3: Moment vs. midspan deflection for beams

Figure 4: Installation of carbon plat near the top and on the tension faces of the beam

Using FRP in a 1960s Gymnasium Building

The high school gymnasium for the Coolidge School District is a two-story, round structure with a dome roof. The building was originally built in the 1960s and consisted of curved masonry bearing walls with a wooden dome roof in a lattice framework.

The gym floor was located at grade in the center of the building, and was flanked by an elevated mezzanine at one courtside and a two-story space with locker rooms at the other. The school district wished to open up the courtside spaces to create elevated mezzanines with bleachers. This would allow the district to move all public seating off of the gym floor, and provide spectators with a great viewing area overlooking the games.

The existing second floor framing consisted of 3x6 nominal wood decking over glulam beams spaced at approximately 10'-0" on center. Once the design process began, it was determined that the existing second floor was not capable of supporting the design live load for the new assembly space with bleachers and spectators. Calculations showed that the moment capacity of many of the floor beams would need to be increased by 30 to 40 percent in order to support the new loads. Shear capacities were closer to the new demand levels, but still inadequate in some instances.

In order to provide the school district with the desired improvements, a creative solution to strengthening the floor was needed. The addition of columns in the space below would have severely reduced the functionality of the first floor area. Strengthening solutions involving additional glulam beams appeared to be costly, and difficult to install. Fiber composite plates and fabrics were suggested by Paragon Structural Design as a possible strengthening method. After a thorough review by the architect, owner, engineer, contractor and the FRP supplier, it was determined that a fiber composite system could be used to strengthen the floor beams in a very economical manner, with little disruption to the space below. This system effectively made the project viable under the budget constraints, and provided the owner with the upgraded space that was needed.

Design calculations were performed by both the Structural Engineer and the FRP Supplier/Engineer in order to determine the strength increase that could be expected with the retrofit system. These calculations were validated by the results of the laboratory study on similar size members. Carbon plates epoxied to the top and bottom of the wood beam provide the additional tension and compression elements required to increase the moment capacity of the retrofitted beams. Carbon fabric wrapped around the beams provides anchoring for the carbon plates, additional confinement for the laminates, and increases the shear capacity of the existing beams. Design considerations such as fire resistance and service deflections were reviewed closely.

The construction procedure followed the parameters described in the Laboratory Study. The floor beams were easily accessible, since they were exposed in much of the first floor space. Due to the presence of the existing wooden floor, the top surface of the glulam beams was not accessible. A horizontal groove about ⅛-inch wide was cut along the span on each face near the top of the beam. The surface of the beam was mechanically prepared with a sander. The beam surface and the saw-cut grooves were then cleaned using high pressure air. The 1.5-inch wide strips of carbon plate were coated on both surfaces with the thixotropic epoxy and pushed into the grooves. The epoxy and plate fit tightly in the groove, which allowed

Figure 5: Saturated carbon fabric being applied to the beam surface

the upper carbon plates to be fully embedded in the beam and would prevent buckling of the plate under service loads. A 3-inch wide strip of the carbon plate was bonded to the tension face of the beam (*Figure 4*).

Finally, a 40-mil thick layer of the thixotropic epoxy was applied and the carbon fabric, which had been saturated with resin, was wrapped around the three faces of the beam (*Figure 5*). The carbon fabric was identical to that used in the laboratory Study. Using hand pressure, any air bubbles were removed, resulting in a smooth finish (*Figure 6*).

This procedure was followed for the 21 beams that were strengthened in the building. The actual construction phase of the retrofit project was completed in less than two weeks, with little interruption to the ongoing use of the locker rooms. The cost of the retrofit was approximately $1300 per beam, or $8.50 per square foot of floor area. This cost was much less than other retrofit strategies that were reviewed. For the Coolidge School District, this relatively new technology provided a good solution to an old problem.■

Figure 6: Finished beams may be painted

Acknowledgements

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Mo Ehsani is Professor of Civil Engineering and Engineering Mechanics (CEEM) at the University of Arizona, Tucson and President of QuakeWrap, Inc. Mark Larsen is a Principal at Paragon Structural Design, Inc., Phoenix, AZ. Nathan Palmer is a graduate student in the CEEM Department at the University of Arizona.

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