LINE Q3 PIPELINE – SLIPLINE REHABILITATION

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ABSTRACT: In December 2009 the Rainbow Municipal Water District (RMWD) detected a falling water level in their large Morro Reservoir. After an exhaustive 24 hour search crews discovered a significant leak in their 300 PSI Line Q3 pipeline, a 2,100 foot long, 24-inch epoxy-coated, steel pipeline installed under the San Luis Rey River in 1995 via horizontal directional drilling (HDD) methods. Closed circuit television (CCTV) found large amounts of sediment and sand within the pipeline. This sand and silt could only have come from a break, crack or perhaps an offset in the steel line.

The first phase of the project focused on getting some portion of the past Line Q3 flow back online. Regulatory requirements eliminated a cut-and-cover option for a new pipeline. The use of the existing 24-inch Line Q3 as a casing was the quickest solution. This entailed cleaning out the sediment and sand build up in the pipe, and determining if it could be sliplined or if a new HDD project had to be re-drilled. The sediment was removed from the existing casing using an HDD drill rig, outfitted with a custom-designed 16-inch spade attached to the lead end of the drilling rods. The drill rig would feed the spade forward into the steel line, and push it into the sediment and retract it back with sediment. A trap door kept the sediment in the spade. After sediment removal was completed it was determined that the casing could be sliplined.

To achieve both the required 305 PSI pressure rating and higher flow rate needed from the slipline carrier pipe, RMWD turned to Fusible C-905® pipe, 16-inch DR 14. To achieve adequate pipe support under the variable working loads, annular grouting was required between the new pipe and the existing steel pipe. Four tremie lines were strapped to the 2,100 LF of Fusible PVC™ pipe during pullback.

This paper will explain the analysis of the failed existing steel casing, the approach taken to clean and rehabilitate that existing casing and the highlights of the design and construction of this new 300 PSI, pressure grouted sliplined pipe project.

INTRODUCTION

The Rainbow Municipal Water District (RMWD) is located in northern San Diego County and owns and operates potable water transmission, distribution, storage and pumping facilities throughout their service area. Over the years they needed to construct pipelines that cross over or under the San Luis Rey River in order to connect the northern portion of their water supply system to their southern supply system.
Line Q3 is an existing 24-inch diameter steel pipeline and is one of just two remaining critical water pipelines connecting these two portions of the District’s water system. It is located one mile east of Bonsall, California, north of Highway 78, west of Interstate 15 and crosses Highway 76.

This bidirectional transmission pipeline facility was constructed in 1995 utilizing horizontal directional drilling (HDD) installation techniques in order to replace a previous pipeline installation at the same location that was constructed in 1974 utilizing conventional cut and cover methods. In December of 2009 a break in Line Q3 following a significant rainfall event resulted in the pipeline being taken down. It was evaluated with closed circuit television (CCTV) in an effort to determine if it could be repaired. It was recommended by the consultant that Line Q3 be replaced. In the meantime, the District only had two transmission pipelines remaining in service and only one pipeline interconnecting the two service areas.

The remaining transmission pipelines cannot replace the capacity of the Q3 pipeline, thus the District’s ability to supply sufficient water to customers was in jeopardy. This situation created the emergency action necessary to replace the Q3 pipeline river crossing as soon as possible.

Line Q3 pipeline conveyed an average daily flow of 6,500 gallons per minute (gpm), which represented about half of the RMWD’s flow between the Hutton and Morrow pressure zones, located on each side of the river. A basis of design report was completed in order to identify the highest ranked alternative for construction. A comprehensive risk analysis, a hydraulic modeling effort and cost estimating results for each alternative was included in an alternatives evaluation matrix. The Basis of Design Report focused on both the best overall project to construct and also on which project to construct if the failed steel casing could not be cleaned out and sliplined. RMWD did not have enough time to wait until the pipeline was cleaned to make a decision on design selection, so both design approaches were evaluated and both were taken to full design completion prior to any commencement of the cleaning effort of Line Q3.

**THE EMERGENCY**

Water districts do not like to alarm their rate payers, especially during times of mandatory water use restrictions. RMWD has just lost the use of Line Q3, which provides 50% of the flow between their 150 Million Gallon Morrow Reservoir on the north side of the river and the Hutton Pressure Zone on the south side of the river. Crews had found the reason why the large reservoir had unexpectedly dropped after the recent December 2009 rainstorms, but RMWD had very limited time to investigate whether they could repair the critical 24-inch HDD steel casing or replace it in time to meet peak summer agricultural water demands and the anticipated fall wildfire season that previously wiped out homes and vegetation throughout their service area.

