REHABILITATION OF J1A CULVERT AT DFW INTERNATIONAL AIRPORT

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ABSTRACT

The J1A Culvert was built during the original DFW International Airport (DFWIA) construction around 1972-74 directly prior to the construction of the northeast cross-wind Runway 13L-31R. This 2,400 foot long culvert was constructed of structural plates bolted together in an open cut to form a 22 foot diameter round culvert. The existing culvert has a protruding end upstream creating an abrupt inlet opening and a battered end downstream to match the 4:1 headwall slope. Native soils were reported used to fill around the culvert structure and the maximum depth of fill is approximately 45 feet. The majority of the east side of the entire airfield drains through this culvert. At some point in the life of this structure subsequent to the original construction, a grout bed reinforced with wire mesh was placed down the invert of the culvert to protect against erosive low flows. In 1994, the upstream and downstream channels were great improved as part of the East Side Drainage Improvement project and two detention basins were added upstream to help normalize flows through this culvert during low frequency events.

A cathodic protection system was not installed with the original construction and concerns over excessive steel corrosion and plate section loss became significant in the late 90’s. During our study five reconstruction options were evaluated to remedy this situation which would not impact airfield operations on the runway / taxiway complex above the culvert. They included the installation of a steel tunnel liner, reinforced Shot Crete / Gunite liner, precast segmental concrete pipe liner, slip-formed reinforced concrete liner and a specialty prefabricated liner system like InsituForm SP. Conceptual structural evaluations including preliminary section layouts for each of these options were conducted. Hydraulic models were created for each viable section to determine the effects of the more restrictive inner diameters and different material surface properties on the upstream detention basins and culverts, inner-culvert velocities and downstream channels. Lastly, an estimate of probably construction cost and life cycle cost analysis was determined to provide for the best long term durability and also provide for the lowest initial and life cycle costs. Engineering design of this project was completed in 2005 and the construction was recently completed three months ahead of schedule.

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INTRODUCTION

The design and construction of the East Side Runway Complex began in 1989 and culminated in the opening of DFWIA’s seventh runway 17L – 35R in the Fall of 1996. This complex included many new taxiways, emergency access roads, building relocations and several taxiway bridges to support the new runway. One of the major development projects in this program was improvements to the drainage collection system on the east side of the airport and incorporation of the drainage systems designed for the new runway. The majority of the new east side drainage system would by necessity tie into the existing J1A culvert which is the only major drainage structure under the east cross wind runway 13L-31R. This 22 foot diameter Structural Steel Plate (SSP) pipe culvert was built during the original airport construction in 1972-74. The unimproved channel upstream of the J1A culvert had over the years delivered enough natural silt to this site that the downstream end of this culvert was “silted in” to within seven to eight feet from the crown. Within approximately 1,000 feet from the outfall of the J1A culvert the unimproved downstream channel crossed the DFWIA property boundary and reached a low water obstruction, Cabell Rd. bridge. Modeling showed that the restricted opening at this old county road bridge would only pass a five to ten year storm event without overtopping. There was also significant concern that when the J1A culvert was cleaned out and the full flows from the new east side drainage system proceeded off the airport property, erosive velocities would impact the confluence at Hackberry Creek and damage the Hackberry Creek Public Golf course at this location.

