Selection of Conduit Material for the Provo Reservoir Canal Enclosure Project

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ABSTRACT

In October 2010, the Provo River Water Users Association, which currently operates the 21-mile-long Provo Reservoir Canal (PRC), also known as the Murdock Canal, and the US Bureau of Reclamation, the owner, broke ground for the Provo Reservoir Canal Enclosure Project, a monumental 3-year, $150 million undertaking that will enclose the PRC into a 126-inch steel pipe with the capacity to carry 400 million gallons of water per day. The enclosure of the canal will save approximately 8,000 acre-feet, or 2.6 billion gallons, of water annually from evaporation and seepage, increase safety along the canal's length in areas that are heavily populated, and offer a number of other benefits.

When the project was conceived, several materials for the enclosure conduit were considered, including a precast concrete box culverts with gasket joints, cast-in-place concrete box culverts, non-cylinder reinforced concrete pressure pipe, welded steel pressure pipe, and fiberglass reinforced polymer pipe. A systematic analysis of the suitability of each material for the application was conducted, which included availability in the necessary sizes, history of each material in similar applications, hydraulic and other engineering properties, available joint types and the ability of each material to reduce leakage, economic feasibility, and the constructability of each. This paper provides a detailed discussion of each of these parameters from the unbiased viewpoint of the project owner as well as the design engineer.

INTRODUCTION

The Provo Reservoir Canal Enclosure Project (PRCEP) will be a significant step in the Provo River Water Users Association's (the Association's) objective of enclosing the 21-mile-long canal and increasing the capacity to help meet the growing water needs of the Wasatch Front. The Provo Reservoir Canal (PRC), also known as the Murdock Canal, is a century-old open-channel water conveyance facility north and east of Utah Lake. Twenty-one miles in length, it starts at the mouth of Provo Canyon in Orem and continues in a northwesterly direction to the Point of the Mountain in Salt Lake County.

This landmark $150 million project will be a significant undertaking and will address public safety concerns associated with an open canal located in an urbanized area. The project will also reduce evaporation and seepage losses by approximately 8,000 acre-feet, or 2.6 billion gallons, annually; improve water quality by eliminating external sources of contamination; provide redundancy for drinking water supplies to the Salt Lake Valley; provide in-stream flows to help with the recovery of an endangered fish species; and, finally, allow for the development of a recreational trail along the length of the enclosed canal. When complete, the PRCEP will provide a reliable water delivery

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system with reduced operation and maintenance requirements. It will also be the largest conveyance facility in Utah and provide water to over 1 million end users.

When the project was conceived, several materials for the enclosure conduit were considered, including precast concrete box culverts with gasket joints, cast-in-place concrete box culverts, non-cylinder reinforced concrete pressure pipe (RCPP), welded steel pressure pipe (WSP), and fiberglass-reinforced polymer (FRP) pipe. During final design, each of these enclosure materials was evaluated, and three alternatives were included in the contract documents for receiving competitive bids from contractors. This paper provides a detailed discussion of the enclosure materials considered and a comparison of their engineering characteristics that ultimately led to bidding of multiple enclosure materials for the Project.

PROJECT HISTORY AND BACKGROUND

The first reach of the Murdock Canal was constructed in the early 1850s by John Riggs Murdock and a group of early Mormon pioneers who had settled in Lehi, Utah. The canal diverted water from American Fork Canyon and conveyed it across the bench to fertile, but parched, soils near Lehi, Utah. This was at that time perhaps the most extensive canal work that had been undertaken in the western US (Murdock 2000). In 1911, the Murdock Canal was extended to the mouth of Provo Canyon by the Provo Reservoir Water Users Company (PRWUC) so that water could be diverted from the Provo River. The canal traversed mainly farmlands and open areas in Utah County for most of its length in the early 1900s. The US Bureau of Reclamation (USBR) enlarged the canal in 1944 to a design capacity of 550 cubic feet per second (cfs), as part of the Provo River Project in order to deliver water from Deer Creek Reservoir to irrigation and municipal water users in Utah and Salt Lake Counties. Figure 1 shows the overall alignment of the canal.

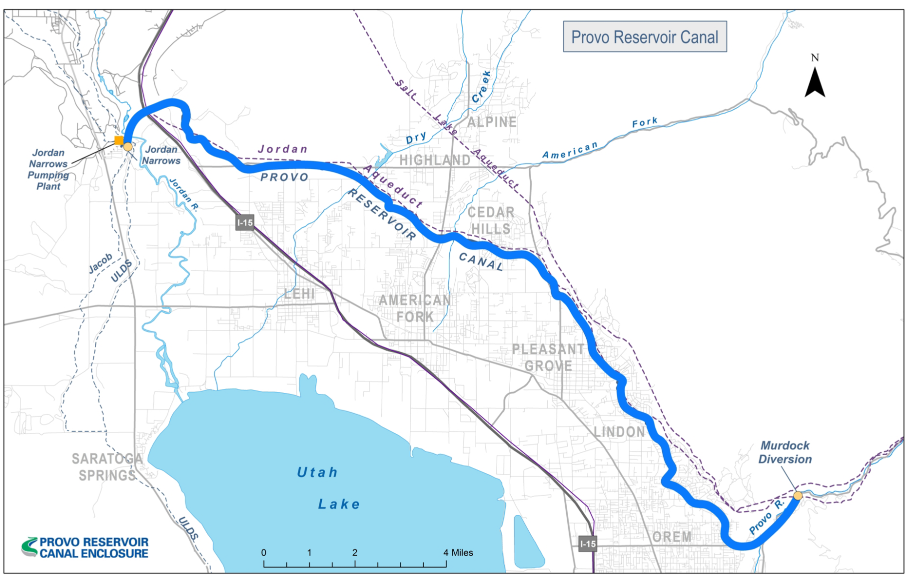

Figure 1: Provo Reservoir Canal Alignment

The project's sponsor is the Association, which operates the canal. Project participants also include the USBR, who is the current owner of the facilities; Metropolitan Water District of Salt Lake & Sandy; Jordan Valley Water Conservancy District; Central Utah Water Conservancy District (CUWCD); and the PRWUC.