**PROJECT OBJECTIVES**

The RMWD identified the following primary objectives at the outset of the preliminary design phase:
- Expedite project repair or replacement due to emergency status and high flow rate of pipeline,
- Save money by trying to use the existing failed 1995 24-inch steel pipeline as a casing,
- Use a non-corrosive pipe material, and
- Stay within existing 20-foot wide pipeline easement.

J. C. Heden and Associates, the Prime Design Firm, identified the following project objectives:
- Identify a solution within RMWD’s budget,
- Provide a range of alternative pipeline solutions that meet the project’s flow and velocity goals,
- Select a pipeline alternative with a long, 75 year design life, and
- Assure that the repaired or replaced pipeline can withstand a range of operating pressures.

Brierley & Associates, a subconsultant on the project, identified the following project objectives:
- Supplement the DR 14 Fusible C-905® pipe pressure rating by grouting the annular space, and
• Expedite the construction schedule by using the existing 1995 steel pipeline as a casing for a new pipeline.

HYDRAULICS

The project design flow was taken as 6,500 gpm at five (5) feet/second maximum velocity. This was determined to be the past average day demand at 5.5 feet/second in the failed 24-inch steel Line Q3 pipeline. In order to protect the pipeline, its valves and fittings, it was decided that the velocity requirement would be more important than the flow rate target. Maximum day and peak hour demands do not surpass the RMWD average day demand because the regional wholesaler of water in San Diego County, the San Diego County Water Authority, makes additional water available to RMWD during these peak events through different pipeline connections within the RMWD service area.

AWWA standards were selected as the design standard for the project. In order to meet the flow rate and velocity objectives within AWWA standards, the Design Team needed to review a range of options to design a project within the failed 24-inch steel casing that would also meet RMWD’s water demand.

The RMWD stated that they wanted a non-metallic pipeline for this project. It was apparent to them that this and several other pipelines in their system had failed prematurely due to corrosion. Their staff and resources are limited and they feel that other pipeline materials already exist so that they can avoid an exhaustive district-wide corrosion protection initiative.

The Basis of Design Report identified 14-inch DR 14 Fusible PVC™ pipe, and a 16-inch DR 14 Fusible PVC™ pipe as applicable and meeting the AWWA standards. Each pipeline was modeled using the KYPIPE2010 steady-state model based upon data supplied by RMWD. Results included:

- Three 16-inch, DR 14, Fusible C-905® carrier pipelines in an HDPE casing conveyed 6,500 gpm at 4.0 fps
- Two 16-inch, DR 14, Fusible C-905® carrier pipelines in an HDPE casing conveyed 5,500 gpm at 5.0 fps
- Two 16-inch, DR 14, Fusible C-905® carrier pipelines in an HDPE casing conveyed 6,500 gpm at 6.0 fps
- Two 14-inch, DR 14, Fusible C-905® carrier pipelines in an HDPE casing conveyed 6,500 gpm at 6.9 fps

The 14-inch carrier pipe alternative was removed from further consideration due to its high pipeline velocities.

INVESTIGATION OF THE FAILED 1995 24-INCH LINE Q3 STEEL PIPELINE

A previous engineering report included closed circuit television (CCTV) pictures of the inside of the failed Line Q3 24-inch steel pipeline. This report concluded that the “Obstruction encountered at 275 linear feet (from the north portal) is believed to be a large rock or a separation in the pipe such as an offset” (RBF Consulting, Inc. (2010)).

The Design Team felt that the casing could be cleaned out and reused, and significant savings could be realized if the blockage was removed and the pipeline found to be a good candidate for sliplining.

The CCTV pictures and the description of their attempts to televise the casing led to the belief that the casing simply had two or three localized sand bars in it, and thus simply removing the sand bars and then sliplining the leaking/failed Line Q3 would avoid the cost and time required for a new HDD drill. Based upon the flow
requirements of the project and the size restrictions of the 24-inch pipeline as a casing pipe, a 16-inch nominal ductile iron pipe size carrier pipe was selected for the carrier pipe size. Two plans or designs were settled upon, both of which included three 16-inch carrier pipes. The pipe was to be pre-purchased by RMWD in order to save time as 16-inch DR 14 Fusible C-905® had never been produced for commercial application before this project.

