1. ABSTRACT

The City of Folsom’s (California) Willow Hill Pipeline Rehabilitation Project (Project) consists of approximately four miles of 30”, 42” and 48” diameter mortar lined and coated welded steel pipe constructed in segments over the last 40 years as development within Folsom occurred. The existing pipeline exhibited deterioration of varying degrees that included offset joints, root intrusion, and structural defects, and resulted in leakage losses totaling an estimated one million gallons per day. Kennedy/Jenks Consultants and HydroScience Engineers teamed together with the City of Folsom to provide design services to rehabilitate and realign the raw water line. The project was broken into two separate segments in order to phase construction according to funding provisions.

The first (or Phase 1) segment slated for design and construction included approximately 7,700 linear feet (LF) of pipeline. Of the 7,700 LF of pipe, 2,500 (LF) was open cut Fusible PVC (FPVC) and 5,200 LF was slipline rehabilitation using FPVC. Construction for the first segment commenced in 2014 and was completed late 2015. Construction of the second (or Phase 2) segment was completed in the winter of 2016/2017. The second phase included rehabilitation of 10,645 LF of pipe. Of the 10,645 LF of pipe, approximately 9,000 LF was slipline rehabilitation (both High Density Polyethylene (HDPE) and FPVC), and 1,645 LF was open cut. Several lessons learned from both design and construction will be discussed, as well as how several of the Phase 1 lessons learned helped to inform the planning and execution of Phase 2. Highlights related to design lessons learned include analyzing the level of detail that the design investigation should incorporate when performing a slining project; refining slipline material selection against material properties of the slipline pipe; and considering the value of having a constructability review performed prior to construction. Highlights related to construction lessons learned include identifying of critical submittals for constructing a successful project; stipulating important differences between annular space grouting in dry vs. wet environments; incorporating collaboration between office and field crew during construction; and allowing adjustments to specific construction elements in order to improve overall construction of the project.

2. INTRODUCTION

The City of Folsom (City), with a team of design consultants, construction managers and contractors, completed a 24” diameter slining project to repair an existing 22,000 lineal foot (LF) pipeline, whose host pipe ranged in size from 30” to 48” diameter and had significant leaks. This paper will explain the need for the project, how the project was separated into phases, the base design considerations used to structure the project, and how we were able to use lessons learned in Phase 1 to improve the success in Phase 2, along with lessons learned in general.
3. PROJECT BACKGROUND

The City is part of regional planning through the Regional Water Authority (RWA) for long-term water supply needs in the Folsom Water Service Area. In 2009, Folsom began working to assess ways to increase efficiencies in our water delivery systems and, more specifically, to develop a program that would comply with the requirements of the Sacramento-San Joaquin Delta Reform Act of 2009 (SBX7). SBX7 requires a reduction of statewide average per capita daily water consumption by 20% by December 31, 2020, and requires “all water suppliers to increase the efficiency of this essential resource” (CWC Section 10608.4(a)).

Based on SBX7, the City of Folsom must assess present and proposed future measures, programs, and policies to achieve water use reduction of 20% per capita. Consequently, the City has launched its water conservation program and a Leak Detection and Repair Program that, combined, will allow the City to comply with SBX7. To this end, the City obtained a grant from the U.S. Department of Interior, Bureau of Reclamation (USBR) for System Optimization Reviews (SOR). The SOR program included a two-year water management control program that helped identify areas where water conservation may be achieved, as well as areas of needed system improvements.

Through the SOR program, the City has identified that the Willow Hill System, which diverts raw surface water from the Folsom Dam-Water Treatment Plant delivery system and conveys this raw water through 22,000 lineal feet of pipe to the Willow Hill Reservoir to serve the Aerojet industrial needs, required rehabilitation to fix existing leaks. This system has an estimated loss of nearly one-million gallons-per-day during the peak summer period. Repairs to this system would allow Folsom to reduce water waste and reduce conveyance costs within the system.