PROJECT PURPOSE

The canal is being enclosed for several reasons, each discussed below.

- **Realize Water Savings and Environmental Benefits:** Water savings of approximately 8,000 acre-feet, or 2.6 billion gallons, per year will be realized since the current unlined canal loses 8 to 10 percent of the water it transports to evaporation and seepage. This saved water will be returned to the CUWCD and remain in the Provo River to provide in-stream flows for the recovery of the June sucker (a fish species endemic to Utah Lake that was listed as an endangered species in April 1986) or for other Central Utah Project purposes. The CUWCD is willing to fund half of the project costs ($75 million) in return for the water saved and returned to the river along with a conveyance capacity of 80 cfs in the canal during peak design flows.

- **Improve Water Quality:** Currently, the open canal system receives unwanted storm drainage runoff from the surrounding communities along the canal. There is limited means for protecting the canal from intentional or unintentional contaminates that could easily be discharged into the open canal system. Algae blooms are common along the canal later in the season and produce water quality and treatment problems for downstream municipal water treatment plants.

- **Restore and Increase Canal Capacity:** Since the enlargement of the canal in 1944, its capacity has reduced due to increased sediment deposits and vegetation growth along the canal. Enclosing the canal will increase the maximum capacity of the canal from the original 1944 design capacity of 550 cfs to 630 cfs. The additional capacity is for the CUWCD capacity and design contingency.

- **Increase Reliability:** Although the canal still delivers irrigation and secondary water, currently 85 percent of the demands are for municipal water use at the canal terminus. With municipal demands expected to increase in the future, the enclosure project will increase the long-term reliability of the system.

- **Enhance Safety and Security:** Significant residential and commercial development has occurred along the canal corridor since it was built. Providing security for the canal has become more difficult, and public safety has become a greater concern. In the past 30 years, there have been 22 deaths associated with the canal due to drowning. Enclosing the canal will enhance operation and provide a safer and more reliable conveyance system.

- **Recreational Trail:** After the project is completed, a trail will be built within the canal right-of-way by Utah County and cities through which the canal travels. This project will cost $17 million and will provide an aesthetically pleasing recreational facility.

CANAL OPERATIONS AND HYDRAULICS

The 21-mile-long canal has a relatively constant slope along its alignment and drops approximately 96 feet between the start and end points (equivalent to 42 pounds per square inch [psi] static pressure). The existing canal includes 3 inverted siphons and 15 check structures to help maintain head for the existing 41 turnouts. The siphons have maximum static pressures of 60 to 70 psi. The conduit materials considered for the enclosure of the canal would fall into two general categories from a hydraulic standpoint: an open-channel flow box culvert or a low-pressure pipeline. Hydraulic operations of these two systems would be very different. The pipeline alternative would operate under pressure conditions and be downstream-controlled, whereas the open-channel flow alternative would be upstream-controlled and operate under atmospheric conditions.

Operation of the enclosed canal under open-channel flow conditions would be very similar to the existing operating conditions and require check structures to be installed along the canal to help maintain minimum water surface elevations at all turnouts. With upstream control, flow changes at the head of the canal would take approximately 12 to 18 hours to reach the end of the canal.

For the pressure pipeline option, the canal would be operated using control valves at the downstream end of the system. Flow changes in the pressurized pipeline would be able to occur relatively quickly (less than 30 minutes), and additional pressure could be provided at the turnouts. Figure 2 shows a typical cross section of the canal for the two options and hydraulic grade line available at a typical turnout. The hydraulic design of the open-channel flow option would require a 12-foot-wide by 10-foot-high box culvert, while the pressurized pipeline option would require 10 to 12-foot-diameter pipeline depending on hydraulic roughness of the lining material selected.

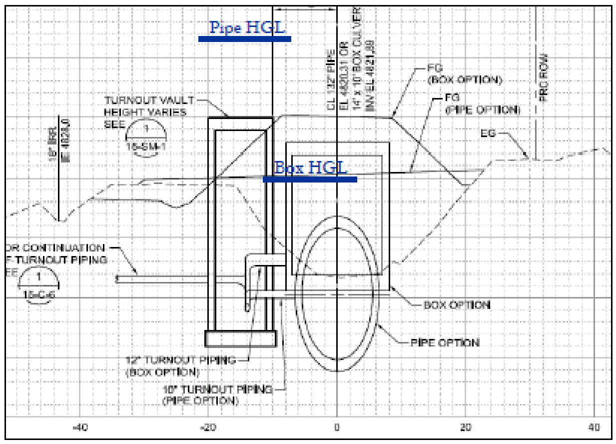

Figure 2: Hydraulic Grade Lines for Pressure and Open-Channel Flow Design Options

ENCLOSED MATERIALS CONSIDERED

A preliminary investigation of enclosure materials that could be considered for the project was conducted; after an initial screening, there were five different materials considered for further evaluation during final design. Ultimately, three alternatives were included in the contract documents for receiving competitive bids from contractors. The following sections describe the five enclosure materials considered and the primary reasons for their consideration.