Since time was of the essence, and the Design Team could not guarantee that the existing 24-inch pipeline could be cleaned out and sliplined, the design of the slipline project and a two carrier pipe HDD were set up as “Plan A”, while a larger three carrier pipe new HDD was set up as “Plan B, “if the existing failed 24-inch Line Q3 steel pipeline was found to be unsuitable for the required slipline.

BASIS OF DESIGN REPORT

Based upon the project’s identified design criteria, the following discrete elements were defined and included in the Basis of Design Report (BODR). It was completed in 3 weeks. These elements included:

- Hydraulic Capacity Requirements
- Pipeline Velocity
- Corrosion Resistance
- Constructability
- Environmental
- Long-Term Operations and Maintenance
- Technical Difficulty During Construction
- Subsurface Challenges
- Easement Modifications
- Permitting Requirements
- Scheduling and Delivery
- Risk Analysis
- Project Cost

CARRIER PIPE MATERIAL SELECTION

The carrier pipeline material selected needed to comply with AWWA standards. The only non-metallic carrier pipe alternatives identified at the outset included HDPE and Fusible PVC™ pipe. The primary issue was the Line Q3 working pressure requirements. Static pressures in the pipeline hover at 300 pounds/square inch (psi). However, transient pressures during summer pumping periods increase the hydraulic grade on Line Q3. Current HDPE pipeline products pursuant to AWWA C906 (AWWA C906, 2007) did not recognize a 16-inch pipe section capable of meeting the project’s pressure, flow rate and velocity requirements. The 2.384-inch wall thickness of a DR 7.3 HDPE pipe results in an inside diameter of 12.63 inches. This inside diameter is much less than that of a Fusible C-905® 16-inch, DR 14 pipe inside diameter of 14.914 inches. The DR 7.3 HDPE pipe has a rated working pressure of 254 psi versus the DR 14 PVC pipe rated at a working pressure of 305 psi (AWWA C905, 2010).

- 39.4% more hydraulic cross sectional area with 16-inch, DR 14, Fusible C-905, versus DR 7.3 HDPE
- 20% higher pressure rating with 16-inch, DR 14, Fusible C-905, versus DR 7.3 HDPE

The Design Team continued to evaluate steel and HDPE as casing materials for the new HDD drill, together will the option of no casing.

INVESTIGATION OF THE FAILED/INITIAL 1974 LINE Q3 CUT/COVER PIPELINE

In addition to designing a new drill parallel to the failed Line Q3 project, the Design Team needed to consider the whereabouts of the initial Line Q3 pipeline. The slipline design portion of the project was relatively straight forward provided that the contractor was able to successfully enter the entire length of the Line Q3 steel casing and remove all of the sand bars. The major obstacles to the new HDD drill portion of the design portion of the project included one known element and one unknown element of the project site.
• Known element: The location of the failed 1995 Line Q3 pipeline
• Unknown element: The location of seven (7) 36 foot tall reinforced concrete piers located directly under the initial cut-and-cover Line Q3 constructed across the San Luis Rey River in 1974. These piers were built to support the 1974 pipeline as it crossed over the river, but were later washed out during floods in the early 1990’s.

Once Line Q3 was cleaned and as-built drawing of the pipe was prepared by GeoSpatial, Inc., the location of Line Q3 was plotted on the design drawings for the revised plan set for the dual carrier pipe alternative. It was then determined that the Line Q3 steel casing had been actually drilled from one side of the 20 foot wide easement to the other, requiring a major HDD design revision and the need to incorporate three dimensional design techniques.

• Unknown Element: The Design Team needed to wait until the as-built survey of Line Q3 casing was complete in order to determine the misalignment of the Line Q3 casing. The new drill portion of the project was redesigned around the existing Line Q3 pipeline alignment. This was a significant variance from the as-built drawings provided to the Design Team.