In addition to the USBR grant received by the City for the SOR program, the City also received a Department of Water Resources (DWR) Proposition 84 Integrated Regional Water Management (IRWM) grant for the Willow Hill Pipeline Rehabilitation Project (Project). The third funding source for the Willow Hill project is the City’s Capital Improvement Program.

The goal of Project was to construct repairs to this system that would reduce water waste, reduce conveyance costs in the system, and allow the City to conserve water, ultimately saving the approximately one-million gallons-per-day during the peak summer period. It should be noted that the original project also targeted providing a solution wherein the raw water line could be converted to potable service at a future time, should drought conditions and/or expansion of the distribution system from future buildout require such. Figure 1 shows the approximate alignment of the Willow Hill Pipeline (in red); water flows from the inlet structure in the north to Willow Hill Reservoir at the southern end.

![Figure 1. Willow Hill Pipeline Alignment](image-url)
4. PROJECT PHASING AND TEAM

Throughout the implementation of the project, key project team members were involved in the development and execution of this successful project. The project spans several years in both design and construction, tied to funding requirements and opportunities. The phasing structure is shown below in Table 1, and the limits and sequence of phasing is shown in Figure 2.

Table 1. Willow Hill Pipeline Phasing Structure

<table>
<thead>
<tr>
<th></th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Cut Footage</td>
<td>2,500 LF</td>
<td>1,645 LF</td>
</tr>
<tr>
<td>Sliplining Footage</td>
<td>5,200 LF</td>
<td>9,000 LF</td>
</tr>
<tr>
<td>Construction Cost</td>
<td>$2.5M</td>
<td>$4.6M</td>
</tr>
<tr>
<td>Contract Change Orders</td>
<td>$161,000</td>
<td>TBD</td>
</tr>
<tr>
<td>Contractor</td>
<td>Mountain Cascade Inc.</td>
<td>McGuire &amp; Hester</td>
</tr>
<tr>
<td>Construction Manager</td>
<td>HDR</td>
<td>HydroScience</td>
</tr>
<tr>
<td>Engineer</td>
<td>Kennedy Jenks/HydroScience</td>
<td>Kennedy Jenks</td>
</tr>
<tr>
<td>Owner</td>
<td>City of Folsom</td>
<td>City of Folsom</td>
</tr>
</tbody>
</table>

As part of the implementation of the Project, the City and the project consultant team discussed various phasing options focused on maximizing the water savings while minimizing total project costs. These discussions provided a road map for pipeline condition assessment, preliminary design, and pipeline rehabilitation methods. By using a phased approach, the City made use of funding over multiple fiscal years and was still able to complete the project by the DWR grant deadline of December 2017. In the first phase, only one segment of the pipeline, shown in Figure 2, was rehabilitated. The reason the City constructed only this segment was to allow the City to install access points to better assess the condition of the pipe in the remaining portion, prepare more detailed bid documents for the next construction phase, and implement any lessons learned from the first round (Phase 1) into the final round (Phase 2).

Figure 2. Willow Hill Pipeline Alignment with Phases 1 and 2.
5. BASE DESIGN CONSIDERATIONS

The preliminary design of the Project included an evaluation of repair and rehabilitation technologies that guided the pipe material selection for the project as a whole. The primary objective in selecting the proper pipe material included the following design criteria:

1. The material must meet National Science Foundation (NSF) 61 potable water standards (in case it would be needed for potable water distribution in the future),
2. The material selected must provide a fully structural, stand-alone solution (without reliance on strength of the existing pipe) and offer a design pressure class rating of 150 psi, and
3. The pipe size needs to have a minimum 24-inch internal diameter to meet system flow requirements.

A fully structural solution was chosen because the condition of the host pipe was unknown and could not be relied upon for the pressure rating of the system. Three rehabilitation technologies were found to be appropriate for further consideration in rehabilitating 30-inch and larger RCP/RCPP pipelines:

1. Loose-fit sliplining
2. Close fit sliplining
3. Cured-in-place pipe (CIPP)

The CIPP technology did not currently meet the required 150 psi pressure class required for this application. For close fit sliplining, “Swagelining” technology was studied but was not recommended due to high unit costs due to location of equipment, limited local industry experience at these diameters, and sophisticated equipment setup. Other close fit sliplining methods that were currently available, could not be used on high density polyethylene (HDPE) pipeline material of this pressure class. Therefore, loose-fit sliplining was selected for design since it was the most common rehabilitation process in the region and would most likely result in a competitive bidding environment from local qualified contractors, thus producing the lowest bid.