Open-Channel Flow Enclosure Materials

Cast-in-Place Reinforced Concrete Box Culvert: Cast-in-place box culverts have been used successfully throughout the western US for large conveyance systems such as the Los Angeles Aqueduct. A hydraulic analysis of the canal system showed that a 12-foot-wide by 10-foot-high box culvert would be needed to meet the design capacity of the system.

With cast-in-place construction, a contractor has direct control of the cost and delivery schedule of the concrete from local sources, and it would eliminate the time and cost of hauling heavy precast boxes from the fabrication plant to the job site. There would be no need for large storage areas onsite, and specialized heavy-lifting equipment would not be required. Several contractors with expertise in cast-in-place box culvert construction were available. One downside of this option was that construction would be highly dependent on climate conditions during the non-irrigation season and during cold weather.

Precast Concrete Box Culvert: A precast concrete box culvert with rubber gasket joints to control water leakage was also considered for enclosing the canal under the open-channel flow option. While large precast box culverts have been available for use in storm drainage systems for the past 30 years, it is only in the last couple of decades that they have been gaining in popularity, particularly when there are time constraints on a project (Florida Department of Transportation 2002). If a relatively watertight joint could be provided, the precast box culvert would be a viable option for the project. To minimize their weights and for transportation, the typical lengths of box culverts are relatively short, at no more than 10 feet, so there would be numerous joints throughout the 21-mile stretch of the project. Proper installation of a precast box culvert system would be heavily dependent on the grade and foundation established along the canal's bottom prior to setting the individual precast sections and the ability to have the gasket joints properly seal.

One advantage to using a precast box culvert over the cast-in-place box is that the former could be manufactured year-round and then installed in the non-irrigation season when the canal is out of service.

Pressure Pipe Enclosure Materials

Welded Steel Pipe: Welded steel pipe, manufactured to American Water Works Association (AWWA) C200 (AWWA 2005), was considered due to its wide use in large-diameter pressurized water transmission applications throughout North America over the past 100 years. The ability to completely engineer and fabricate a steel piping system to the exacting needs of a project would provide flexibility and a wide range of options as a final design solution was being devised.

On this project, where pipe diameters could be as large as 144 inches, steel pipe would have to be specified with welded joints. Gasket-joint steel pipes are available up to 78-inch diameters and maximum working pressures of up to 250 psi. Use of welded joints would greatly reduce or eliminate the possibility of any leakage, a primary goal for the enclosure of the canal. Restrained welded joints would also serve well in those areas along the pipeline route that are susceptible to seismic activity as well as potential landslide areas. In the early phase of design, before suitable pipe material alternatives for the project had been selected, it was determined that only welded joint steel pipe would be used in those sections of the PRC where fault lines were crossed or the imminent threat of landslides existed, amounting to approximately 5,500 feet of pipe.

Available effective corrosion protection systems for steel pipe could provide a 75- to 100-year service life. The 40-foot lengths of typical steel pipe sections would result in fewer joints than the precast box culvert and RCPP options. Finally, pipe manufactured from 36 kilopounds per square inch (ksi) minimum yield steel with a diameter-to-thickness (D/t) ratio of 288 would allow a working pressure of 125 psi and a transient pressure of 188 psi. This would be more than adequate for the 42 psi internal pressure of the pipeline and allow for future pumping of the pipeline should capacity problems become an issue in the future.

Concrete Pipe: Since the PRCEP pressure pipe enclosure option would have to meet a relatively low internal pressure of 42 psi, low-head concrete pressure pipe (or RCPP) manufactured to AWWA C302 (AWWA 2004) or ASTM International (ASTM) C361 (ASTM 2008) were considered. The RCPP has both longitudinal and circumferential reinforcing bars cast in the concrete and is used for internal working pressures of up to 55 psi. This would be more economical than specifying concrete cylinder pressure pipes, which are better suited for higher pressures. Since concrete pipes are gasket-jointed, assembly and installation time for an RCPP system would be faster. While there were concerns about the possibility of shear breaks at joints during installation, a problem commonly associated with O-ring-joint RCPP, the availability of double-gasket Carnegie joints would enable each joint to be tested immediately upon assembly. In cases of damaged joints leading to failure of the air tests, the Carnegie joints rings could be seal-welded.

Since RCPP is manufactured in relatively short lengths of 8, 12 and 16 feet, this would increase the number of joints along the 21-mile pipeline compared with WSP and the cast-in place box culvert, thereby raising the chances of joint leakage during the service life of the system. At the three siphons where pressures were as high as 60 to 70 psi, WSP would be used in those locations, even if RCPP were selected as the material for the pipeline.

Fiberglass Pipe: The use of FRP pipe throughout North America has increased exponentially over the past decade. However, the vast majority of FRP pipes in municipal applications are used for gravity flow. The largest available diameter for pressurized FRP pipe manufacture in the US at the time the project was bid was 108-inch. While one manufacturer was willing to upgrade or build a plant in the vicinity of the PRC if awarded the project, they were uncomfortable with manufacturing fittings above 20 psi. Given the vast number of turns along the pipeline route, there would be numerous fittings that would have to be securely restrained. Serious consideration of the use of FRP on this project ended early in the investigation phase because the final design of the project was on a fast track 10-month schedule.

DESIGN CONSIDERATIONS OF THE ENCLOSURE MATERIALS

Backfill and Geotechnical Considerations

Three basic trench backfill sections were developed for the project that included trench sections for a rectangular box culvert (cast-in-place as well as precast), a flexible pipe, and a rigid pipe.

