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# COMPARING THE DESIGN AND CONSTRUCTION ASPECTS OF 24-IN. DIAMETER FUSIBLE POLYVINYLCHLORIDE PIPE

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**ABSTRACT:** CDM was retained by the Middlesex Water Company (MWC) to design a replacement pipeline for an existing 24-inch water main from the city of Perth Amboy, under the Raritan River, to the borough of Sayreville in New Jersey. The existing cast iron water main, which was more than 100 years old, experienced multiple breaks in recent years requiring emergency repair. Due to site constraints, including the river crossing, soft sediments adjacent to and under the river, and regulatory conditions associated with wetlands and river navigation, these repairs were quite costly, leading to the decision to replace the line.

Based on findings from a geotechnical investigation program and consideration of prevailing site constraints, pipe material and installation methods were identified for the replacement of this existing pipeline. Horizontal directional drilling (HDD) was determined to be the most viable installation technique despite significant uncertainty and risk due to the size and length of the crossing.

The total length of the drill path was approximately 5,365 linear feet. This was the longest fusible polyvinylchloride pipe (FPVCP) pullback of 24-inch or greater diameter completed to date in the world. This paper discusses the design process for this new pipeline, and compares pulling forces predicted during the design phase with the actual pulling forces recorded during the pipe installation.

## 1. SITE HISTORY AND PROJECT BACKGROUND

The Middlesex Water Company (MWC) is a 113-year-old, NASDAQ-listed company providing water, wastewater and related utility services to a population of nearly 400,000 in central New Jersey and Delaware. The water company currently owns and operates a 24-inch cast iron potable water main that conveys water from Perth Amboy, through the banks of the Raritan Bay, across the Raritan River and into Sayreville, New Jersey. This existing pipeline was originally installed in approximately 1904 by Perth Amboy. Within MWC's distribution system, this pipeline conveys potable water across the Raritan River from the township of Woodbridge to the city of South Amboy. In the 1980s, this 24-inch water main was leased by the MWC from Perth Amboy and was ultimately purchased by the MWC from Perth Amboy.

The majority of this section of existing water main is located within marshlands/wetlands and is covered with 0 to 2 feet of muck and reeds. Due to the age, corrositivity and unstable nature of the surrounding environment, the existing main experienced several breaks, requiring costly emergency repairs on an increasing frequency. These outages caused major operations disruptions and repairs were costly due to access impediments associated with the river, soft sediments adjacent to and under the river and regulatory considerations associated with adjacent wetlands and river navigation. Because of this, MWC determined that this existing 24-inch water main had to be replaced in order to continue to provide a reliable source of drinking water to its customers south of the Raritan River.

This crossing was performed by HDD of 24-inch FPVC pipe. The purpose of this paper is to discuss the design and construction aspects of the new 24-inch water main between the Perth Amboy and Sayreville and demonstrate how attention to those aspects, along with management of risk before and during construction risk, can achieve a successful outcome through thoughtful cooperation between participants.

## 2. GEOTECHNICAL INVESTIGATION

The crossing length was approximately 5,365 feet and the subsurface exploration program consisted of 11 geotechnical borings. Eight of the borings were performed in the Raritan River using barge-mounted, mud-rotary drilling methods. These marine borings extended between 48 to 115 feet below the existing mud line. Three of the borings were performed on land using conventional truck-mounted, hollow stem auger drilling equipment. The land borings extended to between 25 to 50 feet below the existing ground surface. Closely spaced soil samples suitable for identification purposes were extracted from the borings in general accordance with the procedures from the standard penetration test (SPT). Relatively undisturbed thin-wall tube samples of compressible soils were obtained from the selected borings. In addition, bedrock cores were collected in three of the four borings using an NX-size core barrel.