Preliminary hydraulic analysis of the J1A culvert during the east side drainage improvement project lead to concerns about the capacity of this structure with the addition of the new runway drainage system flows and the overall reduction in the time of concentration that the new system would present. Since modifications to this culvert or the addition of a new parallel culvert were unfeasible without taking the cross wind runway complex out of operation for an extended period of time, it was determined that a substantial amount of detention would be needed upstream of the J1A culvert. The resulting area between the outfall of the triple barrel 10 x 10 box culvert (Culvert X1) that conveys drainage flows from east to west under the new parallel runway complex and the inlet of the J1A culvert would only allow a small detention basin with a depth of approximately twenty-five feet. Therefore, the primary detention had to be accomplished upstream or east of the new runway. A large six acre basin with an available depth of approximately forty-two feet was designed at the confluence of the four main drainage channels feeding the inlet of the new runway culvert. Culvert X1 was designed so that the ten year flow would pass naturally, but an inlet control condition would result at lower frequency events and take advantage of the basin storage capacity. Likewise, the smaller downstream detention basin would react in a similar fashion due to the inlet capacity of the J1A culvert. Large drop structures with energy dissipation blocks throughout the exit apron were deployed at the outfall of all the upstream culverts and slotted channel dams were strategically located in the pilot channels to control flow velocities entering the two detention basins. The outfall of the J1A culvert was fully lined for several hundred feet and then partially lined up to the Cabell Rd. bridge. A field of energy dissipater blocks was placed at the outfall of the culvert to reduce the velocities in the channel downstream to natural, non-erosive conditions.
During the construction of the east side drainage improvements the contractor was required to remove all of the silt that had accumulated inside the downstream end of the J1A culvert during the initial 20 years of use. Visual inspections but DFW Code and Maintenance Engineering personnel identified a substantial amount of corrosion of the galvanized metal plates and bolts had occurred. After the completion and opening of the new runway complex in Fall of 1996, a materials testing program was conducted and it was determined that in several areas of the culvert the plates had experienced a significant loss of section. In addition, the grout bed along the culvert invert was in poor shape and scour of the galvanic plate coating and corrosion was apparent. The airport conducted several additional studies throughout the late 1990’s to determine a range of potential remedial actions, but was delayed in acting on these results by events relating to 9-11. Substantial concerns over the stability of this structure and possible impacts to the cross wind runway complex above increased until a rehabilitation program was fully funded in FY 2004. DFW Maintenance Engineering designed and installed an passive cathodic protection system along the crown of the existing culvert to provide some level of protection against further degradation while a final solution was designed and constructed. Freese and Nichols was hired in early 2004 to review past evaluations, study all of the viable rehabilitation options, prepare construction documents for the selected option and manage the construction process.

REHABILITATION OPTIONS

The rehabilitation options that were studied during the initial phase of this project included: Rehabilitation of Existing SS Plates, Structural Steel Tunnel Liner, Shot Crete / Gunite Liner, Precast Segmental Concrete Pipe Liner, Cast-in-Place Reinforced Concrete Liner, and Specialty Prefabricated Liners. All of these options, excluding the selective plate replacement, would decrease the inner diameter of the culvert and would require the flowline of the pilot channel throughout the upstream detention basin to be raised to match new invert elevation at the J1A culvert inlet. A hydraulic analysis of each viable rehabilitation option was conducted to determine if changes in the amount of detention storage, culvert inlet condition and surface roughness coefficient would create a condition where the cross-wind runway complex could be overtopped and flooded. Since the grade of this culvert is already set and unchangeable, the peak flow velocities inside the culvert had to be evaluated for scour potential. In addition, it was important to determine if the proposed options resulted in increased exit velocities that would exceed the capacity of the energy dissipation structures to slow to normal conditions prior to reaching the airport property line. Finally, a full evaluation of the probable construction costs and full life cycle costs for each viable rehabilitation option was provided.

Some areas of the existing culvert appeared to exhibit only minor corrosion or degradation of the steel plates and bolts. A process to selectively replace damaged plates and to clean and rehabilitate the remainder of the lightly impacted areas was initially determined to be an essential component of the overall rehabilitation scheme. This cleaning and minor repair process would reduce the amount of full liner that would be required and lower the total anticipated construction cost. The original plates were bolted up from the outside of the culvert shell prior to embedment. While these bolts could be removed from the inside, replacement plates would have to be anchored with a different bolting system that only required access to one side of the plate.
To comply with the Owner’s requirement for a resulting 30 year solution and to duplicate the stress resistance provided by the original bolts, a heavy duty stainless steel bolt with a special locking lip design would have to be used. At a cost of roughly $16 per bolt, selective plate replacement would be much more expensive than originally anticipated. Concerns that plates fabricated to the standard radius of the culvert might not fit tightly at any given location due to imperfections in the actual culvert section were later upheld when the detailed LIDAR survey results were obtained. DFW Environmental Affairs decided that the slurry from any wet cleaning methods would have to be fully captured, tested and most likely hauled to a Type V landfill. While dry methods like CO₂ cleaning would result in a greatly reduced waste stream, the method itself is very costly. After evaluating the amount of culvert surface area that could receive light rehabilitation and projecting an estimated construction cost for this work, it was determined that for approximately 20% more a full liner could be placed in these sections.