Cast-in-Place and Precast Box Culvert: The trench section for the cast-in-place and precast box culverts was designed to have a 1-foot-thick granular bedding material under the box culvert, backfilled with material specified to be 6 inches minus earthfill compacted to 90 percent (see Figure 3). Based on the native material available onsite, this would generally require the contractor to import a bedding material or crush and process onsite materials for bedding and then backfill with a native earthfill material. An added 2 feet of cover over the box culvert would have to be provided to help protect it from deterioration due to sun exposure and freeze thaw cycles of the concrete.

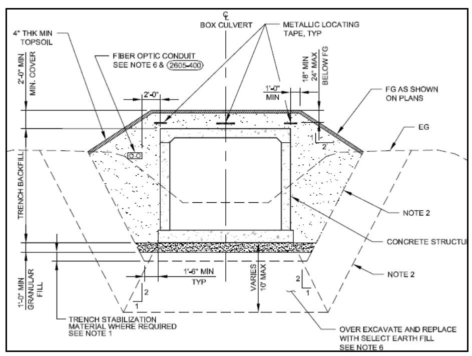

Figure 3: Trench and Backfill for Concrete Box Culverts

Flexible Pipe: A flexible pipe material such as WSP or FRP pipe relies heavily on the structural strength of the backfill material surrounding the pipe. The large diameter of the pipeline warranted the requirement for a controlled low-strength material (CLSM), commonly referred to as flowable fill, to achieve consolidation of a good material under the haunches of the pipeline. The CLSM was specified from the bottom of the pipe trench to 33 percent of the outside diameter (OD) of the pipe for steel pipe (Figure 4) and would provide sufficient side support (Watkins et al. 2010).

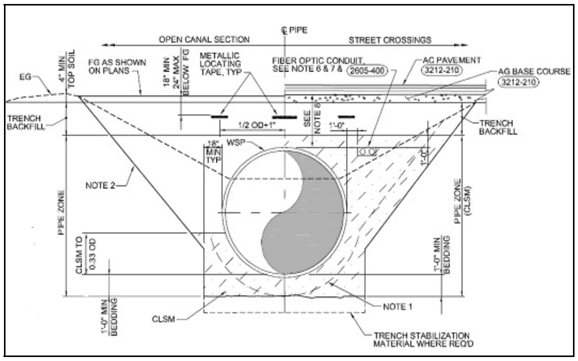

Figure 4: Trench and Backfill for Flexible Pipes

To develop an economical means for providing CLSM, the project specifications allowed the use of native soils for batching CLSM. Finney at al (2008) have shown that the practice of using native soils exclusively to create CLSM for pipeline backfill serves to reduce the cost of materials; they recommend that for large-diameter pipeline construction, CLSM be considered for both rigid and flexible pipes. Pipe zone material above the CLSM to 1 foot above the top of the pipe was specified as a well-graded, 1-inch minus, granular material compacted to 90 percent. Trench backfill from the pipe zone material to a minimum of 4 feet above the top of pipe was specified as a 6-inch minus earthfill, compacted to 90 percent. At roadway crossings, the entire pipe zone material was CLSM followed by a granular material compacted to 96 percent.

Rigid Pipe: Reinforced concrete pressure pipe is considered a rigid pipe material and develops much of its strength from the concrete wall section. Its reliance on the backfill around the pipe is less compared with a flexible pipe. The trench section for the rigid pipe (Figure 5) required CLSM from the bottom of the trench to 25 percent of the OD of the pipe to help achieve good consolidation under the haunches of the pipe. Above the CLSM, backfill material was specified to be a 6-inch minus earthfill, compacted to 85 percent. At roadway crossings, the backfill material above the CLSM was specified to be a granular material compacted to 96 percent.

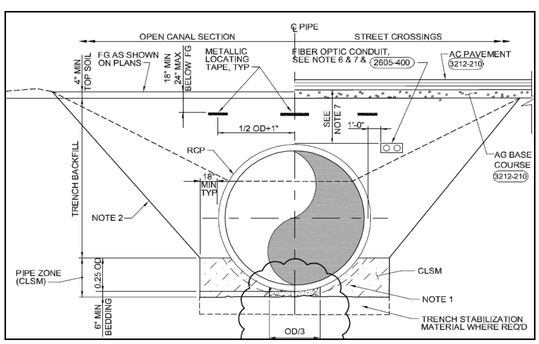

Figure 5: Trench and Backfill for Rigid Pipes

Normally Consolidated Soils and Differential Settlement: A significant challenge discovered with the box culvert during final design was the potential for differential settlement along portions of the 21-mile-long canal alignment. The invert elevation of the box culvert option was dictated by the hydraulic grade line requirements at the existing turnouts. This forced the invert of the box culvert to remain at the approximate invert elevation of the existing canal. Enclosing the canal with a 10-foot-tall box culvert, adding a 1-foot-thick roof section, and covering it with 2 feet of earthfill created a finished grade elevation for the box culvert option that was approximately 3 to 5 feet above the existing canal bank. This 3- to 5-foot-high finished grade embankment placed additional loads on normally consolidated silts and soft clays beneath the existing canal that could result in 2 to 5 inches of differential settlement over very short 30- to 40-foot reaches along the canal alignment. To counteract these areas of differential settlement, the design for the box culvert included reaches where the contractor would be required to over-excavate and replace these silts and soft clays with a compacted select earthfill material.

For the pressure pipeline options, the centerline of the pipeline was placed approximately 1 or 2 feet below the invert of the existing canal. The completed backfilled conditions of the pipeline did not create an increased load along the canal alignment and greatly reduced the potential for differential settlement.

Joints

A relatively watertight joint was critical for the enclosure project, considering half of the project was being funded by the 8,000 acre-feet of annual water savings returned to the CUWCD and the Provo River. Regardless of the enclosure material selected, it was important to select a joint that would help the owner recapture annual evaporation and seepage losses experienced with the existing canal.