A description of the subsurface conditions encountered from these marine and land borings is as follows:

### Marine Borings

**Organic silts/clayey silts/silty clay:** Very soft organic silt, clayey silt and silty clay were encountered at the mud line and extended to depths between 10 to 90 feet below the mud line. Meandering channels filled with silty sand, beds of peat were also present at some locations within this unit. Occasional layers of shells were also encountered at two of the marine borings at depths approximately 60 feet and 68 feet, respectively.

**Silty sand:** Medium dense to very dense silty sands were encountered interlayered within and/or below the silt/clay stratum in six of the marine borings. Intervals of stiff to hard clay and silty/sandy clay were also present within this unit at some locations. These sandy soils were typically encountered at depths varying from approximately 13 to 95 feet below the mud line, and this layer varied in thickness from about 3 to 27 feet.

**Diabase bedrock**: Diabase bedrock was encountered in all three selected borings where bedrock was cored and the depths varied from 46 to 110 feet below the existing ground surface.

### Land Borings

**Fill materials:** Fill materials were encountered at the surface of the land based borings and fill typically extended to depths varying from approximately 7 to 12 feet below the existing ground surface, and typically contained a significant amount of construction debris.

**Organic Soils: P**eat, medium dense silty sands containing organics or soft organic silty clay were encountered below the fill stratum at depths varying from approximately 7 to 12 feet below the existing ground surface.

**Sands/clay:** Loose to medium dense sands and silty sands with gravel, and stiff to hard silty clay was encountered below the organic silty clay stratum at depths varying from 25 to 50 feet below the existing ground surface.

## 3. SELECTION OF INSTALLATION METHOD AND PIPELINE MATERIAL

Based on findings from the geotechnical investigation program and consideration of prevailing site constraints, the installation method and pipe material were identified.

At the preliminary stage of the project, four installation methods were evaluated. These were open-cut trenching, microtunneling/pipe jacking, conventional tunneling and HDD. HDD was determined to be the most cost effective installation technique despite significant uncertainty and risk due to the size and length of the crossing.

In addition, four pipeline materials were also evaluated at preliminary stage of the project. These were ductile iron pipe, high-density polyethylene pipe (HPDE), fusible polyvinylchloride pipe (FPVC), and steel pipe. All of these pipeline materials were evaluated for replacement of the existing 24-inch water main for its applicability on the trenchless portions of the project. FPVC pipe was selected as the carrier pipe (without an outer casing) for the trenchless crossing of the river.

## 4. DESIGN

The design analyses were performed in two continuous stages. The intent of the initial stage (Stage 1) was to conduct technical analyses with differing HDD installation scenarios. Analyses performed in the second stage (Stage 2) used modified parameters for the long term use of the water main and a modified frictional factor based on discussions with HDD specialty contractors and the results from Stage 1.

**Stage 1 of the technical analyses included:**

1) Evaluating the required depth and vertical alignment of the HDD crossing below the Raritan River,
2) Evaluating the risk associated with hydraulic fracturing of the soils,
3) Estimating safe pull force,
4) Evaluating the stresses on the pipe during the HDD installation, and
5) Making recommendations for selecting the pipe wall thickness for installation.

**Stage 2 of these analyses included:**

1) Revised parameters to reflect the long term use of the water main,
2) Revised frictional factor based on discussions with contractors, and
3) Revision of the recommended pipe wall thickness based on the selected vertical alignment geometry for the crossing, bore entry and exit angles, radius of curvature, and pipe installation methods.

A description of the Stage 1 and Stage 2 analyses is as follows.

**Stage 1 Technical Analyses**

One of objectives of Stage 1 analyses was to identify the vertical alignment for the HDD crossing. The vertical alignment for the HDD crossing was determined based on the subsurface characteristics of the Raritan River. The subsurface characteristics that were considered when locating the vertical alignment included:

- Shell deposits located approximately from elevation -65 feet elevation to -75 feet as revealed in two of the marine borings. HDD operation in such a potentially porous material may result in loss of slurry pressure.