A steel tunnel liner section fabricated from 3 gauge galvanized steel was determined to be applicable for this project. An inner diameter of 20 ft. would fit within the most restrictive section of the existing culvert with a 3 in. gap top and bottom. This type of liner differs from the existing SSP in that the majority of the bolted connections are made through radial flanges inside the liner. The annulus between the existing SSP pipe and the new 2-flange steel tunnel liner would be filled with high strength grout. Square holes are provided for the through-plate bolted connections (outside to in) to hold the bolts while the nuts are tightened. This section required a grouted invert to protect the steel and the bolted flange that protrude 1¼ in. inside the wall from scour. The cathodic protection system installed through the culvert was not sized to protect the existing culvert and a new steel insert in close contact and might lead to eventual corrosion when the sacrificial anode diminishes. The grouting process under the bottom panels was anticipated to be difficult to control and ensure that a full and continuous grout bed is established. Maintaining the exact position of the liner during the grouting process would be difficult and if the liner started to float up on the grout bed there is little that can be done to remedy the situation. The installation of an interior grout bed after construction of the new liner would be required to protect the invert section. The means of reinforcing and anchoring this bed to the inside of the liner were debated. A distinct disadvantage of this option would be the need for periodic inspections and maintenance, including possible recoating and corrosion protection. While this option should last for the required duration, eventual replacement will be needed when this service life is exhausted. While adapting a common steel tunnel liner for service in a drainage culvert would have some constructability advantages, there would also be some significant construction challenges.

Extensive research into Shot Crete / Gunite lining systems showed that although this system is widely used on hard rock tunnels, for various reasons it was not applicable here. One major design constraint was that the proposed liner solution had to perform adequately for a service life of 30 years and that any structural strength from the existing SSP had to be completely discounted. It was determined that a reinforced Gunite section would not be capable of withstand the full earth pressure load and remain viable for the required life of the structure. Additional soil pinning anchorages or soil stabilization would have been required to support the Gunite section and lessen the static loads. The current body of knowledge indicates that this technique has never been used on a tunnel of this diameter or nature before. The skill of the Gunite applicator also has a tremendous impact on the final quality of the product. Defects in
workmanship may not be noticeable to the applicator or impact serviceability for years. After discussions of the preliminary finding pertaining to this liner option with DFW Airport, it was agreed that this option would not be pursued further.

Precast reinforced concrete panel segments have been used successfully in many large tunnel projects around the world. Custom forms are used to fabricate invert, common wall and crown wedge segments that are bolted together and grouted into place. Precast concrete panels are relatively expensive to fabricate and transporting from the fabrication facility can greatly add to the cost depending upon the distance. This system becomes more attractive economically as the length of the tunnel increases. At a little over one-half a mile, the J1A culvert was determined to be too short to afford the fabrication of custom forms for this project alone. A search for projects around the world that are already underway using Precast concrete panels did not identify any available formwork of the proper dimension. Therefore, this option was discarded as economically unfeasible.