Pipeline material options for loose-fit sliplining include PE4710 HDPE and C905 polyvinyl chloride (PVC). Both pipe materials are fusible, providing for a continuous, joint-free length of installed pipe between valves and/or connection points. In addition, both material formulations meet the NSF 61 standard. To meet the minimum pressure class requirement of 150 psi, a dimension ratio (DR) of 13.5 (160 psi) and DR 25 (165 psi) was needed for HDPE and PVC pipes, respectively.

Based upon the recommendations produced out of the preliminary design process, both HDPE and fusible PVC (FPVC) pipe materials were identified as the qualified pipe materials for construction of the slipline sections for this project.

6. OVERALL LESSONS LEARNED – SLIPLINING DESIGN

Sliplining design presented some unique situations once the construction phase began for both Phases. Fortunately, some of the Phase 1 lessons allowed for improvements to be made for both design and construction of Phase 2. The design lessons learned are described herein.

Lesson Learned #1 – Reconsider Relevance of Utility Survey

Because sliplining, which is a “trenchless” technology, made up 68% of the construction within Phase 1, whereby the horizontal and vertical location of existing nearby utilities would not interfere or be impacted by the sliplining operation, the decision was made to not include identifying/locating existing utilities in the sliplining segments during design. In addition, the decision was also made to not identify pit locations on the plans in order to avoid directing the Contractor’s means and method. The hope of the project team was that the Contractor would plan their sliplining pit locations with consideration for site constraints, underground existing utilities, technical/equipment capabilities, and consideration for overall construction efficiency.
During construction of Phase 1, utility locating and investigation by the Contractor ultimately was performed after the pit locations were designated. Unfortunately, some of the selected pit locations ended up being near heavy utility congested areas. This required the Contractor to have to adjust to these constrained conditions which resulted in the Contractor issuing change order requests to the City. The Change Order requests were comprised of additional cost to either revisit their sliplining plan as a whole to avoid the congested utility areas, or implement the additional construction elements into the project in order to protect the nearby utilities during sliplining operations. Because there were not specific instructions in the contract documents directing the Contractor on where to place the pit locations with specific consideration for existing utilities, the City paid for these change orders.

Based on the lessons learned from the outcome of Phase 1 as it related to existing underground utilities and pit locations, the project team decided to incorporate specifying pit locations and performing utility survey for Phase 2. In order to place pits in areas that were most practical, the design team decided to perform a constructability review by meeting with pipeline manufacturers and supplier representatives to discuss slipline alignment(s) and possible pit locations. From these discussions, utility survey and suggested pit locations were incorporated into the design of the Phase 2 plans. The contract documents further allowed the Contractor to investigate alternate pit locations and utility investigation based on ease of constructability.

The sliplining plan in Phase 2, submitted by the Contractor, ultimately relied upon the survey provided in the approximate locations identified on the Phase 2 plans; all pit locations selected were within those anticipated. No change orders were issued on the subject, and the designer maintained the golden rule of not directing means and methods in selecting pit locations.

Lesson Learned #2 – Conduct Key CCTV and Potholing Work During Preliminary Design

During Phase 1 project predesign, a desktop and field analysis was conducted to evaluate the condition of the existing pipeline and provide preliminary recommendations for rehabilitation of the pipeline. The desktop analysis included review of record drawings, daily construction reports, construction submittals, and geotechnical reports developed by others for projects in the area surrounding the existing pipeline. The field analysis was performed using Closed Circuit Television (CCTV) inspection. Prior to the CCTV inspection, the design team and the City decided that only existing access points and portions of the pipeline would be CCTV inspected. Installation of additional access points to allow for additional inspection was discussed but not incorporated due to the added cost and possible delay in getting the project out to bid.

