FRP Strengthening of a Fire Damaged Industrial Plant

By Peter Milligan, P.E.

In December 2002, the KBP Coil Coating Plant located in Denver, Colorado experienced an internal fire that lasted several hours, damaging the structure. The bulk of the damage from the heat was realized in the reinforced concrete folded panel roof system and several beams. The local damage to the inner concrete cover and the loss of concrete prompted a comprehensive repair, including the use of carbon fiber reinforced polymers (FRP). To limit possible future damage from fire, the FRP repair was protected using an innovative, UL Listed fire protection system.

Figure 1: Facility Plan View.

The extent of the damage from the fire was fortunately confined to approximately 15% of the folded roof panel area. The comprehensive repairs of this area included:

1) shoring of the fire-damaged folded roof valleys,
2) hydrodemolition of the damaged interior concrete,
3) replacement of the damaged concrete areas by shotcreteing,
4) epoxy injection of existing shear cracks,
5) application of carbon composite laminates to the peaks and valleys of the folded slab to increase positive and negative moment strength to compensate for the permanent loss in steel strength,
6) external shear strengthening for both the fire damaged area and other areas of folded roof slab not affected by fire, and finally,
7) fireproofing the structural FRP applications in the fire damaged areas.

Folded slab sections are essentially a beam element with maximum negative moments located at the peak of the folded roof slab, the interior column lines and the exterior column lines (*Figure 1*). The maximum positive moments are at mid-span of the folded roof slab and on the bottom of the valleys. The engineer of record conducted a SAP2000 finite element analysis of the fire-damaged area that quantified the deficient areas of the folded slabs requiring rehabilitation. *Figure 2* illustrates the resulting tension deficiencies that became the target design values for the carbon fiber reinforced composite system applied to these areas. The required tension indicated in the finite element analysis was used for the design of the FRP composite strengthening systems. The bulk of the deficiencies were in the East-West direction (parallel to the peak and valleys). Some flexural reinforcing was also completed in the North-South direction perpendicular to the peak and valley axes.

The carbon composite system is a relatively simple retrofit method for concrete members requiring additional flexural tensile force. The carbon fibers used for the flexural strengthening of these folded roof panels have fibers oriented in a single direction, referred to as "uni-directional". This optimizes the tensile properties of the fabrics. The materials are linear-elastic and their behavior under load is well represented by Hooke's Law. The tensile modulus of the carbon composite is multiplied by the design strain, resulting in the design stress. The design strain is determined by application type. The required area of carbon composite is determined by the required tensile force, in this case, from the output of the finite element analysis. The layout of the carbon composite was determined by the computed tensile force to be resisted by the composite laminate and the bond strength of the concrete substrate used to develop that tensile force.

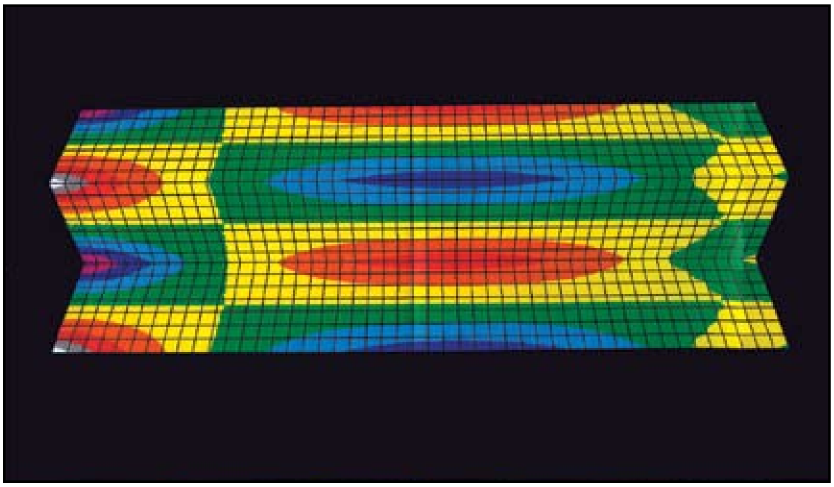

Figure 2: FEM Stress Output Example.