Cast-in-Place Box Culvert: To help provide a conduit as near to watertight as possible, the cast-in-place box culvert was designed to include 6-inch plastic water stops at all wall-to-slab construction joints and at all expansion joints spaced at maximum 40-foot intervals. An expansion joint with the 6-inch water stop is shown in Figure 6. Cast-in-place box culverts are known to have minimal leakage, and the allowable leakage specified for the cast-in-place box culvert was 0.05 percent of the contained volume in a 24-hour period. For the 21-mile-long canal, this would be approximately 29 acre-feet (~9 million gallons) over a 6-month operating period. This low leakage amount was not unreasonable considering that the 71-mile, 10-foot-wide by 7- to 9-foot-high Los Angeles Aqueduct easily passed an allowable leakage test of 2,000 gallons per mile per day over a 7-day period.

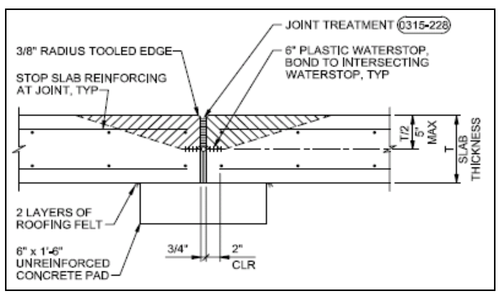

Figure 6: Expansion Joint for Cast-in-Place Box Culvert

Precast Box Culvert Gasket Joints: The joint considered for the precast box culvert was a double-gasket joint as shown in Figure 7. This type of joint has seen very little use in the US but is starting to gain popularity in Europe. The advantage of a double-gasket joint is that it can be air-tested in the field after installation, and defective joints can be identified and corrected prior to putting the box culvert into service. During the initial final design phase of the project, a number of precast manufacturers in the US were contacted regarding the proposed double-gasket joint. Most of the manufacturers stated that they had very limited experience with gasketed box culverts because of the difficulty associated with installing a gasket on a square, flat surface. The tolerances required for fabricating precast boxes to accept these double-gasket joints were very tight and would require a high degree of quality control and performance requirements. During installation, gaskets on square box culverts have a high potential to roll and not provide a watertight joint. The uncertainty of the double-gasket joint on the precast box culvert eventually led to not including the precast box culvert as an alternative in the bidding documents.

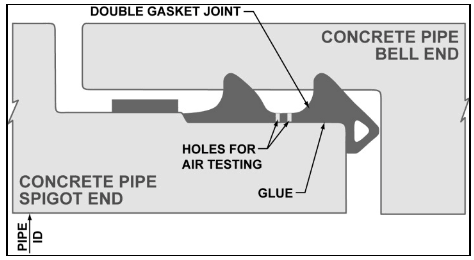

Figure 7: European Double-Gasket Joint for Precast Concrete Box Culvert

Welded Steel Pipe: The typical joint used for large-diameter steel pipe, larger than 78-inch, is a single- or double-welded lap joint as shown in Figures 8a and b, respectively. For the enclosure project, single-welded lap joints were the primary type of joint used. In locations where the pipeline was near geological hazards such as fault crossings and potential landslides, double-welded lap joints were specified. Double-welded lap joints allow for an air test as each joint is assembled. The welded joints provide a watertight system and also control thrust forces created by elbows or special fittings. To make the steel pipe option more economical, the project specifications allowed interior joints to be welded after backfilling the pipe, a common practice that significantly reduces the installation time for restrained joint steel pipelines. Of all the pipe materials considered, only the welded joint steel pipe option would have zero allowable leakage. This was advantageous since the PRC was being enclosed to minimize any water loss.

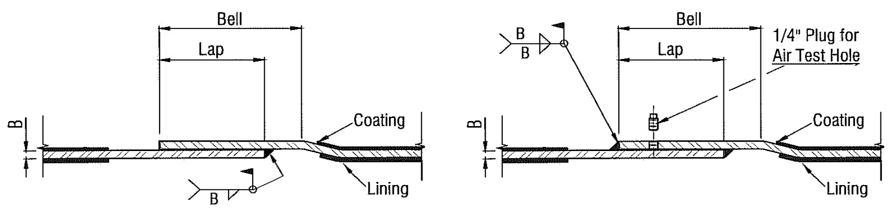

Figure 8a, b: WSP with Single and with Double-Welded Lap Joints

Reinforced Concrete Pressure Pipe: Joint options for RCPP include single- and double-gasket O-ring joints, as well as single- and double-gasket Carnegie steel ring joints. Double gasket O-ring and Carnegie joints are shown in Figure 9a and b. Concrete bell joints on large-diameter pipelines have a history of cracking due to shear forces created during or following installation. The enclosure project elected to permit the use of double-gasket Carnegie joints to provide additional shear resistance at the joints and to allow an air test to be performed in the field as each joint was installed. The steel Carnegie joints could also be seal-welded if for some reason the double-gaskets did not provide a watertight joint. Thrust restraint for the RCPP option required a transition to restrained lengths of reinforced concrete cylinder pipe (AWWA C300). In addition, the Carnegie rings in the transition areas need to be welded to a rolled can referred to as a "skirt," which is tied to the reinforcing cage. This then requires additional longitudinal and circumferential reinforcing steel to structurally handle the longitudinal forces created by thrust. The canal alignment generally has long radius curves and at relatively low static operating pressures, providing thrust restraint for the RCPP option was not unreasonable. Allowable leakage rates for the RCPP option was 4 gallons per inch-diameter per mile of pipe over a 2-hour period. For the 21-mile-long canal, this would be approximately 67 acre-feet (approximately 22 million gallons) over a 6-month operating period.

