Selection Process Challenges: Force Main Study Considers Variety of Trenchless Technologies and Corresponding Stakeholder Impacts

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1. ABSTRACT

Prestressed concrete cylinder pipe (PCCP) from the 1970s can be failure prone. In the City of Virginia Beach, VA, a regional authority operates a 5,000 linear foot (LF) section of 48-inch PCCP force main in a high consequence-of-failure location without proper in-line valving to isolate a failure. An engineering study for replacement was initiated.

A 350 LF section of the force main is located under a 10-lane highway connecting high-end shopping malls and interstates to popular beaches along the Chesapeake Bay. Based on the interconnectivity of the force main network, the ability to isolate this section by redirecting flows provides a potential opportunity for trenchless alternatives to open-cut replacement, including pipe rehabilitation technologies and horizontal directional drill (HDD). Rehabilitation technologies include cured-in-place pipe liner, slilining using fusible polyvinyl chloride pipe or high-density polyethylene pipe, pipe bursting, and hand-applied fiber reinforced polymer liner.

Triple-bottom-line guidelines require focusing on social and environmental impacts of each technology in addition to cost. Detailed conceptual designs were developed to understand access, easement, and construction ramifications and how they compare to an adjacent HDD.

In many instances, only one rehabilitation technology seems applicable to a project. As more technologies gain footing in the market and the need for trenchless work grows, it will be critical to understand proper vetting during the preliminary design phases. This paper shows a real-world example of how trenchless technologies are allowing engineers to get creative and benefit stakeholders; but understanding minor differences can make a big impact and drive the selection process.

2. INTRODUCTION

The Hampton Roads Sanitation District (HRSD) owns and operates a large, regional force main interceptor system and 13 wastewater treatment plants providing service to approximately 1.7 million residents in 18 counties and cities in the Hampton Roads region of Virginia. HRSD determined, based on risk, that a significant section of a large diameter force main needed to be replaced by relocated out of private property. In 2016, HRSD contracted with AECOM to design the relocation of approximately 4,700 linear feet (LF) of 48-inch diameter prestressed concrete cylinder pipe (PCCP) force main in the City of Virginia Beach (City), VA.

This section 48-inch PCCP force main was installed in 1976 prior buildout of the high-density neighborhood of Wesleyan Chase. As a result the force main is located within private property via easements, mostly in backyards of residences and through parking lots of apartment complexes. Limited access to the force main and its lack of grade
uniformity put the force main at high risk for air entrapment and failure from internal corrosion. In addition, there are no valves along the section to provide isolation if a force main failure in the area occurred. HRSD decided to develop a cured-in-place pipe (CIPP) project to design the relocation of the force main and eliminate the risks corresponding to its current location.

Two major roadways and corresponding right-of-ways (ROW) were considered as locations for the new alignment. Ultimately, the Diamond Springs Road alignment was selected (see Figure 1). At the northernmost end of the project, whether or not to extend pipe replacement across Northampton Boulevard was a challenging decision. Northampton Boulevard is a 10-lane highway connecting the interstate to outlet malls and popular beaches along the Chesapeake Bay. As a result, three options were considered and are listed below and shown in Figure 1:

Option 1: Connect to the existing force main along Shell Road, south of Northampton Boulevard (i.e., no replacement of the force main across Northampton Boulevard)

Option 2: Connect to the existing force main along Shell Road, south of Northampton Boulevard, and rehabilitate the existing force main to the northern side of Northampton Boulevard

Option 3: Continue the new force main along Diamond Springs Road and construct the force main across Northampton Boulevard via trenchless method such as horizontal directional drill (HDD)

Figure 1. Selected force main relocation alignment and options on the northern end of the relocation

This paper presents an analysis of Options 2 and 3, specifically constructing a new force main across Northampton Boulevard via trenchless methods and the alternatives for rehabilitating the existing 48-inch PCCP force main across Northampton Boulevard. The analysis considered not only cost but also the social and environmental consequences to determine the triple-bottom-line (TBL) outcome of both options.
The other facet of this paper and interesting realization is that there are a considerable number of ways to rehabilitate a large diameter pipe. Within the context of this project, the engineer compared:

- CIPP
- Pipe bursting (not discussed within the context of this paper)
- Sliplining with fusible polyvinyl chloride (FPVC) pipe or high-density polyethylene (HDPE) pipe
- Hand-applied, fiber-reinforced polymer (FRP) liner

Sections 3 through 5 describe in detail how the engineer developed high-level design concepts for each rehabilitation alternative and trenchless crossing. These concepts were used to estimate site layouts; construction times and costs; stakeholder impacts; and, environmental considerations to perform the alternatives analysis.

3. DESIGN BACKGROUND

Open-cut installation of the new force main across Northampton Boulevard was eliminated early in the preliminary engineering report (PER) phase because Northampton Boulevard is a heavily traveled corridor and limited work hours and conflicts with other existing utilities would reduce the efficiency required for open-cut installation. The construction challenge of the roadway can be seen in Figure 2, showing the number of lanes and traffic flows near the approximate location of the existing 48-inch force main. Ruling out open-cut installation resulted in the consideration of two main alternatives to renew the pipeline capacity across Northampton Boulevard: construct a new pipe across Northampton Boulevard via trenchless methods or rehabilitate the existing force main.

With HRSD’s help, the engineer determined operating and physical requirements for the rehabilitation or replacement design. Hydraulic modeling showed that typical maximum operating pressures in the 48-inch force main were 33 pounds per square inch (psi) or lower. Using a 1.5 safety factor as specified in the HRSD Design and Construction Standards (HRSD, 2018), the design would require a new liner or pipe to handle operating pressures of 50 psi. Because present and planned changes to HRSD’s interceptor force main system will reduce the required capacity of the force main, the required inner diameter (ID) was set at 42 inches. However, because the length of force main required to cross Northampton Boulevard was limited to approximately 350 to 500 LF depending on trenchless method, a reduced ID of approximately 36 inches was considered. Modeling showed that a reduced ID for such a short section would not result in significant increases in head loss in the system.
4. TRENCHLESS ALTERNATIVES

The engineer considered several trenchless methods including HDD, jack and bore, microtunneling, and guided bore. HDD was determined to be the most appropriate and cost-effective method, based on available work space for equipment and pipe lay-down, subsurface geotechnical conditions, pipeline geometry, and clearances to existing surface features and buried utilities.

The jack and bore and pilot tube methods were judged to present a risk of settlement of the roadway based on the site geotechnical conditions. Borings taken at the crossing locations indicated loose sands and a high water table. These conditions increase the risk of excessive voids forming along the bore path due to potential flowing-sand conditions and therefore a risk of undermining the road subbase. Microtunneling is appropriate for the local subsurface conditions (closed-face microtunneling can be below the groundwater table), but this method was determined to be more expensive than HDD for this application.

The recommendation in the PER is a HDD with the following design guidelines:

- an approximately 500 LF long installation;
- 42-inch ID HDPE pipe;
- 50 psi maximum operating pressure;
- And 25 to 30 feet maximum depth (to top of pipe) installation.

The estimated cost for the HDD was $1.2 million (M). The alternative was to use the existing 48-inch PCCP force main as the host pipe for sliplining or structural-liner rehabilitation.

5. REHABILITATION ALTERNATIVES

Three rehabilitation alternatives for the existing force main across Northampton Boulevard were evaluated (sliplining, CIPP, and FRP liner). All three alternatives would require isolating the section of force main underneath Northampton Boulevard. Figure 3 shows the limits of the pipe rehabilitation and the proximity to significant roadways and businesses. Because of the interconnectivity of HRSD’s force main system and the linked wastewater treatment plants (WWTPs), the section could be isolated without a bypass system for approximately 1 month, which was confirmed by hydraulic modeling. Some of the flows would change direction and discharge to a different WWTP than normal during this time. The design would include the use of line-stops on either end of the rehabilitation limits to isolate flows during rehabilitation construction.
In general, AECOM considers sliplining a reasonable method of rehabilitating the existing 48-inch force main. Sliplining involves installing a smaller, carrier pipe into a larger host pipe (in this case, the existing 48-inch force main), grouting the annular space between the two pipes, and sealing the ends. AECOM would limit sliplining to HDPE or FPVC pipe materials to maximize capacity in the new carrier pipe in lieu of diameter-limiting bell and spigot pipe such as ductile iron or traditional PVC.

