North American Society for Trenchless Technology (NASTT)
NASTT's 2018 No-Dig Show

Chicago, IL
March 17-21, 2019

MM-T1-04

Corrugated City of Steam – Emergency Repair of the Drama Tunnel

Mo Ehsani, Professor Emeritus of Civil Eng., U. of Arizona, and President, QuakeWrap, Inc., Tucson, AZ USA
Ryan Kelly, Project Manager, FRP Construction, LLC, Tucson, AZ USA

1. ABSTRACT

Beneath every university campus, there are miles of tunnels used to transport utilities throughout the entire campus. These tunnels become deteriorated over time, and repair solutions that do not interrupt campus activities are often sought by university management. The University of Arizona used corrugated metal pipe (CMP) in many of its tunnels, and in some cases the steel was worn all the way through the pipe wall. The University requested a severely deteriorated CMP section be repaired with a carbon fiber reinforced polymer (CFRP) liner.

The 96-inch diameter CMP was buried 4-feet below grade and 162 feet of the pipe was repaired. Retrofit work consisted of: surface preparation by sandblasting, installation of wire mesh, spraying of 3-inch gunite mix to create a bondable surface within the CMP, one layer of longitudinal, unidirectional carbon strips 24-inch wide at a 48-inches spacing, and a full layer of unidirectional carbon fabric in the hoop direction.

The construction proved to be very challenging with steam being carried throughout this particular tunnel in various pipes. The temperature in this tunnel was above 115 °F, and the pipes carrying steam presented many obstructions to the installation. The tight spaces, along with the heat, required a 35-ton AC unit to be ordered. This unit helped to create airflow and cool the tunnel to a workable temperature. The project was successfully completed at the end of August 2017, with a repair method that did not require interruption to campus operations.

2. INTRODUCTION

Utility tunnels are frequently used on large campuses such as universities, colleges, medical complexes, etc. These tunnels, which are typically buried several feet underground, house utilities, for example pipes to convey chilled water, hot water and steam, fibre optics and telecommunication cables, etc. They typically run from a central plant to various buildings, and their inlets to the buildings are through the basement of the structures. With the passage of time, additional utilities are often placed in these tunnels, making them very congested. At the same time, the often wet, and sometimes hot, environment in these tunnels provides a perfect setting for corrosion.

The first of the utility tunnels on the campus of the University of Arizona was built in 1931 at a cost of $49,275 (Cooper,1989). During World War II, the tunnels were designated as bomb shelters and food and water were kept in them. This network of tunnels has grown significantly over the years as the University has added more structures; it is estimated that there are 6.5 miles of tunnels under the campus (Fig. 1) (Kopach, 2010). The majority of these tunnels are made of precast concrete boxes. Even in the relatively favorable dry conditions of southern Arizona, water can reach these structures and cause corrosion. Two years ago, about 1,000 feet of a section of such reinforced concrete tunnels, that was damaged due to watering of the grass above, was repaired. The current project was a different location and involved repair of a corrugated metal pipe tunnel.

Fig. 1. The network of 6 ½ miles of utility tunnels under the campus of the University of Arizona; the project site is shown with a red circle.

This project is located at a very busy area of the campus with significant pedestrian traffic. Figure 2(a) shows a view of the campus looking north. Speedway Blvd. is a major thoroughfare in Tucson that runs in the east-west direction through the campus. On the north side of the boulevard are many structures such as a large parking garage that is used by commuters and the business school. In addition, many student apartment buildings are located on the north side of Speedway. Every day thousands of people walk through the Speedway underpass (shown by a blue line in Fig. 2a) to access the main campus. Figure 2(b) shows the view looking south as one exists the underpass below Speedway Blvd. The tunnel is in front of the School of Theatre, Film and Television, formerly known as Drama School, thus the name Drama Tunnel.