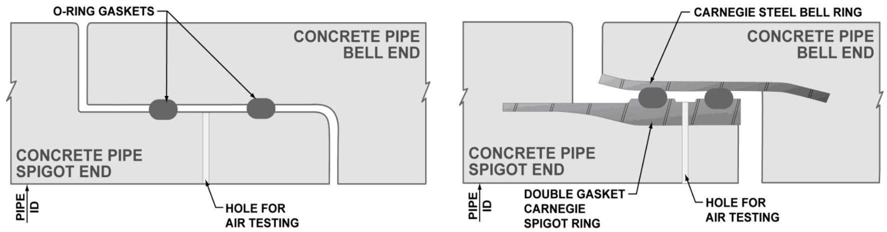

Figure 9a, b: Double-Gasket O-Ring Joint, Double-Gasket Carnegie Joint for RCPP

Corrosion Protection

Potential corrosion issues along the canal included the corrosivity of the native soils, winter salting, and de-icing agents at the 34 separate road crossings of the canal and electrical interference with the existing Jordan and Alpine Aqueducts that parallel the PRC for approximately 75 percent of its length. Each of the enclosure materials considered had corrosion protection requirements to help achieve the 75-year design life of the project.

Cast-in-Place and Precast Box Culvert: The cast-in-place and precast box culverts were designed to include 1 foot of free board between the maximum normal operating water surface and the top of the box. During operation, the floor and walls of the box culvert would stay saturated; however, the top of the box would remain subject to intermittent wetting and drying cycles that would increase the corrosion potential of the roof. The potential for de-icing salt corrosion would be greatest at the road crossings, and the design required the box culvert to use epoxy-coated rebar at all existing and future road crossings. As an alternative, the contractor had the option to provide a polyurethane coating on the roof and walls of the box culvert at road crossings. Both the cast-in-place and precast box culverts were required to be electrically continuous so that the corrosion of the reinforcing steel could be monitored and mitigated in the future if required. For the precast box culvert, this would require all joints to be bonded. Test stations would be placed at ¼-mile intervals.

Steel Pipeline: Steel pipes are typically protected internally and externally by means of cementitious or dielectric barriers. Coating options for this project included a dielectric tape with cement mortar overcoat or a flexible paint system (polyurethane). Lining options included cement mortar lining and polyurethane. To offset the effects of stray currents from nearby impressed-current protected systems, a deep well anodic system with low voltage was specified along the length of the pipeline. Test stations were specified to be placed at ¼-mile intervals for long-term monitoring.

Reinforced Concrete Pressure Pipe: While corrosion is an imminent threat to the metallic reinforcements of RCPP, it is not common to employ cathodic protection systems. In most cases, the concrete on the inside and outside of a pipe is counted on to prevent corrosion in the long term; in aggressive corrosion-prone conditions, this often leads to damage of the pipe. To help monitor the effects of corrosion on the pipeline and to provide the opportunity to cathodically protect the RCPP in the future, the design required bonding of all pipe joints for electrical continuity, along with the installation of test stations at ¼-mile intervals.

Manufacturing Considerations

Cast-in-Place Box Culvert: For the construction of cast-in-place box culverts, a base slab and footing is first built and allowed to cure for 24 hours. Unless the height of the culvert is more than 10 feet, the side walls and top slab are typically built monolithically, keeping the construction joints vertical and at right angles to the axis of the culvert. Side walls and top slab are built using internal and external forms, with reinforcement placed between the forms; concrete is then pumped into the forms, following which the structure is allowed to cure. For long conveyance systems, reusable folding slip forms are typically used that allow a contractor to place multiple floor and wall sections every day. Expansion joints are placed along the length of the culvert system at set intervals.

Precast Box Culvert: The process of manufacturing precast box culverts involves the preparation of an interior form and wire reinforcements and an exterior form that is assembled around the reinforcement. After proper assembly of the forms, concrete is pumped in. The section is then set aside to cure. After curing, the section is disassembled by removing the forms, and the box culvert is stored prior to transportation to the job site. For this project, it was determined that only the wet-cast method would be permitted on this project (see following RCPP subsection for definition of wet-cast method under RCPP manufacturing). The precast box culvert option was considered until the last minute while local manufacturers were working to try and incorporate the European double-gasket joint (Figure 5) into their product line. It was finally decided by the owner and engineer that precast boxes would not be a considered for the PRCEP since the gaskets had never been used before in the US; in Europe, they had been used only on 7- by 5-foot boxes, and special equipment was needed for the 12- by 10-foot boxes on this project.

Steel Pipeline: Steel pipe used in the water works industry is typically manufactured by the welding of helically wound long lengths of steel coil, custom manufactured to the desired wall thickness (based on working pressure, transient pressure, etc.), accurate to 1/1,000 of an inch, and ultimately producing large cylinders of the required internal diameter. The use of submerged arc welding ensures that the pipe seams are joined by full penetration welds. The cylinders are then cut to the desired lengths of typically 40 to 50 feet. This is followed by the lining and coating of the cylinders with the specified corrosion protection system and either storage at or transportation to the job site. On this particular project, one of the lining and coating systems specified was polyurethane, which is sprayed on at minimum thicknesses of 25 to 35 mils. The vast amounts of pipe that would be needed on the PRCEP would require an around-the-clock manufacturing process to ensure that the contractor had sufficient pipe in their inventory once they began the task of installing the pipe.

