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Is it Round, Square or Oval: Repair of a Culvert with Multiple Cross Sections

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1. ABSTRACT

A culvert directs the flow of Red Butte Creek beneath Sunnyside Avenue in Salt Lake City, Utah. This culvert consists of three sections: 1) 48-inch RCP, 2) oval-shaped masonry/concrete, and 3) 4' x 3' box culvert. The concrete/masonry section was the oldest and in the worst condition with visible aggregate and a large crack throughout the crown of pipe. The conventional option of open trench excavation and replacing the culvert was deemed too costly and would cause significant impact to the roadway and creek. Therefore, a trenchless technology was decided.

The repairs were carried out in winter 2017 and consisted of implementing grout, Carbon Fiber Reinforced Polymer (CFRP) products, and Glass Fiber Reinforced Polymer (GFRP) products. The sections of culvert were initially prepared using grout to create a profile suitable for CFRP/GFRP. CFRP was then installed to strengthen the masonry/concrete culvert since it was in the worst condition, while the 48-inch RCP and box culvert was rehabilitated with GFRP since these sections of pipe were in satisfactory condition.

The construction proved to be very challenging with an unusually warm winter season in February. This required intensive bypass pumping and evacuation of the workspace in order to allow high flows to run through the culvert. Nevertheless, the project was successfully completed at the end of February 2017 with a repair that minimized the loss of flow capacity through the culverts and was also unobtrusive to the environment and public.

2. INTRODUCTION

In Salt Lake City, Utah, there are four main creek systems that convey water from the Wasatch Mountain Range through the Salt Lake Valley and into the Jordan River. These creek systems become part of the Salt Lake City Public Utilities (SLCPU) storm drain system. Red Butte Creek is one of these creeks, which also collects urban runoff downstream of the Red Butte Dam (Fig. 1). At the location of Sunnyside Avenue, a culvert that consists of three different cross sections directs flow underneath the roadway (Fig. 2).

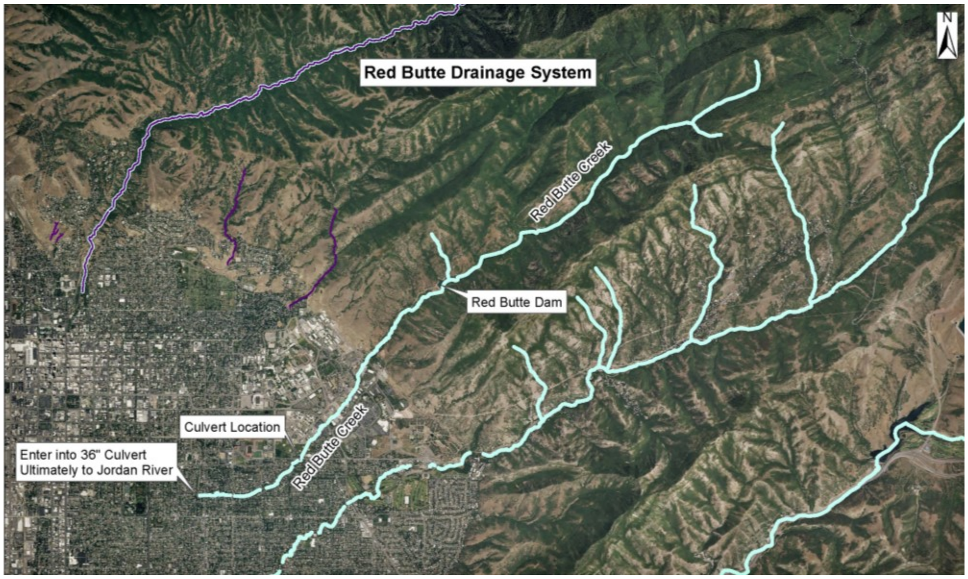

Fig. 1. Red Butte drainage system in Salt Lake City, UT

Fig. 2. Project site location for culvert under Sunnyside Avenue

As the population of the city grew over the years, Sunnyside Avenue was widened, and it is believed that these expansion projects are the source of different culvert cross sections being used on this site (Fig. 3). The original project is estimated to have been built pre-1900s and it included an 83-ft long masonry/concrete (m/c) oval-shaped culvert 48-in. wide by 48-in. high.

The first expansion is estimated to have taken place post-1940 and resulted in adding a 28-ft long segment of a reinforced concrete box culvert 48-in. wide by 36-in. high. The next widening project took place around 1980 and the culvert was extended from both ends utilizing 48-in. diameter reinforced concrete pipe. This resulted in 16 feet of new culvert on the north end and nearly 33 feet on the south end.