Phase 1 and Phase 2 designs ended up relying on record drawings for sections of the existing pipeline that did not have existing access pits for CCTV equipment, or where CCTV equipment could not traverse due to obstructions within the pipeline or existing water in the pipeline that could not be pumped out. CCTV and potholing to verify existing pipeline conditions and alignment were assigned to the Contractor as part of the construction work instead. This created many issues for the contractor and additional costs to the City. Examples included:

1. During Phase 1 construction, the Contractor decided to install the carrier pipe into a submerged host pipe without knowing the condition of the pipe or knowing if there was an obstruction. The Contractor ended up successfully installing the pipeline, but they did not follow the Technical Specifications of the contract documents in their practices. Without proper planning, the rogue installation attempt could have caused a major delay in construction and possibly further negative impacts such as increased cost, noise, and aesthetic disturbance to the surrounding neighbors. As it was, the event required onsite deliberation and re-evaluation by the Engineers, City staff, and Construction staff in order to complete the installation.

2. In Phase 1, at the location where an old canal transitioned to a pipeline, there was limited record drawing information available and CCTV could not be completed due to water in the pipeline. There were numerous manholes and limited room for providing the lay lengths required for the sliplining operation. The ultimate design included sliplining and open cut sections. During construction, the Contractor found that the available record drawings were not accurate for this particular area: Additional construction had been conducted that was otherwise not represented in the record drawings. In the end, the construction plans through this area were not applicable to the actual in-situ configuration, and the Contractor had to propose an alternative, new pipeline alignment due to prohibitive factors for sliplining through the actual configuration.
3. In Phase 2, the design called for sliplining the existing pipe in Riley Street, yet the Contractor was unable to field locate the existing line in multiple locations. After an extensive field investigation, the Contractor found that the existing pipeline varied from record drawing alignment in both horizontal & vertical directions, explaining why it couldn’t be located by potholing in the location in which it was expected to reside. The Contractor had to hire a locating subcontractor that used ground penetrating radar and CCTV equipment to ultimately locate the divergent footage of pipeline. All this work was included in a change order. The Contractor spent a total of $35,000 in additional change orders to locate an additional 900 feet of pipeline.

In all three instances described above, the additional work and risk that transpired during construction could have been avoided if inspection pits were installed and additional investigation work was conducted during preliminary design. Expensive change orders and construction delays from attempting to pothole in erroneous locations could have been avoided. The design effort would have been more streamlined and accurate, resulting in more streamlined construction as well.

**Lesson Learned #3 – Perform Geotechnical Investigation Early On**

During Phase 1 of the project, the project team decided to forgo performing a geotechnical investigation. This decision was based on the fact that 68% of the Phase 1 construction was sliplining. In addition, the City also had geotechnical information from previous projects in the area of the open-cut portion proposed for this phase. During construction, two areas in which the City would have benefited from having a detailed Geotechnical Report were (1) rock and (2) groundwater. Even though a bid item for rock excavation was included in the event that rock was encountered during construction, there was uncertainty in the estimated bid quantity given the lack of site-specific geotechnical data in areas slated for excavation. In addition, the Contractor also encountered groundwater in a portion of the project during construction that increased the construction cost for excavation and grout mix injected between the slipline pipe and the host pipe.

The lesson learned in this case is to perform detailed geotechnical evaluations early on in the design to assist with contract document preparation and to have cleaner and tighter bids. A detailed geotechnical evaluation would have aided in identifying the presence of groundwater, rock, cobbles, and the necessary shoring/Sheeting requirements for this project.

**Lesson Learned #4 – Look Closely at Pipe Material Properties Relative to Sliplining Feasibility**

Both HDPE and FPVC materials were included as bid options for the Contractor in the Phase 1 contract documents to promote competition and lower bids. FPVC was the pipe material selected by the Contractor who was awarded the Project. During construction, the Contractor communicated their relief for having chosen FPVC over HDPE, as the annular space afforded by FPVC was greater than that of HDPE. In fact, the Contractor maintained that it would be very difficult, if not riddled with complications, to attempt sliplining with only one inch of circumferential annular (free) space. The small annular gap with the HDPE pipe would, in effect, limit the ability to push/pull the HDPE pipe through bends in the smallest diameter sections (30” sections) of host pipe. The Figure below provides a graphical representation of sections and dimensioned gaps based upon both HDPE and FPVC sliplining scenarios.