CANDIDATE PROJECT ALTERNATIVES

Each project alternative initially began with three 16-inch PVC carrier pipelines, but later two 16-inch PVC carrier pipeline alternatives were added to the list of alternatives due to budget concerns. The design team and RMWD assigned weights to each evaluation criteria, conducted a comprehensive risk analysis of each alternative, completed an exhaustive construction cost estimate of each and then scored each of the eleven candidate alternatives based on ten different criteria. Environmental, corrosion, O&M and permitting conditions were considered the same for most of the alternatives. A noise study and typical multi-agency permits would have to be secured regardless of the alternative selected. The alternatives included the following:

<table>
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<tr>
<th>Alternative No.</th>
<th>Q3 Slipline</th>
<th>Bore Hole Dia.</th>
<th>Casing Diameter</th>
<th>Casing Material</th>
<th>Carrier Pipelines</th>
<th>Alternative Ranking</th>
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<tr>
<td>1</td>
<td>No</td>
<td>60-inches</td>
<td>48-inches</td>
<td>HDPE SDR 21</td>
<td>3 x 16-inch</td>
<td>1</td>
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<td>3 x 16-inch</td>
<td>7</td>
</tr>
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<td>4</td>
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<td>42-inches</td>
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<td>38-inches</td>
<td>Steel</td>
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<td>6</td>
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<td>None</td>
<td>n/a</td>
<td>2 x 16-inch</td>
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</tr>
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</table>

• Alternative No. 1 scored the highest of all alternatives that could meet the project’s object of providing a total flow of 6,500 gpm with pipe velocities of less than 5.0 feet per second. It would have been built if the sliplining could not have been performed.

• Alternative No. 4 scored the highest of the two pipe alternatives and was to be constructed in the event the sliplining of the Line Q3 steel casing was successful.

• The actual alternative to be constructed had to wait until the proposed cleaning of the 1995 Line Q3 steel casing was attempted.
PROJECT CONSTRAINTS

As is the case with most projects, time, money, weather and customer demands often bear down upon the Design Team without prior warning. The Design Team was well prepared for each obstacle it encountered.

The environmental subconsultant on the team, ICF International, was able to quickly arrange for a joint meeting with the environmental regulators in San Diego and explain the project so that separate meetings were avoided. Only two agencies needed to become involved. This action resulted in the submittal of a Section 1602 California Fish and Game Streambed Alternation Agreement Notification. After the State’s review of the notification they concluded that the project was exempt from securing the Section 1602 agreement. The Army Corps of Engineers also had limited comments.

The presence of special status animals, including the Least Bell’s vireo, the southwestern willow flycatcher and the arroyo toad identified during field surveys generated the requirement for a comprehensive noise study since high noise levels were anticipated by the regulators from the drill rig and the earth moving equipment. The noise study determined the need for 18-foot high noise walls on the north side of the project during the summer months, and noise walls 16-feet high on the south side of the project (see Figure 3).

CLEANING OF THE 1995 LINE Q3 STEEL CASING

A set of plans and specifications were prepared and bid out in June, 2010. The Line Q3 casing clean-out and HDD contract involved an initial task of requiring the contractor to first explore and clean out the Line Q3 pipeline so that a determination could be made if it could be sliplined. Once that decision was made the contractor would be authorized to order the proper size HDPE casing material for the new drill, or second phase of the project. If the Line Q3 casing was not usable, a larger diameter HDPE casing would need to be ordered for the new drill in the second phase, as that new drill would now contain three carrier pipelines. The cleaning operation required the services of a special 16-inch diameter spade (Figure 4) that the Design Team designed for the contractor to fabricate. This spade was affixed to the lead end of the drill rod, driven by a Ditch Witch JT-100 drill rig. The contractor’s crews easily advanced the spade through the north end of the 2,100 casing.

The CCTV inspections had already revealed that the south 1,000 feet of the casing had no blockages whatsoever. The primary reach of concern was the initial 400 feet of casing, as measured from the north portal. This reach is where the river is currently located and was historically indicated on past plan sets. It is also where the piers were constructed for the 1974 Line Q3 cut-and-cover installation.

The spade was designed with a front trap door (see Figure 5) to retain sand once it was thrust into a sand bar located within the casing. The trap door would retain the sand within the spade as the drill rig withdrew the spade back towards the rig.
Once the spade was backed out of the casing, it was rotated 90-degrees and emptied by the crew members (see Figure 6). The pipe averaged one-half pipe full of sand each time it was withdrawn back towards the drill rig until the sand bars were removed.

Two sand bars were encountered while cleaning the casing from the north. The rig never needed to clean the Line Q3 casing from the south portal as that half of the project was shown to be free of obstructions by the initial CCTV. It took the contractor six days to complete the work and he was paid a daily rate.