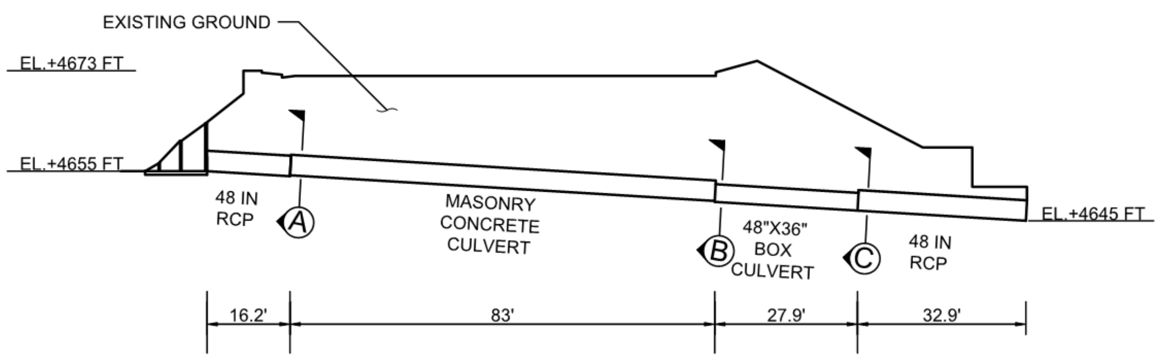

Fig. 3. Elevation view showing locations for different shaped culverts.

The depth of the culvert is approximately 18 feet below street level. Sunnyside Avenue consists of four lanes of traffic and is one of the main east-west roadways that provides commuters access to the University of Utah campus area.

Prior to rehabilitation of the culvert, the condition of the m/c section was in the worst condition, with the channel of the flow line being completely eroded, visible aggregate throughout the conduit, and a large crack throughout the crown of the pipe.

Some of the individuals involved with the project remembered the consequences of a poorly maintained culvert. A few years earlier, in 2009, a culvert failure caused a major roadway collapse within Immigration Creek to the south, which cost $700,000 to repair. There was concern that a collapse of the m/c conduit that is part of the Red Butte Culvert could cause a major roadway collapse and a creek blockage. Therefore, a proactive solution for Red Butte Creek was the main driver for this project.

Phase I of the culvert rehabilitation was completed successfully in the spring of 2016 and consisted of installing 6 inches of concrete with wire mesh to the culvert flow line of the m/c section of culvert as shown in Fig 4(b). Rehabilitation of the remaining deteriorated portions of the m/c culvert shown in Fig. 4(c), and the box culvert and reinforced concrete pipes were all parts of the repairs conducted in 2017 that are being reported here.

(a) (b) (c)

Fig. 4. The original m/c culvert: (a) damaged invert; (b) repaired in 2016, and (c) deteriorated interior surface

3. Repair Options Considered

Since Sunnyside Avenue is considered one of the main roadways providing access to the University of Utah, open cut excavation was not deemed a desirable alternative to repair the culvert, due to the high cost, major disruption this would cause to traffic, and impacts open cut excavation could have on Red Butte Creek. Consequently, it was determined that a trenchless rehabilitation method would be best for the culvert.

SLCPU decided to design a repair utilizing Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) products. At the time, SLCPU had not implemented this type of repair in any part of the storm drainage system. Other trenchless technologies were considered; however, due to the irregularities of the culvert cross sections, a typical slip line type repair was not feasible due to major cross-sectional area loss. A design was completed and solicited through the typical advertising process. Three contractors submitted bids. FRP Construction, LLC was the lowest bidder and the only bidder that came in below the engineer's estimate ($200,000) for all the work desired to be completed as part of the contract advertised. Thus, FRP Construction, LLC was awarded the contract for this project.

4. Wet Layup FRP

Fiber Reinforced Polymer (FRP) has been successfully used in various repair and retrofit projects since it was introduced by the author in the late 1980s (Saadatmanesh and Ehsani 1988). As the name implies, FRP is comprised of a polymer (such as epoxy, vinyl ester or polyester) that is reinforced with fibers (such as carbon or glass). Carbon FRP (CFRP) has been successfully used in a number of repair and strengthening projects for concrete pipes where the resin-saturated fabric can be applied internally to the deteriorated pipe (ICRI 2008; Ehsani 2009).

