# Advanced Composites for Structural Strengthening

*The State of the Industry*

*By Scott F. Arnold, P.E.*

The last twenty-five years has seen Fiber Reinforced Polymer (FRP) composites move from testing in the laboratory to multi-million dollar projects in our civil infrastructure. The use of these advanced composite materials has been historically dominated by the aerospace industry, the military and the recreational industry (e.g. skis, boats, race cars). Although these industries still remain the primary users, the civil infrastructure industry is fast becoming a major contender.

The first applications in the FRP industry for the use of structural strengthening and rehabilitation started with research and testing done in the 1980s. Its first major breakthrough occurred in the late 1980s, when seismic retrofits successfully increased the ductility of a full-scale 6-foot diameter reinforced concrete bridge column that was tested at the University of California at San Diego (UCSD) (*Figure 1*).

This testing breakthrough opened the door, and since then the industry has flourished. FRP applications have been performed on a variety of structural elements such as columns, beams, slabs, walls, pipes, and storage tanks. FRP provides various enhancements to existing structures such as shear strengthening, flexural strengthening, axial load strengthening, lap splice enhancements, corrosion repair & protection, and blast mitigation. Through many years of testing and applications, structural strengthening with FRP materials has proven to be an effective retrofit solution when properly designed and installed. FRP in civil infrastructure began with seismic retrofits of bridge columns and has since expanded to a range of civil applications, and it should continue to expand for years to come.

## History of Growth

There have been many FRP projects that have ranged from small scale (dollar amount in the thousands) to large scale (dollar amounts in the multi-millions). There has been more growth in the industry over the past 20 years, as engineers have become more and more familiar with its applications and have gained more confidence in the abilities of FRP as a structural material like steel and concrete. As more successful applications and advancements were made over time, FRP projects continued to grow in quantity and size. The square footage of FRP installed on projects over the years is shown in *Figure 2*.

*Figure 1: Wrapping of Full Scale Bridge Column at UCSD.*

No matter the size of the project, each one completed to date using FRP is unique and cannot be designed and installed purely on the basis of past applications. Each project must be designed based on clearly-defined performance criteria in order to achieve the desired design goal. Even then, the skills of the contractor installing the material can prove to be a weak link if they have not been properly trained and certified by the FRP manufacturer. Poor workmanship on the design and installation has lead to failures of FRP strengthening systems, which stresses the importance of always using good workmanship and quality control to ensure the proper design and installation of FRP composites.

In addition to the history of its growth, recent testing developments have shown a potential for more growth for FRP in civil infrastructure. Developments in the strengthening of gypsum shearwalls and various steel components show that this industry has not yet begun to reach its full potential. With more research and development along the way, we expect this industry to continue to grow as more advances are made in years to come.

## Case History – Plum Point Chimney Project

A good example of an innovative application of FRP in Civil Infrastructure is the Plum Point Chimney project (*Figure 3*).

The chimney was deficient in longitudinal reinforcement and required additional flexural capacity. A unidirectional carbon composite system was installed longitudinally on the exterior and interior of the chimney, in order to provide the required additional vertical reinforcement. In comparison to more conventional methods such as steel or concrete,

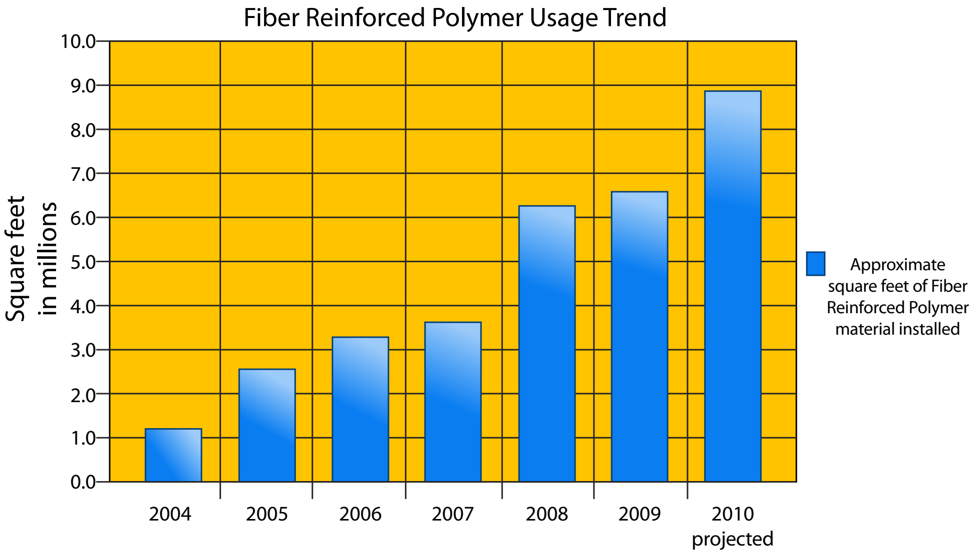


*Figure 2: Chart Showing Number of Square Footage of FRP Installed Over Time.*

the FRP provided an effective solution. Time and money was saved due to its ability to be installed in a quick and efficient manner with trained and certified applicators. Had traditional solutions such as concrete encasements been used for this project, more weight would have been added to the chimney stack thus increasing the loading and causing more potential strengthening work for the structure. The major benefit of using fiberwrap is that the additional moment capacity was provided to the chimney stack without adding virtually any weight. In addition to its high strength, the FRP's lightweight and low-profile nature made it an excellent tool for strengthening and rehabilitation.

## Conclusion

Even though FRP has already come a long way in its many uses for structural strengthening and rehabilitation of existing structures, we have only begun to scratch the surface of this powerful strengthening tool. As demonstrated over the past 20+ years, new advancements and applications will be found through extensive testing and research. Once the structural testing has validated a particular application, the next step is to prove that the application will provide a cost effective solution when compared to conventional retrofit schemes. It is interesting to compare these overall costs and to see how these relatively expensive materials can still be more cost effective when all aspects of an installation are considered. We expect the type and number of projects to continue to grow as we realize a larger market share of our civil infrastructure.▪

*Figure 3: Application of FRP on Exterior (Left) and Interior (Above) of Plum Point Chimney.*

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