Cast-in-Place (CIP) Reinforced Concrete conduits have a long successful history for this type of application and a concrete section would perform well structurally even when the existing steel culvert looses all load bearing capacity. The calculated wall thickness for this application is 18 inches, but the section could be reduced to 12 inches with additional reinforcing steel. For reasons of constructability, it was recommended not to use a section thinner than 15 inches. At the most restrictive location in the existing culvert, Station 42+00, the maximum inner diameter using the reduced wall thicknesses is 18 feet. The use of an 18 foot ID throughout the liner section was anticipated to save money during construction by simplifying the required formwork, but will increase the amount of concrete required throughout the non-restrictive sections. Slip forming using a rolling form system is an efficient method of constructing this liner, but due to the cost of the formwork will require that a constant ID be used throughout the liner. This option will also provide substantial control for the establishment of a constant invert grade throughout the liner section. The main advantages of this option are the common and proven construction methods, the durability of the finished product, and the virtually maintenance free surface that does not require expensive coatings or continuous corrosion protection. The resulting inside diameter using this liner method will be smaller and more restrictive for full flows than the other options. Supplying concrete to the working zone will require extensive high pressure pumping and slick line hoses which along with the slip form machinery could be damaged or lost in the event of a large rain event during the construction process.

During our investigations into the various structural rehabilitation options for the J1A culvert substantial discussions were held with InsituForm representatives and their associated installation contractor, AffHolder. InsituForm supplies many different prefabricated pipe liner products to our industry and has recently launched a product line called InsituForm ArmorGRIP™ that is suitable for large diameter pipe applications. This product is typically used for the renovation of large sanitary sewer lines and the largest retrofit that has been accomplished so far is 10½ feet in diameter. InsituForm proposed fabricating panels for this project that would be approximately 4 feet wide by 10 feet long by 2-3 inches thick. Each panel would weigh approximately 2000+ pounds. The panels have a polymer concrete core for structural rigidity with a fiberglass reinforced plastic shell on both sides. The panel are
assembled with tongue and groove joints longitudinally and bell and spicket joints circumferentially. As the panels are assembled in the field, each joint is bonded with an epoxy product and has to be braced in place as the epoxy cures. The anticipated strength is 12,000 psi and the modulus is 1.5 M psi. A 0.050 inch thick gel coat is applied at the factory to the inner surface for protection. Hydraulic analysis of this option showed that the ultra smooth inner surface resulted in exceptionally high velocities for all flow regimes considering that the slope of the culvert is not modifiable. The ArmorGRIP™ product is fairly flexible compared to the other options that were evaluated and InsituForm expressed concern over lateral support. Some deflection of the crown is anticipated and for this product to work correctly firm lateral support along the spring line is required. InsituForm proposed drilling through the existing SSP and pressure injecting grout into the surrounding soil every 5 to 10 feet along the culvert liner section to enhanced future stability. The Insituform ArmorGRIP™ product is an exceptionally strong prefabricated panel that could greatly reduce the erection time and potentially save DFWIA a substantial amount of money. This product does not have the strength of either the steel or concrete options and the keyed joint between the panels will not allow moment transfer across the joint. This product has been used for smaller diameter pipe rehabilitation projects, but InsituForm admitted that actual design calculations for this unique, larger application have not been performed. They only intend to furnish the ArmorGRIP™ panel system if their certified installation contractor, AffHolder, performed all of the construction work. Since Federal dollars were involved in the funding of this project, a no-bid turn-key approach was determined by DFW Airport to be unfeasible and this option was dismissed.

One hybrid rehabilitation option which used a reinforced concrete invert combined with a structural steel tunnel liner was explored. A CIP concrete invert section can be placed with little formwork and the surface can be hand finished. This solved a construction problem for the steel tunnel liner option, setting the invert sections, and eliminated the additional invert grouting required to protect the steel. Steel pipe manufacturers have a proven system for attaching steel plate pipe segments to concrete and use this method in their steel arch product line. This system would allow the bottom quarter of the liner to be cast concrete which includes the liner attachment embedded in the top of the concrete edge. Standard steel tunnel liner sections would be used to complete the top three-quarters of the section. This option allows the contractor easy access by using a smooth concrete base to set up the scaffolding required to erect the steel liner segments. It also eliminated the primary concern of the full tunnel liner section which was maintaining the proper grade while fully grouting in the invert segments. The disadvantages of this option are the required mixing of trades (steel and concrete) and the same long term life cycle inspection and maintenance issues noted earlier for steel liner.