Reinforced Concrete Pressure Pipe: Reinforced concrete pressure pipe is manufactured using either the wet-cast or dry-cast method of construction. The dry-cast process conforms to the basic principle of making a pipe by consolidating relatively dry concrete, with zero slump, between an inner core and an outer form. Dry-casting is an ideal method for quickly producing pipe that does not require tight tolerances and for situations where it is acceptable to have some shrinkage or deformation of the concrete pipe. In the past, this method has had problems with certain aspects of quality control related to the placement of reinforcing steel in the pipe and ability to minimize leakage at the joints.

On the PRCEP, only the wet-cast method of manufacture was permitted. The wet-cast process uses a relatively wet concrete mix that is placed in a concrete form and allowed to cure. The pipe is made vertically in the annular space between an inner core and an outer form. This process is most commonly used for large-diameter-pipe production where the pipe sections are manufactured, cured, and stripped at a single location. To help provide a watertight joint on the RCPP, very tight tolerances for each joint needed to be maintained. For this reason, it was recommended that only wet-casting be used for manufacturing.

Transportation and Hauling Considerations

Cast-in-Place Box Culvert: Transportation and hauling considerations for the cast-in-place box culvert are relatively simple compared to the other enclosure material alternatives. This alternative would not require heavy lifting equipment such as cranes and large excavators for lifting prefabricated enclosure materials into place. For continuous construction, a contractor would have to make sure that concrete could be delivered to the job site unabated while maintaining orderly logistics of the process. The typical right-of-way width along the canal is approximately 100 to 120 feet wide which would requiring the contractor to utilize this space wisely for maintaining construction access roads for concrete and delivery trucks and for storage of rebar and other necessary materials along the alignment. Due to the weather conditions in Utah, cold-weather concrete would have to be used during much of the non-irrigation season.

Precast Box Culvert: Due to the heavy weights of the 12 -foot-wide boxes, transportation to the job site would certainly be a challenge. During design all of the manufactures consulted indicated that they would try to set up a precast facility relatively close to the project site to try and minimize transportation and hauling costs. It was anticipated that precast box sections would be stored off site in a staging area and specific sections of the precast box would be delivered after the foundation had been prepared. Heavy equipment with the capability to move the boxes around would be needed.

Steel Pipeline: For steel pipe manufacturers, transportation and hauling was a significant consideration. Multiple steel pipe manufactures were consulted during design and pipe plants capable of making up to 144-inch pipe were currently available in California, Arizona, Oregon, and South Carolina. The sheer immensity of the project would require approximately 2,500 truckloads of pipe and fittings to be transported to the job site. For this reason many of the manufactures considered using rail for transportation and also considered the option to have bare steel pipe shipped to the job site and then lined and coated by a local applicator closer to the construction site. For a project of this size many of the manufactures indicated they would plan on building a new facility or upgrading one of their existing facilities to accommodate the larger sizes of pipe required.

The largest manufacturer of steel pipe in the US had plants capable of manufacturing pipes of up to 156-inch diameter; one was located in Southern California, a distance of more than 600 miles from the project site. This manufacturer had recently shut down a plant in Utah, located close to the PRC. If this plant were to be retooled and placed back into service, freight costs alone would be $7 million to $9 million less than if the pipe were manufactured in Southern California. The Utah plant was located in Pleasant Grove, Utah, and was equidistant from each end of the 21-mile canal. If the project were awarded to this manufacturer, it would clearly make sense to bring the Pleasant Grove facility back into service.

Reinforced Concrete Pressure Pipe: Due to the dimensions of an average RCPP section, it would not be possible to transport the pipe to the job site without the use of "lowboy" trailers. The walls of the pipe would be approximately 1-foot thick, and ODs would be more than 13-feet. This would make the sections very heavy and would limit the number of pipe sections that could be transported on one truck without exceeding the allowable highway weight limits. Rail transportation was considered as well. RCPP manufactures considered the possibility of making the pipe onsite to avoid transportation costs, but because of the cold weather climate in Utah this would introduce the increased cost of cold weather concrete construction or require a heated manufacturing facility that could be used until the concrete cured.

Constructability Considerations

Cast-in-Place Box Culvert: While construction of the cast-in-place box culvert system would be relatively simple, construction in cold weather would be of concern and much of the box culvert would need to be blanketed or heated while it cured. Also discussed previously, provisions had to be made in the design to account for potential differential settlement of 2 to 5 inches following installation.

Precast Box Culvert: The short lengths of precast boxes— 8, 10, or 12 feet—would enable the contractor to easily negotiate the numerous tight curves along the canal's alignment. However, moving the heavy boxes around on the job site would be challenging.

Steel Pipeline: The 40-foot-long sections of pipe would make it difficult to negotiate the numerous curves along the canal's alignment without the use of mitered sections and fittings but would also minimize the number of joints along the pipeline. The relatively light weight of the steel pipe would be advantageous compared to the RCPP and precast box culvert. To maximize the use of 40-foot sections of pipe, the design engineer allowed for the centerline of the pipe to be adjusted up to 4 feet on both sides. Use of CLSM would minimize the compaction efforts that would otherwise be needed for backfill in the haunch areas of the pipe.

Reinforced Concrete Pressure Pipe: The heavy weights of the RCPP presented a challenge, similar to the issues discussed with precast box culverts. Specialized equipment would be needed, with an associated cost. Backfilling would not be as labor-intensive, and use of CLSM in the haunch area would be advantageous. The shorter lengths of the RCPP would enable the pipe to negotiate the alignment curves without the need for too many fittings, but it would also lead to having at least twice as many joints as with the steel pipe.

OVERALL MATERIAL COMPARISON

Table 1 shows the comparison of all four enclosure materials that were closely considered for inclusion as a viable product for final bid.