Carbon fabrics are typically supplied in 24-inch wide rolls that are several hundred feet long. The thickness of the fabric is approximately 0.02-0.03 inches depending on the weave pattern and the aerial weight of the fabric. Among the advantages of FRP products is that they are anisotropic, meaning that the strength of FRP is different in x- and y- direction and it depends on the amount of the reinforcing fiber that is present in each direction. As an example, one of the carbon fabrics used on this project was unidirectional and had an aerial weight of 27 oz per square yard. When this fabric is saturated with resin in the field and allowed to cure, it becomes a laminate with a thickness of approximately 0.05 inches. If this laminate is tested in tension, it will require a breaking force of 6700 pounds per inch width of the fabric along the length of the fabric (in the zero direction) to cause tension failure of the sample. However, the laminate has negligible tensile strength in the transverse direction (along the width of the fabric).

Another fabric used in this project was a biaxial glass fabric that includes fibers in both 0 and 90-degree directions. This fabric essentially works as a grid of reinforcement similar to steel bars placed in orthogonal directions. In addition to strengthening, the FRP also serves as an impervious layer that prevents moisture and oxygen to penetrate the pipe wall. It is known that oxygen is the fuel to the corrosion process. By stopping the influx of oxygen, the corrosion process is virtually arrested.

Note that each single layer of FRP is only 0.05 inch thick. Therefore, applying one or two layers of FRP causes virtually no reduction in pipe diameter. In fact, in most FRP repair projects, the smooth surface and the reduced friction that will result from the repair will cause an increase (rather than a reduction) in the flow capacity of the pipe.

5. Design of Retrofit

The solution provided for this project is shown in Fig. 5. The cross sections correspond to those shown in Fig. 3.

As stated earlier, the most severely damaged section of this culvert was the m/c which was part of the original construction. The invert of this region was lined with concrete a year earlier and remained in good condition. The regions near the spring line and crown that were deteriorated were repaired with gunite. A 4-in. X 4-in. steel mesh was installed on the wall prior to the application of gunite.

FRP reinforcement included one layer of a unidirectional carbon fabric in the hoop direction, and another layer of the same fabric in the longitudinal direction. In addition, a single layer of biaxial glass FRP was applied to the invert section of the culvert up to the spring line. These fabrics were properly overlapped to develop their full strength and to prevent intrusion of water between the joints.

The walls of the box culvert and the circular reinforced concrete pipe were in fairly good condition. These segments were repaired by application of a single layer of biaxial glass fabric over the entire interior surface.

One of the advantages of the wet layup FRP is its ability to conform to any shape onsite. However, care must be taken near the corners to ensure that sharp angles do not cause damage to the fibers within the fabric. Consequently, all transition points from oval to box to circular were hand patched with cementitious grout or gunite to achieve a smooth transition surface.

6. Field Installation

The construction started on January 23, 2017. As in most construction projects, unforeseen conditions caused by inclement weather added to the challenges of this project. The site was covered in nearly 2 feet of snow (Fig. 6) and the crew could not move the equipment and materials into the culvert due to limited access. A skid steer was used to clear the snow and to provide access to the culvert.