The utility tunnel in this project was constructed of corrugated metal pipe (CMP). It has a diameter of 96 inches and houses several pipes, including one that conveys steam. Consequently, the temperature inside the pipe is above 115 °F. About a month before the beginning of the Fall 2017 semester, a section of the deteriorated tunnel failed. The soil and concrete sidewalk above the pipes partially caved into the pipe. The University immediately contracted with Sun Mechanical Contracting, Inc, an Arizona-based full-service mechanical contracting and construction firm with offices in Tucson and Phoenix, to perform the repairs. As the first step, Sun Mechanical removed the soil from the top of the tunnel to eliminate the gravity loads acting on the pipe. Temporary shoring was also provided by Sun to prevent collapse of the surrounding soil (Fig. 3a). The figure also shows how badly the crown portion of the CMP had corroded.

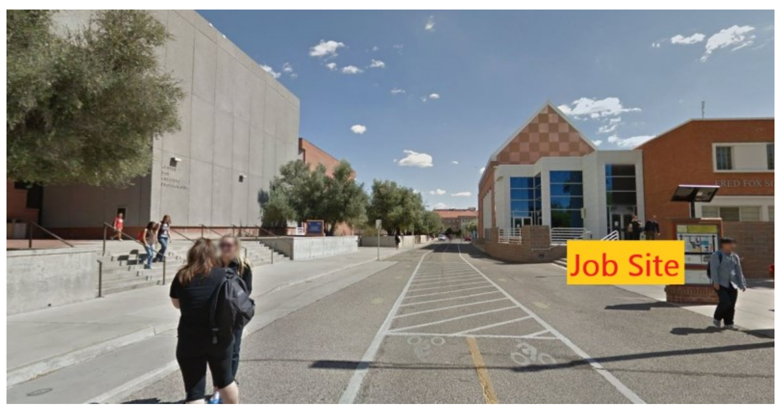
At this time the University and Sun contacted QuakeWrap and FRP Construction for developing a repair system for the tunnel. These three companies had teamed up together in the past on other projects. Two years earlier, QuakeWrap had successfully repaired a 1000-ft section of concrete tunnel for the University with carbon Fiber Reinforced Polymer (FRP). The fact that this design could be implemented very quickly before the Fall semester would begin, was a major factor in selecting an FRP solution. Thus, the team of Sun Mechanical as general contractor and FRP Construction as the subcontractor was formed to repair this tunnel. QuakeWrap, Inc. would provide the materials and engineering design for the tunnel.

3. DESIGN WITH CARBON FRP

The general contractor provided a new section of CMP with the same 96-inch diameter and placed it on the top of the tunnel where the crown was corroded away. The overlapping portions of this pipe segment were bolted to the existing tunnel, to create a continuous pipe section. Examination of the tunnel revealed that much of the CMP was corroded to various degrees. So, a part of the design included providing a reinforced concrete liner with sufficient ring stiffness to resist the external loads from soil, traffic, etc. The objective was to design a fully structural liner capable of resisting all loads independent of the old CMP tunnel.

Figure 3(b) shows the tunnel with the new segment of corrugated metal pipe placed at the crown region and bolted to the old pipe. A steel wire mesh was attached to the entire surface of the tunnel (Fig. 3b). The design included spraying a 3-inch thick layer of gunite to the entire surface of the 162-ft long tunnel. The design details are shown in Fig. 4.

(a)



(b)

Fig. 2. Project site location and access.

Over the last twenty years the American Concrete Institute (ACI) Committee 440 has developed design guidelines for repair and strengthening of structures by external application of Fiber Reinforced Polymer (FRP) systems (ACI 440.2R-17). Although not specifically developed for repair of pipes, these guidelines do provide a wealth of information that can be used in other applications. For example, they provide reduction factors based on the type of fabric (glass or carbon), the type and duration of loading (e.g. sustained or short term), and the environment that the FRP will be exposed to (e.g. dry, wet, chemical exposure, etc.). For carbon FRP, the environmental reduction factor for interior exposure is 0.95, and for exterior exposure such as bridges, or aggressive environment such as chemical plants and wastewater treatment plants, the reduction factor is 0.85.