**DRILL RIG SET-UP AT THE NORTH PORTAL**

The contractor, Golden State Boring, of Ontario, CA (GSB) elected to mobilize a Ditch Witch JT-100 drill rig (see Figure 7) to complete their casing cleaning task and to conduct the PVC pipe pullback operation. It has a maximum rated pullback force of 100,000 pounds, more than enough to pull the wet PVC pipe through the 24-inch steel casing. In cooperation with Underground Solutions, Inc., GSB pulled a 21-inch diameter pig through the entire length of the 2,100 foot casing in order to determine if there would be any obstructions. They did not find any.

**RMWD PRE-PURCHASE OF THE CARRIER PIPE**

In an effort to expedite the project and not delay the contractor, RMWD negotiated a price with Underground Solutions, Inc., (UGSI) the manufacturers of the 16-inch PVC pipe prior to the bidding of the contract. Their contract with UGSI included the pipe, delivery of the pipe to RMWD’s yard, fusion services of the pipe, and limited assistance to the contractor during the pullback operation. This pipe pre-purchase was a critical step in the project as UGSI had never manufactured or installed this 16-inch DR 14 fusible PVC™ product in a commercial application before. They needed factory specific tooling to be procured in order to meet their specified delivery date.

**FUSING OPERATION AT THE SOUTH PORTAL**

With the drill rig situated at the north end of the project, the fusing machine provided with the RMWD pre-purchased pipe was set up at the south end. The south end included a horse pasture that was used with a construction easement to store and string the fused PVC pipe. UGSI provided the fusing machine and technician. The group of GSB and UGSI averaged about 10 successful fuses each day, or about 400 feet of 16-inch PVC pipe.

The project did not require one continuous string and one continuous pull, so three (3) 700 foot long lengths of pipe were staged in the horse pasture and then they would be fused together as they were pulled into the casing (see Figure 9).

The PVC pipe was very flexible and easy to work with. Its relatively light weight did not pose any problems for the contractor’s crew members during pipe unloading and during pipe positioning into the fusing machine. The external beads were all removed from the fused pipe, but the internal ones were not since this potable water pipeline was not planned to be pigged.
The PVC pipe was connected to high-pressure steel Romac restrained flanged coupling adapters at the steel pipe interfaces adjacent to the steel pipe valve manifolds in the project. The PVC pipe was provided in ductile iron pipe size (DIPS) and fit very well with all connections.

**TREMIE PIPE INSTALLATION AND PIPE PULLBACK**

Since a critical aspect of this project included taking advantage of the host casing by injecting heavy grout into its annular space to further support the 305 psi PVC pipe, the tremie pipes needed to be designed into the project. The Design Team elected to proceed with a set of four (4) 2-inch ASTM 3608 HDPE static tremie lines, each positioned at 12, 3, 6, and 9- o’clock on the cross-section of the pipe. (See Figure 12).

The tremie lines were attached with 1-inch stainless straps on 15’ centers and cut in lengths of 1050, 750, 500 and 250 feet. Each was marked so that the grout pumps could access them when it was their turn to receive grout.

Identical grouting operations were set up at each portal in order to reduce the maximum grout length through the 2-inch tremie lines from 2,100 feet to 1,050 feet.

The securing of the tremie pipe to the carrier pipe had to be completed during the pullback operation (See Figure 11). Since the drill hole did not have to be kept open the contractor was able to pace his crews and carefully secure the tremie lines and re-measure each one so that no mistakes were made.

The primary concern with the HDPE pipe was to be sure the contractor secured the proper tremie pipe material. The initial tremie pipe was brought on-site late and promptly rejected as not meeting the project specifications. With the short notice, only 500 foot rolls of the required 2-inch ASTM 3608 tremie pipe material could be delivered to the project site. In order to keep on schedule, the resident engineer allowed the use of electrofusion welds on the 1,000 foot and 750 foot sections. The Design Team recommends the use of continuous tremie pipe (non-spliced pipe) on all grouting projects due to the high grouting pressures.
355 PSI PRESSURE TEST FOR PVC

The owner required that the PVC pipe be tested at 50 psi above its rated pressure class. Since the pipe was rated at 305 psi it needed to be tested at 355 psi. The Design Team determined that the low point in the HDD profile represented the 300 psi working pressure so it subtracted the hydraulic head equivalent to the elevation head at the south portal, the location for the pressure test. The test pressure used at the south portal was 338 psi. This pressure resulted in a test pressure of 355 psi along the low and flat horizontal tangent of the HDD profile of project.