- Location of the underlying bedrock, as the risk of borehole collapse is greatly increased if the alignment encounters bedrock that requires changing of the drill bit. In addition the delay in changing drill bits and the slower drilling progress will increase the cost of the project.

- Hydrostatic pressures on the pipe become more restrictive at greater depths.

- The depth of cover at ascent or decent of the alignment, because a sufficient cover is necessary to avoid “frac-out” at ascent or decent of the alignment.

Considering the above characteristics, for the purposes of this Stage 1 technical analysis, an alignment with the deepest part of the pipe (the central section) located at elevation of -60 feet was recommended with radiuses of curvature along the entry and exit locations in the alignment set to 5,107 feet and 3,310 feet, respectively. At greater depths, there is a high potential of encountering rock, particularly on the Perth Amboy side of the alignment. Therefore, an elevation of -60 feet was used in evaluating the overburden loading.

For the purposes of this Stage 1 technical analysis, the vertical alignment was established with a pipe entry angle of 9º and a pipe exit angle of 11º.These angles were determined based on consideration of the shell stratum, rock and maintaining cover as discussed above.

**Evaluating Pipe Thickness**

With FPVC pipe selected as the pipe for this HDD crossing, different pipe wall thicknesses of the FPVC pipe were considered. FPVC pipes are identified based on their dimensional ratio (DR). The DR is defined as the ratio of pipe diameter to wall thickness. The pipes evaluated for this project included DR-18, DR-21 and DR-25. Table 1 shows the difference in properties of the three pipes.

Table 1 – FPVC Pipe Properties for Different Dimensional Ratios

| DR | OD (in) | Minimum Pipe Wall Thickness (in) | ID (in) | $\gamma_{pipe}$ (lbs/ft) | g | Maximum Working Pressure (psi) | Pipe Critical Buckling Pressure (psi) | Minimum Allowable Bend Radius (ft) |
|---|---|---|---|---|---|---|---|---|
| **DR 18** | 25.80 | 1.43 | 22.76 | 72.33 | 1.4 | 235 | 190 | 538 |
| **DR 21** | 25.80 | 1.23 | 23.19 | 62.59 | 1.4 | 200 | 117 | 538 |
| **DR 25** | 25.80 | 1.03 | 23.61 | 52.09 | 1.4 | 165 | 68 | 538 |

Source:http://www.undergroundsolutions.com/pipe-dimensional-data.php)
DR: standard dimension ratio of outside pipe diameter to pipe wall thickness.
OD: pipe outside diameter
ID: pipe inside diameter
$\gamma_{pipe}$: weight of empty pipe
g: specific gravity of pipe

The HDD alignment was evaluated for axial tensile stress and buckling stress with and without a tensile reduction factor. This factor is generally used to account for chemical (or radiation) degradation that may occur during long-term operation conditions. The following pipe properties of FPVC pipe were used in the calculations:

- Pipe tensile strength: 7,000 psi
- Pipe safe pull stress: Tensile strength/2.5 = 2,800 psi
- Pipe modulus of elasticity: 400,000 psi

In the initial stage of the calculations, the results assumed an empty FPVC pipe. The results showed that the tensile stress due to friction between the soil and pipe and buckling stress would not have sufficient safety factors (greater than 1) for any of the pipe thicknesses evaluated if FPVC pipe was installed as an empty pipe. Therefore, a modification (i.e., to fill the pipe with water) to the installation procedures was considered and it was evaluated during both Stage 1 and Stage 2 analyses. By maintaining the FPVC pipe that has entered the bore full of water during the entire pullback period, the pipe can be centered in the bore, thus reducing the friction forces and tensile forces on the pipe. This also counters the hydrostatic pressure acting on the pipe from the river that can cause ring collapse and reduces the forces acting on the pipe to only the effective unit weight of the soil. The above grade portion of the pipe can be kept empty during the pull-in.