Flexural Strengthening

Carbon composite for negative moment strengthening was applied to the topside of the folded roof peaks at the interior and exterior column lines (*Figure 3, page 48*). Note that at the internal column lines, the negative moment strengthening was continued past the point of maximum tensile requirement to develop the carbon composite system in a manner similar to the development of conventional reinforcing. The positive moment reinforcing was applied to the underside of the folded roof valleys at the mid-span inside of the building over the repaired concrete areas (*Figure 4, page 48*). This composite system repair had to be applied around the shoring that was to remain in place until the work was completed.

continued on next page

Figure 3: CFRP Negative Moment Strengthening.

Shear Strengthening

In addition to the fire-damaged areas, analysis of the existing structure determined that the areas to each side of interior column line B were deficient in shear strength for current code requirements. During the application of the FRP to the fire damaged areas, the application of bi-directional glass composite to the non-fire damaged areas for the structural upgrade were completed as well. Epoxy injection of existing shear cracks was completed prior to shear strengthening with the glass FRP composite.

Figure 4: CFRP Positive Moment Strengthening.

To restore the shear strength of both the fire damaged section and the remainder of the folded roof panels at the interior column line B, a bi-directional glass composite system was used. This glass composite was composed of plus and minus 45-degree oriented fibers (*Figure 5*). Often, the shear strengthening of beams, slabs, and walls can be effectively accomplished with the use of uni-directional composite systems, with the fibers oriented parallel to the applied shear force. The advantage of using uni-directional composite for shear strengthening is the added ductility associated with the retrofit, as well as the additional strength. The advantage of the bi-directional glass composite for this application was to apply the strong fibers at the principal stress axes for the tensile forces in the folded roof panel faces. This added more stiffness and strength to the existing system as opposed to the uni-directional fiber approach, and thus was favorable for this type of repair. Tensile testing was completed to verify FRP to substrate bond strength.

All areas of concrete repair to receive FRP composite strengthening systems were prepared for bonding using sand blasting for surface preparation. After application and curing of the fiber reinforced composite systems, the shoring was removed and the fireproofing was applied to complete the 1-hour rated assembly (fiber reinforced composite and fireproofing). This fireproofing is a UL listed system that provides fire ratings to FRP strengthening.

Figure 5: GFRP Bi-directional Shear Strengthening.

Fire Protection

The application of the fireproofing material was completed in several steps with 4 different materials. The first is a primer material used to improve the interface between the fiber reinforced composite and the second layer of the system, the dash coat material. The dash coat is applied as a starter material to build the third layer, a cementitious insulation for fire protection. The thickness specified for this application was 1.25 inches, based on the requirement for a 1-hour structural rating. This cementitious material was applied in two lifts by spray methods. After the required thickness was installed, the surface was troweled to provide a smooth finish, similar in appearance to the other areas on the underside of the folded roof slab. After the insulation material had been installed, the final coating was applied to complete the assembly (*Figure 6*).

Figure 6: Fire Proofed FRP Assembly.

The cementitious insulation material is used to insulate the epoxy matrix material in the fiber reinforced composite systems. Structural testing under ASTM E119 fire loads with thermocouples applied was required as a reference by the permit authorities for this proposed assembly to be accepted.

Figure 7: ASTM D3039 Testing of FRP Site Panels

Quality Control and Quality Assurance Programs

Quality control and assurance, as well as material testing, cannot be overlooked in the use of fiber reinforced composite materials. These procedures are just as important as concrete cylinders, structural steel samples, or other conventional structural strengthening material.

All of the fiber reinforced composite materials and other materials associated with the assembly were applied by experienced and manufacturer certified personnel. The installation contractors kept an installation log of all materials, including lot numbers and areas of the installed materials. The material logs are for reference, if required, for the ASTM D3039 material testing to be completed on panels of fiber reinforced composite materials made on site. These panels were sent to an independent laboratory and tested to verify design properties of the materials (*Figure 7*). If the properties had been determined to be deficient, the installation logs would be used to locate remediation. Because the application was reliant on the transfer of the tensile force in the composite to the folded slab, bond testing per ASTM D4541 was also completed (*Figure 8*).

The author would like to acknowledge the contributions of Mr. Carl Mangone of Fay Engineering (the engineer of record) and Mr. Bruce Collins of Restruction Corporation (the fiber reinforced polymer installation contractor).

Conclusions

This case study for strucutral repairs and remediation was an excellent demonstration of new and innovative structural repair technologies in one unique location.▪

Figure 8: ASTM D4541 Testing of Bond Critical FRP.

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