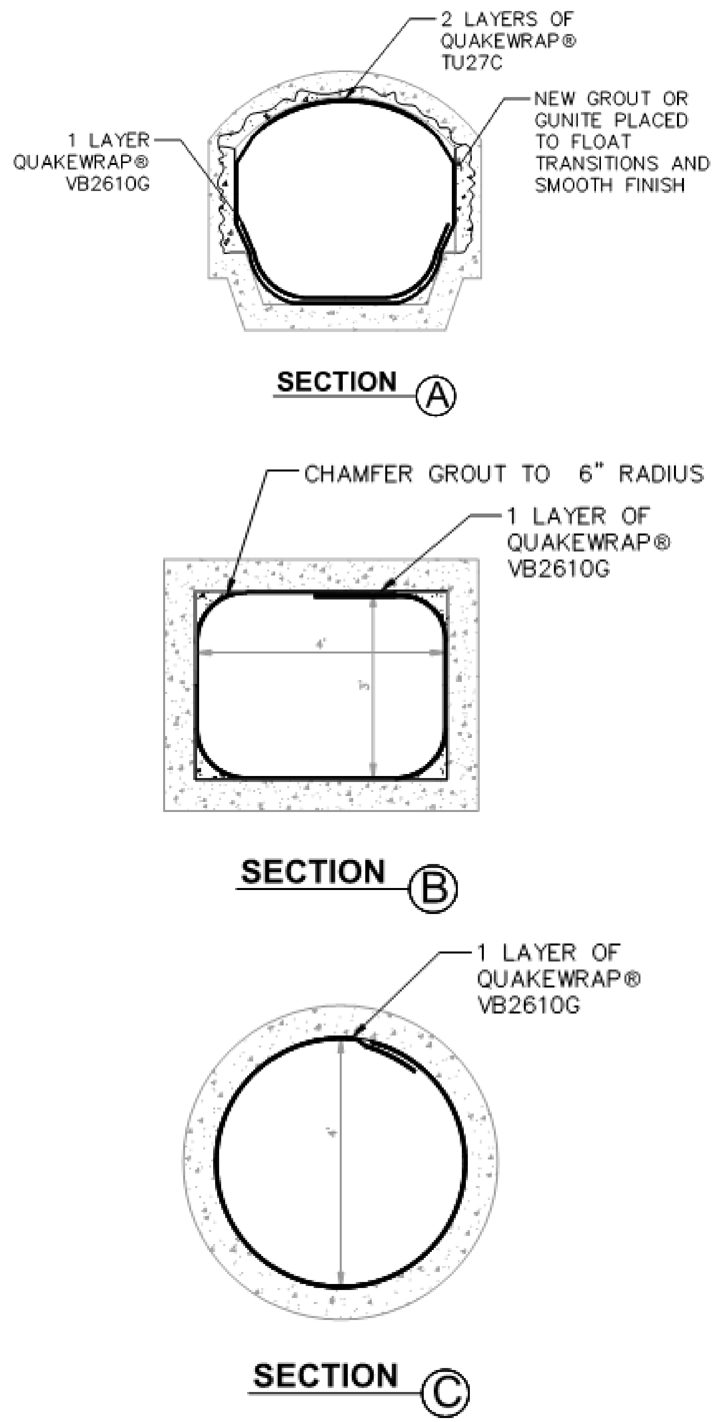

Fig. 5. Design of retrofit for different sections of the culvert

Application of FRP requires a dry surface on the pipe to ensure proper bonding. One of the reasons for the January starting date of the project was to avoid repairs in spring when warming temperature would cause melting of the snow and excess flow through the culvert. Following a pre-construction meeting, Salt Lake City diverted the flow of the creek about a ¼ mile upstream of the culvert. However, upon further inspection it was realized that there was an additional storm drain that was feeding into the culvert downstream of this diversion. The crew built a dam outside of the culvert and employed a pump to bypass the flow to the nearest storm drain. This required pumping the water over a height of more than 30 feet into a manhole. The water would freeze overnight which would make continuous operation of the pump impossible. A crew member was assigned to watch the pump during the evening hours to operate the pump manually and prevent freezing of the water inside the pump/discharge line.

Fig. 6. Snow covered site made access to the culvert difficult

The surface of the culvert was prepared by sandblasting it to a Concrete Surface Profile 3 (CSP3) to facilitate adequate bonding of the gunite. A 4 X 4 steel wire mesh was anchored to the m/c culvert and the transition areas. A gunite technique that allows the mixing of water and dry components at the nozzle was used to coat the surface of the culvert. That surface was finished by hand trowel and subsequently breeze blasted to a CSP3 profile to facilitate adequate bonding for the wet layup FRP.

The various layers of carbon and glass fabric as described earlier were saturated in the field using a saturating machine. The culvert surface was cleaned and primed with a thin coat of epoxy. The resin-saturated bands of fabric were bonded to the interior surface of the culvert as described in the design section above. When applying FRP attention must be paid to apply the fabric under a slight tension to avoid any kinks. Otherwise, when subjected to tension, the fabric will attempt to rid itself of the kinks first before resisting any tension. Similarly, sharp changes in curvature must be avoided. For this reason, the transition areas were filled with gunite to provide a smooth surface devoid of sharp edges and corners. A diesel forced air heater was set up outside the culvert and provided heater air flow through the culvert. In addition to keeping the crew more comfortable, the warm air helps with faster curing of the epoxy.

The crew must also ensure that all points of the FRP remain in contact with the substrate surface and no air is entrapped below the FRP. The design guidelines provided ACI Committee 440 offer guidance for the acceptable size of air bubbles and techniques for fixing such voids. The edges of the FRP layers must also be properly finished with an epoxy paste. Figure 7 shows the finished surface of the culvert at various locations. A time-lapsed short video showing the crew installing the FRP inside the culvert is available here (http://tinyurl.com/y83ujt3j).