In the HDD operation, FPVC pipe is fused and strung along the surface prior to being pulled through the bore hole. As the pipe is pulled, it must overcome frictional forces as it is dragged along the surface. These forces are represented by a coefficient of friction, ($V_a$). In general, $V_a$ could range from 0.1 to 0.5 depending on the method used during pulling. For the purpose of this evaluation, the following two values for coefficients of friction ($V_a$), representing different pulling methods, were used.

- $V_a$ of 0.10 was used to represent FPVC pipe supported on rollers as it is pulled into the bore hole.
- $V_a$ of 0.50 was used to represent FPVC pipe pulled along the ground surface without the support of rollers (ASTM F 1962-05).

A coefficient of friction ($V_b$) of 0.30 was used for a lubricated bore hole and after the (wet) pipe exits (ASTM F 1962-05). A $V_b$ value of 0.30 was selected based on the range given in published articles and based on discussions with pipe manufacturers.

In addition, two scenarios for the pulling operation were also considered. The first scenario assumed that the pipe was fully-filled with water during the pulling operation and was performed for $V_a$ equal to 0.10 and 0.50 for DR-18, DR-21 and DR-25 FPVC pipe. The second scenario assumes that the pipe was partially-filled with water during the pulling operation and was performed for $V_a$ equal to 0.10 and 0.50 for DR-18, DR-21 and DR-25 FPVC pipe.

Results of these analyses indicated that DR 18 pipe was found to have safety factors greater than 2 for both the partially-filled and filled pipe scenarios when resisting axial tensile stress based on friction coefficients ($V_a$ = 0.10 and $V_a$ = 0.50) during the pull. DR21 pipe was found to have safety factors equal to 1.5 or greater for both the partially-filled and filled pipe scenarios, when resisting axial tensile stress based on friction coefficients ($V_a$ = 0.10 and $V_a$ = 0.50) during the pull. The safety factors were found to be less than 1 in both scenarios using the DR 25 FPVC pipe.

Based on these results it was concluded that DR18 and DR21 FPVC pipe were acceptable for use in the HDD crossing of the Raritan River with the proposed alignment. DR25 was not recommended for the HDD crossing as it did not meet the factor of safety requirements for resisting ring collapse.

**Assessment of Soil Deformation**

Further, circumferential strain analyses were also performed using SIGMA-W (SIGMA/W is a finite tool, which was developed by GEO-SLOPE International Ltd.) to evaluate pipe and soil behavior at critical sections. Based on the interpreted profile, the critical locations along the alignment of the pipeline were selected for evaluation. These critical locations were identified based on soil strength , which is deemed critical, soil overburden at pipe depths and water elevation.

Circumferential strain analyses indicate that by locating the HDD alignment at elevation of -60 feet, the local soil deformation of the circumferential bore (36-inch diameter) was negligible and the borehole was stable. Upon completion of Stage 1 analyses the following conclusions and recommendations were established:

**Stage 1 Conclusions**

1. The initial stage evaluations indicate that the deepest part of the vertical pipe alignment (the central section) should be located with springline at elevation -60 feet. A deeper vertical alignment was not recommended because the deeper alignment might encounter a shell layer; and below the shell layer, the Diabase Bedrock. The hydrostatic pressure on the pipe also becomes a restriction at greater depths. Installation of the pipeline at a shallower depth was restricted by the higher risk of a soil fracturing occurrence.

2. Calculations determined that wall thicknesses of DR18 and DR 21 FPVC pipe installed at elevation -60 feet would both meet and exceed the design criteria considered for HDD installation for fusible PVC C-905 pipe with either of filled or partially-filled pipe condition and with various coefficients of friction. However, the safety factor for DR21 pipe against buckling stress with a tensile reduction factor was only approximately 1.5.