The carbon FRP product used for this project was a unidirectional fabric where all fibers are aligned in the longitudinal (warp) direction of the fabric. The dry fabric weighs 18.5 oz per square yard, or 0.13 pounds per square foot and is supplied in 24-inch wide rolls. Once the fabric is saturated with resin in the field, the combined system weighs about 0.35 pounds per square foot. The cured system has a thickness of only 0.04 inch (Table 1). Unlike steel that is isotropic (i.e. has the same strength in all directions), FRP products are anisotropic and their strength depends on the orientation and amount of the fibre in that direction. The fabric used in this project has a tensile strength of 102,700 psi which corresponds to a breaking force of 4,100 pounds per inch width of fabric in the longitudinal direction.

(a)

(b)

Fig. 3. (a): Removal of the soil above the failed tunnel and shoring of the trench; and (b): Placement of new corruga segment at the crown and the steel reinforcing wire mesh.

Table 1. Material properties of carbon FRP tested according to ASTM D3039

Fabric Type	**U18C**
Fiber type and architecture	Unidirectional Carbon
Aerial Weight of Fabric (oz/yd^2)	18.5
Ply Thickness (in.)	0.040
Fiber Properties:	
Tensile Strength (ksi)	550
Tensile Modulus (ksi)	33,500
Ultimate Elongation	1.64%
Density (lb/in.^{3})	0.065
Laminated with J300SR:	
Tensile Strength (ksi)	102.7
Tensile Modulus (ksi)	9,950
Ultimate Elongation	1.1%
Breaking Force (lb/in.)	4,100

Because there are virtually no fibres in the transverse (weft) direction of the fabric, the strength of the fabric in that direction is ignored. Combining the tensile strength of the fabric with the environmental reduction factors described earlier, the carbon FRP could provide a strength of:
0.95 * 4,100 lb/in = 3,895 lb/in. along the length of roll.

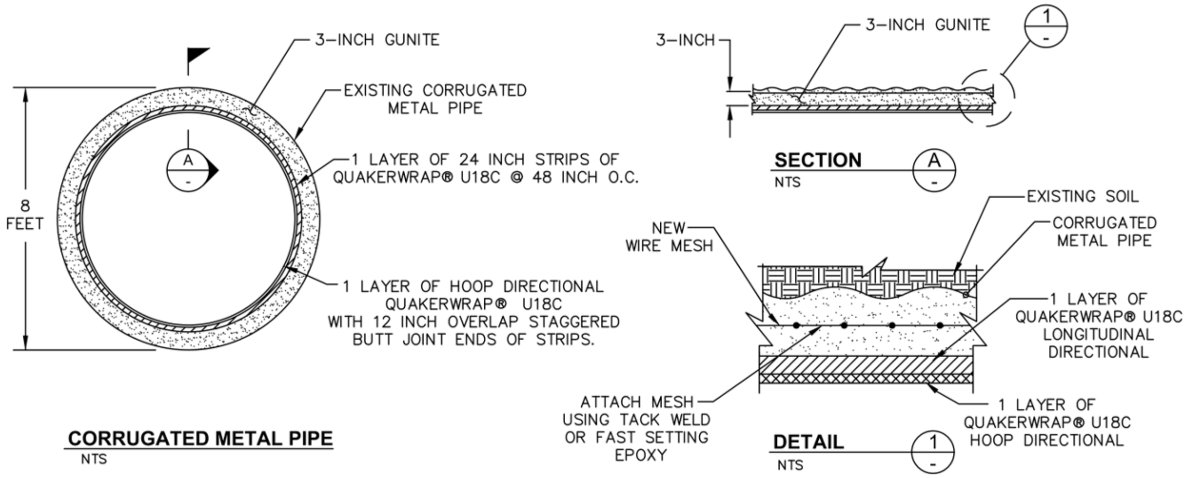


Fig. 4. Design of the retrofit system for the corrugated metal pipe tunnel.