Cast-in-place box culverts, RCPP, and WSP were all entered as equivalent options. Precast box culverts were not due to uncertainties in the type of reliable joints that could be provided. RCPP was an acceptable choice as it will handle pressures up to 55 psi which exceed the 42 psi static pressures of the pipeline option except at the siphon locations. WSP with a diameter-to-thickness (D/t) ratio of 288 was specified, and it would handle 125 psi of pressure. The CLSM was specified up to 25 percent of the OD of the RCPP and 33 percent of the OD for WSP. The material beyond the CLSM was more stringent for WSP than it was for RCPP. For the box culvert options, where differential settlement was a possibility, the specification required over-excavation and replacement with select earthfill. Reinforced concrete pressure pipe was specified with a double-gasket Carnegie joint, while steel pipe had single-welded joints. WSP was expected to have zero leakage per year, the cast-in-place box culvert would have allowed 9 million gallons leakage over a 6 month period, while both the precast box culvert and the RCPP would have been permitted up to 22 million gallons over a 6 month period. The placement of test stations for all options would allow for corrosion monitoring. Electrical continuity in all options provided the ability to specify cathodic protection for both the box culvert and RCPP. A deep well anodic system with low voltage was specified for the WSP. The typical 40 to 50-foot lengths of WSP would reduce the number of joints in the system but would require additional specials and fittings to negotiating bends in the canal’s alignment. For RCPP, the shorter lengths would help in negotiating the curves better but would double the number of joints in the system. Other manufacturing and transportation and hauling costs were also considered.

CONCLUSION

Following the due diligence on each of the four enclosure materials, whereby various engineering properties were explored, cast-in-place concrete box culverts, WSP, and RCPP were selected for competitive bidding. The FRP pipe option was abandoned early on because of size limitations (largest available diameter manufactured in the US was 108-inch) and unsuitability of fittings for pressures above 20 psi. While the precast box culvert option was considered until the final phase of the design, it was ultimately abandoned due to the lack of any proven service of the European double-gasket sealing system in 12- by 10-foot box sections either in Europe or the US. The WSP option had superior leakage rates compared to the other options. The owner had a fixed budget of $150 million and was interested in receiving bids on the WSP, RCPP and cast-in-place box culverts options in order to determine the most viable solution for enclosing the canal. In the end, steel pipe with polyurethane lining and coating was selected by the low-bid contractor.

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Table 1: Comparison of Enclosure Material Options

Criteria	ALTERNATIVE ENCLOSURE MATERIAL OPTIONS			
	Cast-in-Place Box Culverts	**Precast Box Culverts**	**Reinforced Concrete Pressure Pipe**	**Steel Pipe**
Permitted in Final Bid	Yes	No	Yes	Yes
Hydraulics	Gravity	Gravity	Pressure	Pressure
Pressure Capability	N/A	N/A	55 psi	125 psi (188 psi w/ surge)
Backfill / Geotechnical	In areas of differential settlement, over-excavation and replacement w/ select earth fill. Potential for differential settlement.	In areas of differential settlement, over-excavation and replacement w/ select earth fill. Potential for differential settlement.	CLSM to 25% OD, 6-in minus earthfill, 85% compaction, to 4 ft above pipe	CLSM to 33% OD, 1-in minus granular matl, 90% compaction, to 1 ft above pipe and 90% compaction to 4 ft above top of pipe.
Joints Type	Expansion joints every 40 ft, w/ 6-in plastic water stops	European double-gasket system	Double Carnegie gasket	Single weld, inside
Allowable Leakage	9 mil.gal/6 months	22 mil. gal/6 months	22 mil.gal/6 months	0 gal/6 months
Corrosion Protection	Epoxy-coated rebar OR polyurethane coating on roofing at road-crossings to protect from de-icing salts, electrical continuity, test stations	Epoxy-coated rebar OR polyurethane coating on roofing at road-crossings to protect from de-icing salts, electrical continuity, test stations	Bonded joints for electrical continuity, installation of test stations for monitoring ever ¼-mile interval	Dielectric coating options, deep well anodic system w/ low voltage, test stations for monitoring every ¼-mile interval
Manufacturing Considerations	Construction in cold-weather consideration for concrete	European double gasket considered, but no experience in the US or Europe w/ 12-by-10-ft boxes. Cold weather concrete or heated facility required.	Wet-cast method only permitted to enable very tight tolerances for joints. Cold weather concrete or heated manufacturing facility required.	Advantageous to have pipe made in proximity of jobsite to reduce freight and also keep up constant supply of pipe and fittings
Transportation / Hauling	Relatively simple deliveries of concrete and rebar to the construction site. Contractor to coordinate uninterrupted supply of concrete, rebar, and availability of other materials	Expensive transportation and hauling if box culverts not made close to the project site. Boxes would be very heavy, challenge of storing onsite and moving around the jobsite	Expensive transportation and hauling if pipe not made close to project site. Require "lowboy" trailers, very heavy w/ 1-ft thick walls, moving around challenge	Expensive transportation and hauling cost if pipe was not to be manufactured close to the project site. Relatively light-weight compared with other products
Constructability	Cold weather would require special concrete	Boxes bulky and heavy to move around, but short lengths were an advantage for negotiating bends in alignment	Pipe very bulky, but shorter lengths were an advantage, but would significantly increase the number of joints on the project	Pipe was relatively light, longer lengths would result in less joints, but challenge for negotiating bends, would need lots of miters and fittings

For seismic and landslide prone areas of the canal alignment, amounting to a total of 5,500 linear feet, it was determined early in the design process that only steel pipe would be used in those areas, regardless of what the final material for construction would be. This was also the case with the three siphons where pressures were in the 60 to 70 psi range