**Stage 1 Recommendations**

As a result of the evaluation of the various analyses, the installation of DR18 or DR21 FPVC pipe at elevation -60 feet was recommended. It was also recommended that the pipe should be filled with water during the pulling process to the elevation of the river and rollers should be used during pullback of the pipe in order to reduce the friction forces and tensile forces on the pipe.

**Stage 2 Technical Analyses**

Based on recommendations from the Stage 1 analyses, final technical analyses were performed. The recommended soil parameter values from Stage 1, vertical alignment geometry and requirements during construction, such as rollers and maintaining a specific water level within the FPVC during pulling, were used in the Stage 2 analyses.
The HDD alignment recommended as part of the Stage 1 technical analyses was further evaluated for axial tensile stress, buckling stress with and without a tensile reduction factor, and long term buckling stresses. The conditions assumed in the Stage 2 technical analyses were as follows:

- The pipe was filled with water to the level of the river during pullback.
- The alignment was established with both a pipe entry and exit angle of 8º.These angles were selected to provide additional overburden cover at the beginning and end of the pull.
- The deepest part of the pipe (the central section) was located with a springline at elevation of -60 feet.
- The radiuses of curvature along the two curves (at entry and exit points) in the alignment are both 3,800 feet. These radii values were used to reduce risk of encountering the shells, rock and maintain depth to stay within the internal range that would maintain borehole integrity and reduce risk of soil fracturing.

Two input parameters that were modified for the Stage 2 technical analyses were the coefficient of friction ($V_a$) and the modulus of elasticity. A coefficient of friction ($V_a$) of 0.30 was used to reflect a more conservative value of the friction reduction due to the use of rollers as recommended by various HDD contractors. The pipe modulus of elasticity of the FPVC pipe was reduced from what was used in the Stage 1 technical analyses to take into account the long term behavior of the pipe. A value of 300,000 psi representing 75 percent of the short-term value was used.

With pipe fully-filled with water, the results of the Stage 2 analyses suggested that factors of safety against axial tensile stress for both DR 18 and DR21 pipes are greater than 1, which is the recommended factor of safety according to Horizontal Directional Drilling Good Practices Guidelines.

DR 18 pipe had factors of safety against bulking stress greater than 2, which is the recommended factor of safety according to ASTM F 1962 – 05, both with and without a tensile reduction factor. However, the DR21 pipe did not meet the minimum safety factors recommended to resist buckling stresses for the long-term condition. Use of DR 21 pipe for HDD installation at this location was therefore not recommended.

Upon completion of Stage 2 analyses the following conclusions and recommendations were provided:

**Stage 2 Conclusions**

The wall thickness of DR 18 FPVC pipe installed at elevation -60 feet meets the design criteria considered for HDD installation for FPVC C-905 pipe with pipe filled with water during installation based on the parameters used in the Stage 2 analyses. DR21 pipe did not meet the required safety factor against buckling stress and therefore was not acceptable for use in the HDD installation.

**Stage 2 Recommendations**

Based on the results of the above Stage 1 and Stage 2 technical analyses, the following recommendations for this project were:

1) Use of FPVC DR18 pipe for the HDD installation under the Raritan River.
2) The FPVC pipe should be supported on rollers as it is pulled into the bore hole.
3) Pipe should be full of water when in the borehole during the pulling operations.
4) The vertical alignment should have an entry and exit angles at 8º.
5) Both curves in the alignment have a bending radius of 3,800 feet, which is greater than the minimum allowable bending radius.

## 5. CONSTRUTION

Northeast Remsco Construction, Inc. (Remsco) of Farmingdale, New Jersey, was selected as the general contractor for the project. Major subcontractors were the Mears Group, Inc. (Mears), who performed the horizontal directional drilling, and Underground Solutions Inc. (UGSI), who provided and fused the FPVC pipe.

### Horizontal Directional Drilling

Before starting the horizontal directional drilling, key personnel from CDM and MWC met with the Remsco and Mears to finalize the construction details concerning the HDD process, recognize potential risks, and identify potential solutions to those risks. It was also agreed at that time to make minor adjustments to the borehole path in order to facilitate the drilling operation. These included increasing the entry angle to 13º, making the vertical depth 65 feet and increasing the exit angle to 12º.