HYDROLOGY AND HYDRAULIC ANALYSIS

The hydrologic and hydraulic impacts of proposed culvert modifications and improvements to the upstream watershed were analyzed for the 50-year and 100-year storm frequency events using discharge flows of 4,403 cfs and 4,561 cfs, respectively. The proposed changes to the study area consists of the various liner systems, upstream headwall and entrance condition modifications and reduction of available storage volume in the upstream detention basin resulting from the increased flow line elevations required to provide positive drainage to the new
J1A culvert liner. This analysis was performed with the HEC-1 and HEC-RAS public domain programs available from the Hydrologic Engineering Center and widely used and accepted in the engineering community.

Results from this analysis showed that each liner option, except the InstituForm option, will increase storm water surface elevations within both of the upstream detention basins and increase the velocity within and at the outfall of the J1A culvert. Enough existing freeboard is available in both detention basins to accommodate the higher water surface without impacting adjacent Runway/Taxiway systems. Increased velocities within and directly downstream of the J1A culvert are at the upper end of an acceptable range for each of the liner materials. The existing energy dissipation blocks and the fully lined concrete channel downstream of the J1A culvert appear to be adequate for the increased exit velocities. The flows downstream of the J1A Culvert have sufficient distance to normalize so that the peak velocity at property line is virtually unchanged. This modeling also indicates that if the proposed culvert entrance is battered to match the existing headwall and if the entrance condition is tapered so that the ID is larger directly at the opening and reduced to the standard ID over the first 50 feet of the liner the increase in water surface elevations within the detention basins directly upstream of the culvert is reduced. The steel tunnel liner and hybrid concrete invert / steel tunnel liner resulted in virtually the same water surface elevations in the upstream basins. The steel liner options reduced the freeboard by approximately 3.5 feet for the 100-year storm event, while the concrete option only reduced the freeboard by 2.1 feet. An analysis of the remaining future upstream development capacity was considered but not fully analyzed during this evaluation.

ESTIMATE OF PROBABLE CONSTRUCTION COST

Based upon the structural investigations, evaluations and preliminary designs performed during this analysis, it was determined to proceed with full cost evaluations of the steel tunnel liner, CIP reinforced concrete and hybrid concrete invert / steel liner sections. Each cost estimate was separated into three major sections; Site Work, Pipe Work, and General Conditions. The Site Work section contains site preparatory work and earthwork for site staging, material storage and handling and equipment ingress and egress in and about the work zone. The Pipe Work section contains costs for the specific liner option including the upstream headwall and channel modifications, which were assumed to be similar for all three. The General Conditions section slightly varies according to anticipated equipment and resources assumed for each liner option. Unit costs were based upon current DFW area industry average prices and an escalation factor of 2.5% was incorporated to account for the time required to design and bid the project. All prime contractor and subcontractor bonds, overhead & profit were included as well as markup for General Conditions, mobilization, and an estimator’s contingency of 15%. Direct DFWIA soft costs, including design costs, permitting and inspection fees, material test fees and construction management and inspection costs, were not included. The difference in estimated costs between the CIP reinforced concrete and hybrid options was essentially negligible while the estimated cost for the full steel liner added $600 – $650 K to the total cost. The life cycle cost analysis of these three options showed that the concrete liner would have the lowest cost while the steel liner the highest. The use of steel plate, even though it is coated to protect against corrosion, will
require more frequent inspections and maintenance throughout its life. The hybrid liner naturally fell in between the other two.

DESIGN RECOMMENDATION

Each of the options that were fully evaluated had advantages and disadvantages. Structurally, all three of the final liner options should be capable of performing sufficiently for the required 30-40 year life span, but the concrete liner option could last significantly longer than this. All of these liner options worked equally well hydraulically, but the concrete liner provided a slight advantage in freeboard retention. While the probably construction cost projections for the concrete and hybrid liners were virtually the same, the life cycle cost for the concrete option was significantly lower. DFW Airport Management agreed that based upon these study results, the cast-in-place reinforced concrete option was determined to be capable of providing the best long term solution to stabilize the J1A Culvert structure. This liner option is anticipated to provide the longest life span with the lowest initial construction cost and overall life cycle cost.