The limits of the sliplining concept and estimates of the construction staging areas, access pits, and material layouts are shown in Figure 4. For the sliplining, the rehabilitation limits would be extended from the section of force main underneath Northampton Boulevard south through the Wawa gas station property where the relocation of the new 42-inch force main would begin. A total of approximately 365 LF of force main would be sliplined. However, the alignment would include a 45-degree turn between Northampton Boulevard and the Wawa gas station. The turn would require a third access pit, temporary easements, and traffic control. Pull work performed out of the middle access pit would be required along with several fittings and at least one bend to join the two strings of pipe.
As mentioned in Section 2, the engineer considered only FPVC and HDPE pipe for sliplining. For these materials, installation could be accomplished in two ways: fusing pipe segments in the available space aboveground (also known as a stringout in which the fused pipe is laid linearly as each segment is fused on) and post pull-through or fused in-trench and pulling each time a new segment is fused. In-trench fusing was eliminated from consideration because of a concern about how long HRSD’s system could temporarily reroute flows. Pipe fusing aboveground could be accomplished during normal operations within the force main system, reducing the amount of time needed for isolation, rerouting flows, and pulling the fused segments.

**Cured-in-Place Pipe Lining**

The second rehabilitation alternative that was considered was relining the existing 48-inch force main with CIPP. CIPP is one of the most recognized liner technologies for providing reliable structural rehabilitation of a pipe and has a proven installation history. Although interactive with the host pipe, CIPP provides a structurally dependable new pipe. In rehabilitating existing pipe using CIPP, the pipeline is typically cleaned and inspected first, followed by insertion and curing of the new liner. Similar to sliplining, the force main section would need to be temporarily isolated and flows rerouted.

CIPP lining has two advantages. First, CIPP does not require stringout and the corresponding temporary easements. Second, in some cases, CIPP liner can navigate a 45-degree turn. The reduced construction and material staging associated with the CIPP process made this option attractive.

**Fiber-Reinforced Polymer**

The third rehabilitation alternative that was considered was a hand-applied FRP liner system. This technology uses a carbon-fiber-based, fully structural liner applied to the inner surface of the host pipe. Hand-applied FRP liners are used less often to rehabilitate pipe than CIPP lining and sliplining, but in short sections of pipe where large equipment staging and traffic control can be difficult to manage, hand-applied FRP liners can be beneficial and cost-effective.
The engineer reached out to Fyfe (an Aegion company) during the PER phase for information on its hand-applied FRP liner: Tyfo SCH-41-2X Composite. The physical properties of the fiber and epoxy suggest a strong, structural finished product, once installed. The liner would be more than capable of handling the operating pressures within the force main. The downfall of this technology is largely the installation time, estimated at approximately 2 weeks based on manufacturer input. Using a 1.5 safety factor multiplied against that time to account for unforeseen circumstances and cleaning of the pipe prior to installation, the installation time was estimated at 3 weeks. With a short window for shutting the system down and rerouting flows, the installation time was considered a negative attribute of this technology that was weighed against the positive attributes, such as limited equipment, staging, and traffic control.

**Comparison of Rehabilitation Alternatives**

Table 1 presents a condensed comparison of the three alternatives for reusing the existing 48-inch force main.