Carbon FRP fabric was applied in two layers on top of the gunite. The first layer consisted of 24-inch wide bands of a carbon fabric at a centre to centre spacing of 48 inches, applied in the longitudinal direction. This fabric has an effective tensile strength of 3,895 pounds per inch; so, each 24-inch band provides a nominal tensile force of 3,895 lb/in*24" =93,480 pounds. Since the bands were placed at 48-inch on centre, this fabric provided an average tensile resistance of 93,480 lbs/48" =1,947 pounds per inch along the circumference of the tunnel. This is almost equivalent to providing No. 5 Grade 40 steel bars at a spacing of 6 ½ inches distributed around the circumference of the tunnel.

The second layer consisted of the same 24-inch wide carbon fabric applied in the hoop direction. Each band was cut to a length of 26.2 feet to cover the full circumference of the tunnel with a 12-inch overlap at the end for development length. Adjacent bands would be similarly installed with a 2-inch overlap along the length of the tunnel. With calculations similar to those shown above, it can be demonstrated that this fabric provided a strength of 3,895 pound per inch in the hoop direction. This is equivalent to placing No. 5 Grade 40 steel reinforcement at 3 ¼ inches on centre in the hoop direction. Thus, the carbon FRP solution provides significant strength to the pipe/tunnel.

As a protective layer, a chemical resistant epoxy coating was applied to the top surface of the finished installation. The details in Fig. 4 show the various layers of this composite design.

4. CONSTRUCTION

As stated earlier, to prevent full collapse of the tunnel, the general contractor installed a partial piece of 96-inch diameter corrugated steel pipe on the crown section of the old tunnel and bolted the old and the new section together. Considering the 115-degree temperature in the tunnel, a 35-ton air-conditioning unit was used to provide cool fresh air in the tunnel for a workable environment.

The first step in the repair consisted of covering all pipes within the tunnel to protect them from dust and resin during the repairs. This was followed by attaching a steel wire mesh to the interior of the tunnel (Fig. 5a). Next, a 3-inch thick layer of gunite was applied to the interior of the tunnel. Although shotcrete is a lower cost alternative, the distance for the mixed materials to be transported in the hoses was too long and would have caused the shotcrete materials to harden while in transit. In contrast, gunite that mixes the dry components and water at the nozzle, makes this operation easier. Figure 5b shows the application of gunite to the tunnel. The surface of the gunite is troweled and made fairly smooth with a concrete surface profile (CSP) of 3-light abrasive blast, which is ideal for application of FRP.

(a) (b)

Fig. 5. (a): Attachment of steel wire mesh; and (b) application of gunite.

It is recognized that application of gunite results in wasted materials that rebound off the surface of the structure during the spraying operation. Typically, the rebound amount is roughly 10%, 15%, and 20% when gunite is applied to the bottom, sides, and crown of a tunnel, respectively. This resulted in a substantial volume of wasted gunite that had to be placed in sacks and taken out of the utility tunnel.

The next steps included installation of 24-in. wide bands of CFRP fabric at 48-in. spacing along the length of the tunnel. These bands can be installed in length of 20 to 40 feet long and at the end they are overlapped by 12 inches with the next band to provide strips that cover the full 162 feet length of the repair.

This was followed by installation of the carbon FRP in the hoop direction. These were cut in 26.2-ft long pieces that would cover the circumference of the 96-inch tunnel plus a 12-inch overlap at the end of each band. Adjacent strips were applied with a 2-inch overlap until the entire length of the tunnel was strengthened with carbon FRP. Figure 6 shows a 360-degree view of the tunnel during the installation of the FRP.

The epoxy typically becomes tack-free in 4 hours at a temperature of 75 °F and it reaches its full strength in 24 hours. If necessary, heat can be introduced to expedite the curing process. In this project, the working environment was very warm due to the presence of steam pipes. By turning off the cold air supply, the FRP would fully cure in less than 12 hours.

To provide further protection for the FRP, and a more aesthetic appearance, a final top coat of a chemical-resistant coating is applied to the surface of the FRP. This coating is grey and as shown in Fig. 7, it provides a nice interior surface for the tunnel.