![Figure 3. Section View: Class IV Loose-Fit Sliplining (Standard Sizes) of Existing 30 Inch RCP](image)
The Engineering team and City took heed to the concerns communicated by the Contractor in Phase 1 when embarking on pipe material selection for Phase 2. It was determined during Phase 2 design that some applications required one material over the other due to annular space limitations and allowable bending radii. Given the safe bending radius of HDPE at 60 feet is tighter than the safe bending radius of 538 feet for the FPVC pipe, certain areas of the project (where host pipe sizes were greater than 30”) were designated for HDPE as the carrier material in order to accommodate tight curvature in the existing system. Likewise, where the smaller outside diameter carrier pipe would provide greater ease in slipline installation, FPVC was the designated material. Ultimately, specific footages for each pipe material were provided in the Bid Schedule for the Phase 2 contract documents, a change from Phase 1 where the Contractor was allowed to pick one or the other for use on the entire project during bidding.

**Lesson Learned #5 – Invest in Constructability Review**

In Phase 2, there were two locations in the upper portions of the project where the existing pipeline was routed in easements within private property where it was in close proximity to houses and underneath residents’ yards. The project team initially decided to reroute the pipeline out of the easements and into the public right-of-way. The project was thus designed and bid for an open-cut installation that would relocate the pipeline to within right-of-way limits (Randall Drive). However, during construction it became apparent that the rock and deep excavation for the open cut within the roadway caused the bids to be much higher than anticipated. The design was re-evaluated, as was sliplining within the City’s existing pipeline alignment and easement. The project team determined that the pipeline would be secure within a portion of the existing easement, allowing for a new routing scheme with opportunities for sliplining, less open cut trenching, and reduced overall pipeline footage. In addition to significantly reducing construction costs, the adjusted alignment was also outside of residential streets, reducing associated community impacts.

The key lesson learned in this case was to evaluate multiple alignment alternatives that assess cost vs. risk. Once these alternatives have been established, the next step would be to hire a construction company to conduct a constructability review of the project during the preliminary design phase. The cost for the constructability review early in the preliminary design phase would have saved the project a significant amount of re-design and construction costs. Additionally, this constructability review could have led to identifying that a geotechnical report was needed early on, which coincides with the third lesson learned described in this paper.

![Figure 4. Post-Design Changes to Phase 2 Alignment.](image-url)
7. OVERALL LESSONS LEARNED - SLIPLINING CONSTRUCTION

Sliplining construction lessons learned were also found to be valuable in executing Phase 2 and for informing future design and construction practices in general. These construction lessons are described herein.

Lesson Learned #6 – Don’t Relax on Sliplining Plan Submittal Requirements

The Phase 1 contract documents were very specific in the submittal requirements for sliplining, as well as protocol for performing the work. A detailed work plan and methods statement for sliplining, including specific requirements for cleaning of pipe, CCTV inspection, and proof testing, were outlined for the Contractor as part of the advance preparatory work needed before sliplining operations were to ensue. The first submittal that was transmitted by the Contractor for Phase 1 did not include site specific information, or an actual plan for sliplining (showing pits, lengths of pull, pulling forces, or otherwise), nor did it detail proof testing. The submittal was hence returned to the Contractor as Amend and Resubmit, clearly listing the missing elements. Ultimately, no revised sliplining plan was submitted, and unbeknownst to the engineer and the City, the Contractor proceeded to “proof test” without an approved plan. The result was that the proof test pipe section got stuck at an intermediate manhole. Upon arrival to the site, the Engineer discovered that the “proof test” was for a full 600 foot section of pipe (versus a 40 foot section per the specifications), and that the Contractor chose to push the pipe vs. pull or pull/push, which were the methods described in the contract specifications for performing the work. Consequently, several City staff, both Engineering design companies, the Construction Manager, and several workers from the Contractor’s end were called out to troubleshoot and work through the issues surrounding the failed slipline attempt. Furthermore, the Contractor was claiming unforeseen conditions relative to where the slipline got stuck, even though cleaning and CCTV was, in fact, not performed in advance of the sliplining operations to both confirm feasibility and accomplish proper planning for said slipline.