<table>
<thead>
<tr>
<th><strong>Table 1. Comparison of Rehabilitation Alternatives</strong></th>
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<td><strong>Material wall thickness</strong></td>
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<td><strong>Inside diameter</strong></td>
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<td><strong>Installation method</strong></td>
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<td><strong>Connection to new 42-inch force main</strong></td>
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<td><strong>Installation time</strong></td>
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<td><strong>Pressure rating</strong></td>
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<td><strong>Approximate construction cost</strong></td>
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<td><strong>Pros</strong></td>
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### Sliplining

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<tr>
<th>Cons</th>
<th>HDPE</th>
<th>FPVC</th>
<th>CIPP Lining</th>
<th>Fiber-Reinforced Polymer Lining</th>
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<td>• Requires three access pits</td>
<td>• High bending radius</td>
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CIPP = cured-in-place pipe; DIP = ductile iron pipe; DR = dimension ratio; FPVC = fusible polyvinyl chloride; FRP = fiber-reinforced polymer; HDPE = high-density polyethylene; PCCP = prestressed concrete cylinder pipe; psi = pounds per square inch

The three rehabilitation alternatives would meet the requirements of the rehabilitation design. They all appear feasible for the application and would provide an American Water Works Association Class III or IV pipe. The major differences are installation methods and dimensional/physical requirements. The differences between FPVC and HDPE are minimal. HDPE costs vary over time, which means the difference in cost of the two materials (HDPE and FPVC) could change depending on the time of construction. AECOM recommends fusing the pipe before installation (i.e., stringout) to minimize installation time while the force main is isolated.

### 6. TRIPLE-BOTTOM-LINE CONSIDERATIONS

Criteria for selecting the trenchless or rehabilitation alternative were developed from a triple-bottom-line (TBL) benefit analysis: a three-part framework consisting of social, environmental, and financial components. Although cost is typically a driving factor when considering engineered alternatives, it may not always yield the best overall option, especially when reviewed from a TBL standpoint. With the cost of the crossing only a fraction of the cost of the force main relocation, it made sense to grade the alternatives from a benefit analysis that considered social and environmental impacts in conjunction with costs.

The PER includes a consideration of many challenges in addition to the Northampton Boulevard crossing. To work within a limited budget and maintain efforts on the rest of the force main relocation, the engineer had to keep the TBL relatively high level. From a decision standpoint, exact calculations to quantify every facet of every alternative in relation to each TBL component and subcomponent were not needed. When looking at each alternative from a high level against each of the three TBL components, it became easy to assess one alternative’s advantage over the other. Also, because the installation time was significantly longer (once the force main section was isolated), the FRP liner was eliminated from consideration. However, if installation time had not been such a concern, the FRP liner may have been the most attractive rehabilitation alternative.

### Environmental Impacts

In general, there were no significant environmental impacts from any of the alternatives. Assuming the HDD contractor keeps the fluids contained, environmental impact would be low. The rehabilitation alternatives would require pits to access the existing pipeline. As mentioned previously, a Wawa gas station is located on the southern side of the proposed rehabilitation limits. As a result, any excavation near that area has the potential for contaminated soils and groundwater and therefore the potential for additional costs and treatment. It was assumed that the sliplining would require one additional excavation compared to the CIPP lining, resulting in HDD ranking the highest and sliplining the lowest in the environmental category. The environmental impacts based on sourcing of...
materials used for each alternative (e.g., environmental impacts of HDPE pipe manufacturing) were not studied. However, in other applications, especially with larger quantities of materials, this effort could be included to thoroughly evaluate the environmental impact of one alternative against another.

**Financial Impacts**

As presented in Table 1, the costs of the rehabilitation alternatives range from approximately $1M to $1.1M. The cost of the HDD is estimated at $1M. The difference in cost is negligible when considering the overall project is estimated to cost $14M. The key financial difference in the alternatives is the cost of easements and potential loss of revenue claimed by businesses. Potential loss of revenue negatively affects the rehabilitation alternatives because of their location near businesses, primarily Wawa and the Car Spa. While required staging and work areas are extremely difficult to quantify, it was assumed the rehabilitation alternatives would require more temporary easement than the HDD and have a higher probability of loss of revenue claims.