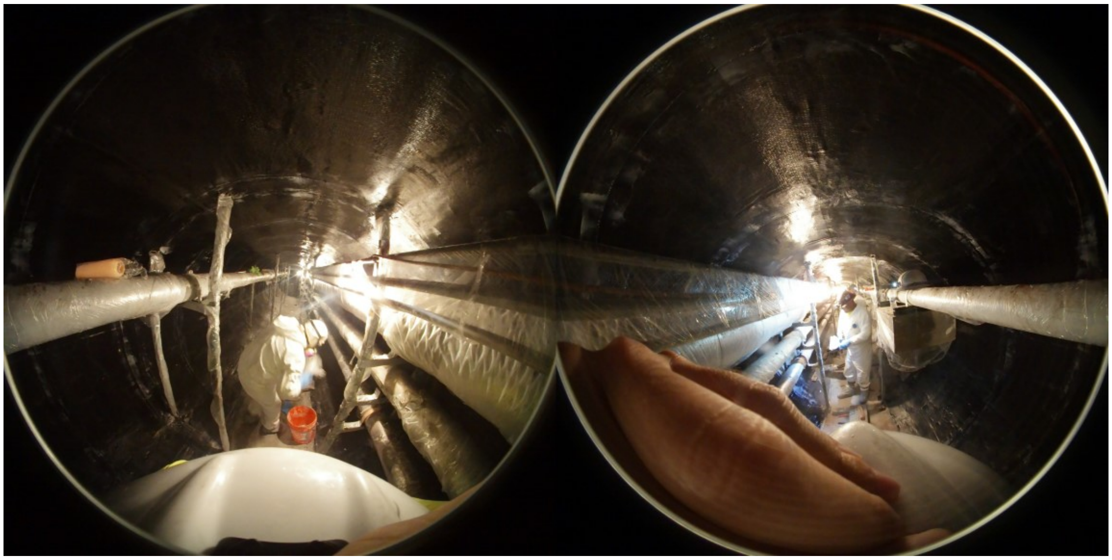


Fig. 6. 360-degree view of the tunnel looking forward and backward during the installation of the FRP.

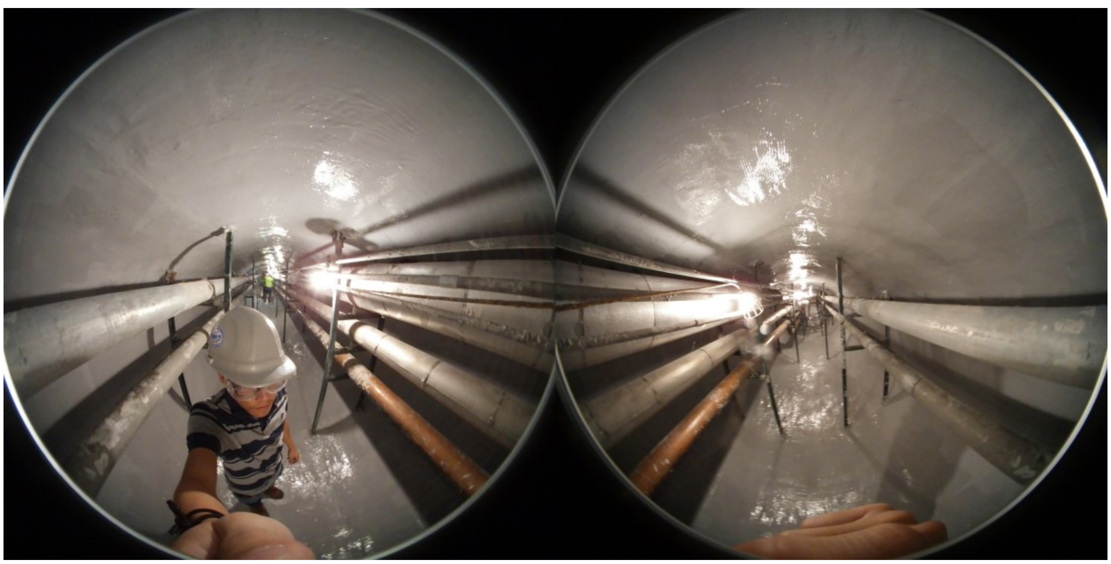


Fig. 7. 360-degree view of the tunnel looking forward and backward during the final inspection after the installation of the FRP and top coating.