The full design of the slip form CIP reinforced concrete liner and associated channel improvements was authorized to begin in September of 2004. A new survey of the culvert using conventional equipment was conducted. Invert, crown and spring line coordinates and elevations were collected at 50 foot increments along the culvert and a full topographic survey of the upstream detention basin was included. Results from this survey showed that long sections of the existing SSP culvert had flattened out of round during service and that the invert slope throughout the culvert varied significantly, but was always positive. The final liner design normalized this slope throughout the culvert by varying the thickness of concrete at the invert and maintaining a minimum thickness of 15 inches at both the invert and crown. Through the most constricted section of the culvert, both the invert and crown had to be reduced to 15 inches and the resultant wall thicknesses at the spring line were 2 foot 11 inches thick. Two mats of reinforcing were required throughout the liner that consisted of #5 bars run longitudinally at 12 inch centers with #7 bar hoops spaced on 12 inch centers also. The upstream pilot channel overlay was 18 inches thick to match the culvert liner and was reinforced with two mats of #5 bars. This overlay was approximately 50 feet wide and 430 feet long. It ended upstream at the face of the 10 foot tall drop structure at the outfall of the X1 culvert.

Coordination with Airfield Operations and DFW DPS personnel on general construction access, site security and airfield access provisions was conducted. An access plan that did not require the contractor to enter the Air Operations Area was crafted and the resultant haul roads and staging areas were designed. A water line on the airfield, but in close proximity to the construction staging area, was identified and plans for tapping into this line and providing a 2 inch feed to the construction zone were provided. The standard FAA specification for culvert construction, D-752, did not address many of the specialized conditions and requirements for this project, so several Special Specifications were created.

The construction documents were completed and approved for bidding by the FAA in April of 2005. At the completion of the bidding process in June of 2005 the apparent low bidder, Gilbert Texas, was awarded the project for a total cost of $5,748,808. This cost included fully lining the
culvert and eliminating the selective plate replacement and cleaning originally shown for the last 424 feet by the outfall.

CONSTRUCTION

It took longer than anticipated to start up the construction because of the lead time in the fabrication of the custom traveling form system used to slip line the culvert. This system had two 25 foot forms sections that were used together so each single placement was 50 feet in length. Each form was hinged at four locations so that it could collapse and pass inside the other form on a gantry system. Concrete injection ports were prefabricated into the form system at the invert, spring line and crown to allow continuous, uninterrupted placements from the bottom up. A system of large drift pins were also built into the forming system to hold the forms in the proper geometric location during concrete placement. As soon as placement was nearing completion and prior to initial set, the drift pins were screwed out of the for to prevent permanent embedment. Banks of pneumatic form vibrators were installed in the field and a sequence of operation was developed that provided good consolidation and a smooth finish to the final product. As the form system moved down the culvert, a point and patch crew repaired the drift pin locations and smoothed out any rough areas or surface irregularities. When production was in full swing, the contractor was able to make back-to-back placements on subsequent days and usually made at least four placements a week. Only one significant rain event occurred during the construction process that impacted the contractor’s operations. Since the event was predicted correctly in advance, the contractor had the opportunity to remove all loose materials from the work site and disconnect all electrical leads. The major flow obstruction presented by the formworks themselves contributed to higher than expected upstream water surface elevations, but the storm frequency was high enough that no significant impact to the basins, airfield or contractor’s equipment was experienced. The bulk of the construction on this project was completed in May of 2006, a full three months ahead of schedule.

CONCLUSION

The conceptual evaluation of the various liners methodologies proved that the cast-in-place reinforced concrete option would provide DFW International Airport with the best long term solution to stabilize the J1A Culvert structure. This option will provide a durable, maintenance free, cost-effective structure that will require very little, if any, future additional costs to maintain. The design proceeded smoothly and the bidding and award were uncontested. Once all systems were in place and construction ramped up, high production rates were maintained and the project was completed early and within budget. The final product is smooth and regular and should easily outlast the runway complex above it.