The pressure test requirements for this segment were zero leakage or no pressure drop for one hour after a four hour initial pumping period when the test pressure was maintained within five (5) psi. The pipe passed the pressure test.

THE GROUT PLAN

One of the best and surely the most controversial aspects of the project was the Grout Plan. The thought of pumping a silica, sand and cement grout mix 1,000 feet through a small 2-inch tremie pipe seemed crazy to the contractor. After a significant amount of negotiation and convincing, all parties came together and the grouting plan commenced early one morning. The highlights of the plan included the following:

- Design of a grout mix that will displace the groundwater in the casing
- Educate others that a cellular grout mix will not accomplish this objective
- Calculate Critical Buckling Pressure on PVC pipe
- Set Limits on Grout Pressures.
- Monitor Pressure Inside 16-inch PVC Carrier Pipe.
- Perform field tests on grout pumps to confirm capacity versus strokes
- Secure four (4) static 2-inch HDPE tremie lines: 250, 500, 750 and 100 feet long
- Set up grouting operation at each portal to reduce length of pumping grout through 2-inch pipe
- Tremie pipe lengths allow contractor to pump grout from the middle of the casing back towards the portal
- Conduct materials testing, slump and take cylinders on all grout batches
- Emphasize safety and have a back-up plan at all times

The PVC carrier pipe was kept full of water (water from the pressure test), with its internal pressure carefully monitored during the grouting operation as an indicator of over-pressurizing from the grout pumps which would lead to pipe buckling. No problems were encountered with pipe buckling.

The Design Team pre-calculated, based upon grout pump stroke counts and casing capacity, how long each tremie pipe should be connected to the grout pump. They then calculated when the advancing grout would pass by the end of the next tremie pipe, so that all water and air would be evacuated from the annular space before the next tremie pipe scheduled to be connected to the pump would take over and further advance the grout head towards the portal.

For the most part the grouting operation went very well. The contractor elected to use on-site batch plant equipment. Except for one pumping portal running low on sand it was a completed and a welcome success.

MEETING PROJECT OBJECTIVES

The project met the base project objectives for each member of the Design Team:

**Rainbow Municipal Water District:**

- Basis of Design Report completed in 3 weeks. Concurrent design of the slipline project and the 3 carrier pipe new HDD project completed in the followings 2 months. Sliplining project completed later that year.
• $3,000,000 estimated savings over a new drill 3 carrier pipe alternative

• A Non-corrosive 16-inch DR 14 Fusible C-905 pipe material was implemented

• No additional easement needed to be obtained from County of San Diego

**J. C. Heden and Associates:**

• The bid for slipline portion of the project was 50% of the owner’s budget for the project

• DR 14 16-inch Fusible C-905 met the pressure class and velocity requirements for the project

• The selected pipeline system, PVC pipe with the grouted annular space provided this service life in this underwater environment

• The three-way pipe system, including the 15 year-old 0.375-inch wall steel pipe, the average 1.75-inch annular grout ring and the DR 14 PVC pie section, can meet the anticipated range of pressures

**Brierley & Associates:**

• The grout filled the annular space and transferred radial loads from internal PVC pipe the outer casing

• The existing 24-inch casing was cleaned in six (6) days and expedited the ability to bring Line Q3 back online

**SUMMARY**

RMWD was very pleased that the failed Line Q3 24-inch 1995 steel casing could indeed be sliplined and that ratepayer funds could be saved. Unfortunately, due to budget cutbacks, the remaining balance of the Line Q3 Project, the two (2) carrier pipe new drill HDD project, was delayed. The constructed 16-inch slipline project is performing extremely well for RMWD, and as more funds become available they anticipate constructing the remaining project at a future date.

**REFERENCES**


American Water Works Association (AWWA), (1997), Polyvinyl Chloride (PVC) Pressure Pipe and Fabricated Fittings, 14 inch (350 mm through 1,200 mm) 48 inch, for Water Transmission and Distribution (C-905)

American Water Works Association (AWWA), (2007), Polyethylene (PE) Pressure Pipe and Fittings, 4 inch (100 mm) Through 63 inch (1,600 mm) for Water Distribution and Transmission (C-906)