In order to prevent a similar situation from occurring as Phase 2 construction was initiated, the Engineer and Construction Manager were adamant about securing an approved work plan prior to commencement of any sliplining operations, including the proof test, at the Phase 2 preconstruction meeting. Additionally, the Contractor was made aware of the specific protocol laid out in the specifications for the advance preparatory work needed, with attention to the maximum allowable footage of pipe to be used for proof testing. Phase 2 realized significantly better outcomes in enforcing these contract requirements as a result. In fact, several elements went into the segment-by-segment planning by the Contractor for sliplining in this phase, with particularly challenging areas seeing the most benefits as a result of proper planning.

As an example of the success realized in having a well thought-out sliplining plan, a push/pull methodology was used in Phase 2 to allow for a continuous 1,500 LF slipline installation through a tight, curved alignment. The first step included successful proof testing of a 40-foot stick through the full footage, where mid-way through the Contractor discovered a section of hand-applied mortar that reduced the inside diameter of the host pipe in that discrete area. The Contractor also had some difficulty making it through a deflection during proofing. Consequently, the Contractor set to work preparing for successful sliplining by addressing the two potential “sticking” points: The location of mortar build-up was sanded down to open up the existing pipe annulus, and the angle deflection was removed to allow for a more gradual curve to accommodate slipline operations. Further, a TT Technologies hydrostatic constant-tension winch was used at one end to enable up to 22,000 pounds line pull of the carrier pipe (see Photo 1). The pull capacity of the winch was much lower than the safe pulling force associated with the HDPE pipe that would be installed in this segment. The winch rope was connected to a pulling head bolted to the pipe, and a swivel in between the cable and pulling head functioned to minimize the amount in which the carrier pipe could rotate. At the tail end of the pipeline, excavators were used with appropriate rigging to position the carrier pipe into place (see Photo 2). Sliplining commenced at an adequate production rate through the first portion of the segment using this setup. Then, from the areas of constriction and tight curvature through to the end of the 1,500 foot segment, the Contractor employed additional measures to ensure success. These measures included adding a 9-inch layer of water at the bottom of the host pipe to reduce skin friction on the carrier pipe; introducing a second winch cable to aid in pulling from the front end; and using a backhoe to aid in pushing at the back end. The work that went into planning for this challenging segment resulted in at least a full day savings on the schedule, not to mention less community impacts associated with one continuous slipline run versus two.
Lesson Learned #7 – Examine Grout Mix Design Appropriate for Subsurface Conditions

Annular space grouting requirements per the contract specifications targeted submittal of the proposed grout mixes, methods, plans and criteria of the grouting operations, including accompanying calculations and information. Additionally, certified test reports for the cement and additives were also required. The submittal for grouting was presented to the Engineer only a matter of days before the work was to be performed, and included an, “Or equal” grouting product. The Engineer determined insufficient information was provided in the submittal in order to qualify it as a true approved equal; hence the submittal was returned as Amend and Resubmit. After two more attempts at submitting the product information, information was still missing in order for the Engineer to make an informed determination. Further, the annular space grout mix design that was presented was tailored to a dry environment, while the work needed for the immediate operations ran directly through a submerged environment. With the clock ticking on the work schedule, several conference calls with the Construction Manager, City, grouting manufacturer, Contractor and Engineer were held in order to navigate applicability and proper design to allow for suitable accomplishment of the annular space grouting in a wet environment. Ultimately, the project team approved the mix design and protocol for the immediate work to be performed, and the Engineer was on site during the operations in order to help troubleshoot in case of an unsuccessful operation. The grouting overcame the water head in the system to serve its purpose.