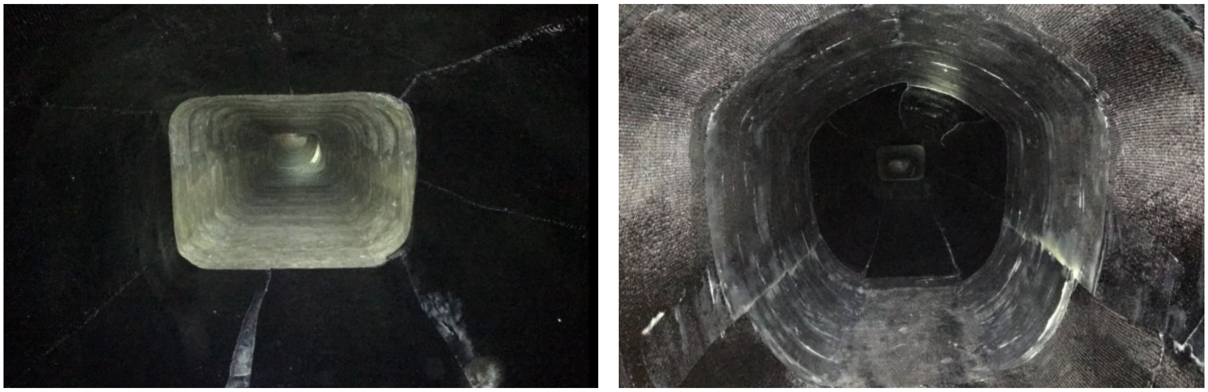

Fig. 7. Finished culvert after the installation of FRP

7. Quality Control

Successful application of wet layup FRP is critically dependent on the good bond developed between the FRP and the surface of the host pipe. ACI 440 guidelines specify a minimum bond strength of 200 psi. These pull-off adhesion tests are performed by bonding a circular tab to the surface of the concrete and FRP (Fig. 8) and subjecting it to direct tension (ASTM D7234). All pull tests on the concrete surface exceeded the minimum 200 psi values, and the bond tests on FRP were higher than 800 psi (Fig. 8), indicating the excellent bond strength of the epoxy.

Because the wet layup system relies on the saturation of the carbon and glass fabric in the field, ACI 400 provides guidelines as to the frequency of field-prepared samples for quality control. These witness panels are 12-in. X 12-in. pieces of fabric saturated with resin that are cured between two flat glass panels. The samples are later shipped to a laboratory specialized in testing of FRP products, where the panels are cut into 1-in. wide x 12-in. long strips and tested in tension according to ASTM D3039. For this project five glass and five carbon FRP samples were tested and showed that the materials exceeded the design values.

Fig. 8. Pull-off adhesion test apparatus for ASTM D7234

8. Lessons Learned

Proper advanced planning had accounted for all the required materials and supplies to complete the project. Unfortunately, mother nature did not cooperate fully and there were some weather-related challenges on this project. Although the flow of the creek was bypassed, warm weather coupled with an unexpected storm drain into the culvert was discovered that required pumping and further bypassing of this flow. The other challenge was the night time temperatures causing freezing of water in the bypass pipe. This was managed by having a crew member watch the pump throughout the night and manually turning the pump on and off to prevent freezing.

Despite these challenges, good communication among the parties and the willingness of the contractor to adapt to these changing conditions resulted in successful completion of this project. In this era when too often such unexpected conditions result in a feud among parties, it was a pleasure to see how entire team embraced these challenges in a positive way. In an uncommon gesture of gratitude in the construction world, the City's inspector on the project provided a glowing letter of commendation to FRP Construction, LLC praising each crew member by name. The long letter ended with "*…I would like to thank your exemplary employees, as they championed this project from start to finish with enthusiasm unknown to most construction work. The traits shown by these men are refreshing in this day and age*."

9. Summary and Conclusions

The masonry/concrete culvert under the major Sunnyside Ave roadway was originally constructed in pre-1900s. The segments added later due to the widening of the street were comprised of different cross sections. Retrofit of the deteriorated culvert with three different cross sections and sizes provided an ideal case with retrofit using GFRP and CFRP products. The repair included restoration of deteriorated concrete surface followed by application of glass and/or carbon fabric saturated with epoxy resin. In spite of inclement weather, the project was successfully completed to the full satisfaction of the owner.

10. References

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