Drilling of a 10-inch diameter pilot hole began on March 11, 2010, using an American Augers 140,000-lb rig set up on the north (Perth Amboy) side of the river. A second drilling rig, an American Augers 880,000-lb rig, was set up at the exit location on the south side of the river in Sayreville to conduct the reaming and pullback operations. Before drilling the pilot hole, 140 linear feet of 42-inch steel conductor casing was installed in order to stabilize the entry point, which contained concrete debris and other rubble and to reduce the potential for breakout due to the shallow depth of cover in the entry area. The initial 700 feet of the 10-inch pilot hole was guided by a gyro tool system. With the path of the pilot hole considered to be the most important factor, the gyro tool system would help prevent deviation that could result in day lighting in the river channel or encountering the nearby bedrock and that tool would be unaffected by magnetic interferences from debris that could affect the accuracy of the survey readings. Tracking was then switched from to a Para-Track II system, which offered the capability of monitoring fluid pressures down hole. This monitoring was increasingly important as anticipated rising pressures and the presence of soft overlying sediments increased the potential for inadvertent returns into the river. The pilot hole was completed on March 31, 2010. The exit point was approximately only 1 foot off line and 6 feet short of the target location.

Between April 6 and April 26, 2010, the pilot hole was reamed to a final diameter of 36 inches. The reaming was conducted in a single pass using 26 inch and 36 inch reamers set up in a tandem configuration. Consideration was given to performing the reaming in two passes. However, before the reaming operation began the project team elected use one pass as less risk was perceived with the fewer number of trips made through the soft sediments that were present in some portions of the borehole.

After completing the reaming a swabbing pass was then conducted to clear cuttings and other solids from the borehole and make the path as straight as possible. An important goal in this procedure was to replace the drilling fluid with new fluid that would have as low a specific gravity as realistically feasible while still having properties capable of maintaining the open borehole. This was desirable since a lighter fluid would minimize buoyant forces. A target specific gravity of 1.2 was established.

### FPVC Pipe

UGSI supplied the FPVC pipe for the project and conducted the fusing operation to connect the pipe joints. The FPVC pipe arrived at the site in 40-foot-long segments, necessitating approximately 135 fusion operations to connect the segments. The segments were initially fused into four intermediate pipe strings before pull back. A single pipe string could not be assembled prior to pull back because space limitations limited prior assembly to less than 1,500 feet in length. This meant that the pull back to be stopped three times while the strings were connected and there was concern that the pipe being pulled back could freeze in place as these intermediate fusion operations were performed.

**Installation**

Pull back of the FPVC pipe into the HDD borehole began on the morning of April 29, 2010.To reach the borehole from the pipe staging area, the FPVC pipe had to traverse a distance of approximately 500 feet. Along this span the pipe was supported on rollers suspended from a crane and booms of multiple excavators over a roadway, which had to be closed and secured with the support of the local authorities, and down a steep hillside with numerous elevation changes. The tail section was supported on rollers placed on the ground within the staging area to protect the pipe from damage by rubble and concrete projections that were present throughout the staging area. Bending radii needed to be carefully monitored and controlled to avoid excessive flexure of the pipe string. In order to minimize pullback forces, the pipe was filled with water during the pullback process. Ballasting the host pipe with water began about half way during pullback of the first pipe string, needing approximately 30,000 gallons of water for each string of pipe.

Pullback continued throughout the day, overnight and was successfully completed approximately 23 hours later at approximately 11:00 a.m. on April 30, 2010. Pullback proceeded smoothly and without any significant problems.