Once the tunnel was repaired, the area above the tunnel was filled with soil, compacted and a concrete slab was placed, returning the area to its original configuration (Fig. 8).

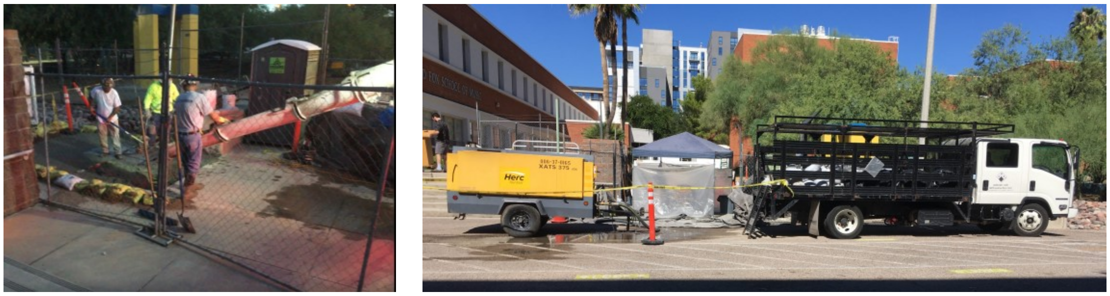


Fig. 8. Placement of concrete to restore the collapsed sidewalk area

5. QUALITY CONTROL

The gunite for this project was designed to have a minimum compressive strength of 3,000 psi. During the project cylinders of the gunite were made and submitted to a laboratory for testing. All gunite tests reported compressive strength values in excess of 4,000 psi. Standard procedure for FRP installations requires a sample of resin-saturated fabric to be placed between two flat glass plates. These samples are cured in the field in conditions similar to that of the project and sent to laboratories for testing. In the labs, the panels are cut into 1-inch wide by 12-inch long strips, tabbed at the ends and are subjected to tensile tests according to ASTM D3039. The tensile tests were successful. In case the strength of the carbon FRP does not match the specified values, ACI Committee 440 does provide guidelines for remediation (ACI 440.2R-17).

6. SCHEDULE AND COST

As mentioned earlier, this project was an emergency repair with little time for advanced planning. The original assumption was to repair 132 feet of the tunnel. However, once the tunnel was accessed, it was determined that a length of 162 feet required remediation. The project started on July 18, 2017 and our plan was to complete the job in 6 weeks. However, the university preferred the project to be completed in four weeks – which would mean a completion of the project prior to the beginning of the Fall semester. FRP Construction changed its original schedule and added additional shifts to ensure a 4-week completion for the project.

The original project estimate was $202,150 and a small change order added another $3,300 to the total cost. The project was successfully completed within budget and within the allotted time frame.

7. SUMMARY AND CONCLUSIONS

The emergency repair of a 162-ft long section of a partially-collapsed CMP tunnel was carried out in July 2017. The tunnel was first lined with a 3-inch thick layer of concrete applied as gunite; this was followed by the application of carbon FRP layers for further strengthening and sealing of the tunnel. The versatility of the FRP system, which eliminates the need for special-ordering of products expedited, the completion of this project. The repairs were successfully completed within the allotted time frame and budget.

8. ACKNOWLEDGEMENTS

The support of the General Contractor (Sun Mechanical) in successful completion of this project is gratefully acknowledged.

9. REFERENCES

Cooper, J.F. 1989 - Places in the Sun, Westernlore Press: The Utility Tunnels.

Kopach, C. 2010 - Climate Action Response, University of Arizona Facilities Management: P4.

American Concrete Institute - Committee 440. 2017. Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures, ACI 440.2R-17, ACI, Farmington Hills, MI, 2017.

ASTM D3039-14. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, American Society for Testing of Materials.