In terms of operations and maintenance costs, assuming that the installations perform to specified requirements and quality inspections are performed, the long-term difference between the alternatives is negligible. In addition, there would be no real net change in the number of air vents, dismissing any increase in recurring exercising of air vents by field crews.

**Stakeholder Impacts**

Businesses and residents obviously prefer that construction not take place in or around their properties. Therefore, limiting the amount of disturbance and the time of construction are considerations that are taken into account during the engineer’s design. For this application, all of the alternatives take place along a commercial, heavily congested corridor. The requirement by the City to keep installation of the pipeline across Northampton Boulevard trenchless makes sense. Using a trenchless method eliminates the impacts to drivers (i.e., temporary stakeholders). Stakeholder impacts are significant for the businesses that will be impacted by the construction outside the roadway that is required for the trenchless crossing. Staging, excavation, and moving equipment can limit pedestrian and vehicular mobility, create noise, create safety hazards, impact the business financially, and impact the way businesses view utility work and their consideration for cooperation. Therefore, when alternatives are reviewed, work zones and their relation to stakeholders (mainly businesses in this case) are critical.

The impacts of the rehabilitation alternatives to the adjacent businesses (e.g., Wawa, Car Spa) are similar. However, there are quantifiable differences. For example, sliplining compared to CIPP lining requires a third excavation (next to the Wawa gas pumps) and fusing and stringout of the pipe. In a dense, urban, commercial area small increases in earthwork and staging of materials can negatively affect business. In this example, the engineer ranked CIPP higher than sliplining. Due to the HDD’s location farther outside the active areas of the Wawa property (and not affecting Car Spa) and open space for stringout in the ROW, the HDD ranked the highest. Equipment for the HDD (drill rig, recycler) could be staged in such a way that customer access to Wawa gas pumps or adjacent businesses would not be impeded.

**Results**

Using a 1 to 5 scoring system (5 being the best) and the qualitative and quantifiable attributes discussed above, rough scores can be applied to each alternative for each TBL category. Figure 5 presents the scores. For this application, the scores were averaged to compare the TBL-based score for the project. The graph shows that even the most basic scoring system can help determine which alternative outperforms the others. In this example, it was an easy case to make; the HDD is the most reasonable choice for the project.

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For applications requiring a more detailed analysis, in which multiple alternatives are evaluated against set criteria, a decision matrix can be helpful. The decision matrix allows weighting of criteria to help prioritize certain conditions over others (e.g., cost could be weighted more heavily than stakeholder impacts and therefore influence the outcome more).

7. RESULTS AND CONCLUSIONS

Today’s projects require significant engineering to find solutions to problems and implement them in a way that is financially, environmentally, and socially beneficial. Fortunately for today’s pipeline engineers, there are significant technologies that allow for trenchless installations where required. In many instances, the project constraints limit the choices for trenchless methods. This application, however, has the opposite situation. Because there is an existing conduit and ability to isolate flows (without bypass), several in-pipe rehabilitation technologies are available. Additionally, adjacent to the existing force main is space for a new trenchless crossing using microtunnel, HDD, or other possible methods. The rehabilitation alternatives coupled with the trenchless installation alternatives yielded numerous alternatives. In addition to the number of rehabilitation and trenchless alternatives, within each alternative are material choices. Having a sufficient number of alternatives to choose from is attractive, but the selection process can be challenging. Many times, this requires developing an engineered concept for each trenchless method, digging into the details of the application. In this case, developing conceptual site layouts, work zones, and staging areas was necessary to see the impacts to the TBL components.

Comparing the project impacts against the TBL components requires some type of comparative process. In this case, a simple scoring system was sufficient; however, in other cases, a more detailed analysis using a decision matrix may be needed. Nonetheless, probably the greatest benefit of using scoring systems and decision matrices is that utilities can find presenting their findings and decisions in public arenas easier and more transparent by showcasing the decision process. When stakeholders can see an engineered analysis of the financial, environmental, and social impacts, the practicality of a decision can be much more appreciated.

8. REFERENCES