## 6. COMPARISON BETWEEN DESIGNED PULLING FORCES AND PULLING FORCES RECORDED DURING THE PIPE INSTALLATION.

Figure 1, shows a plot of the pull back force that was estimated at the outset of the project, as well as the pullback force that was actually observed at the drilling rig. While the observed pull back force was higher than the preconstruction estimate it was still well below the maximum recommended by USGI of 307,100 pounds.

The plot clearly illustrates the effect of filling the pipe with water to control buoyancy. Note, how the increasing pull force before the addition of water, followed by the steady or declining force after water was added.

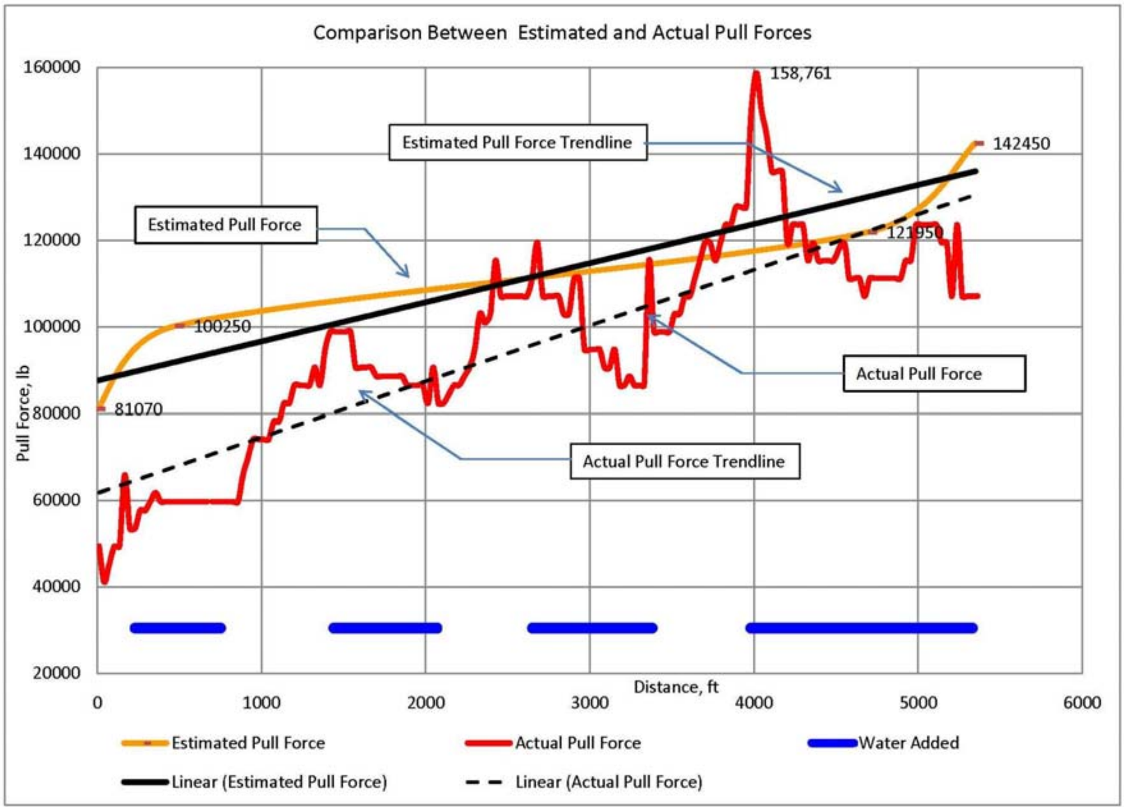


Figure 1. Comparison between estimated and actual Pull Forces.

## 7. CONCLUSION

Projects, even very difficult and challenging ones such as this one can achieve a successful outcome through:

- Careful investigation and design in planning the project.
- Management of risk through project setup.
- Minimizing risk during execution through communication and cooperation between participants.

As already mentioned, this was the longest installation of FPVC pipe of 24-inch or greater diameter pipe completed by HDD methods to date in the world.

## 8. REFERENCES

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