The Phase 2 contract documents were tailored to require mix designs and protocol submitted well in advance of annular space grouting, and for both submerged and dry conditions. The team alerted the Contractor at the preconstruction meeting of the necessity, in order to prevent a similar fire drill, and improve confidence in grouting of annular space for the next phase of work.

Lesson Learned #8 – Incorporate Continuity Between Office and Field Crew During Construction

As construction commences for any project, submittals and RFIs are prepared and provided for review by the Engineer/Owner prior to implementation of the work or product associated with said submittal or RFI. What the Construction Manager and Engineer experienced through this process was at times a disconnect between the Contractor’s “office” staff responsible for preparation and processing of the submittals and RFIs, and the field crew implementing the work associated with those submittals and RFIs. For example, as described previously for Phase 1, the annular space grouting submittal presented the need for several discussions and coordination on how best to perform grout operations in a submerged environment. Since a different grout mix was needed in order to displace the water head in the system, with it came special requirements for the testing of the grout prior to injection on the rig, and testing also at the annulus discharge point. These testing requirements (particularly the sampling of the grout
from the annular space for the flooded section) were established during a pre-activity meeting between the City, Design Engineers, Contractor, and Grouting Subcontractor’s project manager, and were documented in the submittal response on the subject. Unfortunately, the grouting superintendent was unprepared as he wasn’t made aware of the additional sampling requirements placed on the project for the “flooded” section of pipe.

The lesson learned in this case is that the grouting superintendent should be required to attend the pre-activity meeting (in person or by phone) to ensure information sharing between “office” and “field” such that any unique or varying information through submittal and RFI processing responses would be clearly communicated to the field crew in advance of operations commencement. This practice was continued for the remaining Phase 1, and for Phase 2, construction projects when any unique condition was set on the project different from described in the Contract Documents.

**Lesson Learned #9 – Mitigate Heat of Hydration Concerns When Grouting Annular Space**

When cement is mixed with water, the heat generated by the cement’s hydration (an exothermic chemical reaction between cement and water) raises the temperature of concrete. During annular space grouting between the host pipe and the carrier pipe this heat will dissipate into the system. When plastic carrier pipes are used for sliplining it is important to make sure that the system can dissipate this temperature during grouting without damaging the pipe. The Contractor plans for heat of hydration as part of their grouting operations. For example, in Phase 2 Portland cement with a 45 pcf mix design was used, and the heat of hydration temperature for this material was estimated at 169° F. The maximum allowable service temperature for HDPE pipe is 120° F; at 140° F the pressure rating is derated by 50%. There are similar limitations for PVC pipe material.

Since the heat of hydration was above the temperature that HDPE pipe can withstand, the carrier pipe was filled with water and pressurized to a minimum of 50 psi across its entire length. The water temperature was monitored and recirculated as necessary to reduce the pipe temperature. This would allow for grouting the annular space from end to end while maintaining a wall temperature of the HDPE pipe below 120° F. The water in the carrier pipe also mitigated concerns about buoyancy forces by increasing the combined downward force from the weight of the carrier pipe and water to help offset the uplift from the cellular grout.

8. **CONCLUSION**

After the completion of the project, the City ultimately ended up choosing the right combination of sliplining and open cut for a successful project. Splitting the project up into two phases was extremely valuable in order to incorporate lessons learned from Phase 1 into Phase 2, resulting in more streamlined construction, fewer change orders, a better quality product, and increased production during construction. In summary, the following are the key lessons learned:

1) Identify utilities in anticipated work areas  
2) Confirm existing utilities and alignment during design  
3) Obtain geotechnical evaluations early in design  
4) Select pipe materials that are appropriate for the conditions  
5) Invest in constructability review  
6) Require an approved sliplining plan  
7) Evaluate appropriate grout mix designs for varying conditions  
8) Coordinate and communicate with key project personnel  
9) Ensure that heat of hydration is accounted for during annular space grouting

8. **REFERENCES**
