ABSTRACT

When designing to accommodate additional future flows, is it more economical to rehabilitate the existing sewer along with installing a new parallel line, or to replace the existing sewer with a single, larger diameter gravity sewer? And how does a municipality go about making that decision?

The City of Raleigh Public Utilities Department (CORPUD) plans to rehabilitate and parallel or replace approximately 16,000 linear feet of 48-inch and 54-inch gravity sewer in the lower portion of the Walnut Creek sewer basin. In order to make an educated and informed decision regarding rehabilitation versus replacement, the CORPUD initiated an evaluation of multiple rehabilitation technologies and methods for large diameter gravity sewer.

CCTV and pole camera investigations had already been performed prior to start of the project, and indicated that the majority of the existing gravity sewer main and manhole conditions were rated as 4 or 5 under the Pipeline Assessment and Certification Program (PACP) and Manhole Assessment and Certification Program (MACP) rating systems developed by the National Association of Sewer Service Companies (NASSCO). The results of the investigations made it apparent that any rehabilitation technology considered in the preliminary study would need to provide structural integrity independent of the existing host pipe.

Four minimum criteria were utilized for evaluating a dozen rehabilitation technologies. Analysis determined that three of the 12 technologies met the minimum criteria. These included segmented sliplining, geopolymer centrifugal spray-in-place pipe, and cured-in-place pipe (CIPP). Each method was thoroughly researched and ranked for its ability to meet seven additional requirements, and these rankings indicated that CIPP offered a slight advantage over the other two methods for this particular project and client.

Upon conclusion of the rehabilitation evaluations, the project team evaluated four design alternatives:

1. A single, replacement interceptor located in the same alignment.
2. A single, parallel interceptor replacement sized to carry the entire future flow.
3. Rehabilitation of the existing interceptor and construction of a parallel interceptor.
4. A combination of Alternatives 2 and 3 to address areas with potential constructability issues.

Additional analysis indicated that Alternative 2 was the most viable and economical for the CORPUD. This was primarily due to the fact that the parallel line sizes were only one to two typical pipe diameters smaller than the single replacement line, and the cost to install the parallel lines in addition to rehabbing the existing lines outweighed the cost of a single replacement line.

The presentation will discuss the overall project need, rehabilitation technologies and methods evaluated, flow projections and pipe sizing, alternative analyses, and final recommendations for the project.

KEYWORDS

Rehabilitation technologies, flow projections, pipe sizing, trenchless, CIPP, sliplining, spray-in-place, geopolymer, trenchless, replacement, interceptor, concrete
INTRODUCTION

The City of Raleigh Public Utilities Department (CORPUD) needed to rehabilitate and parallel or replace approximately 16,000 linear feet of 48-inch and 54-inch gravity sewer in the lower portion of the Walnut Creek (LWC) sewer basin. The existing reinforced concrete pipe (RCP) was installed around 1975, and closed-circuit television (CCTV) and limited manhole inspections conducted in 2012 indicated that the piping would require immediate attention in the near future due to significant corrosion identified in the majority of the pipe sections.

In order to make an educated and informed decision regarding the best solution for the city and its residents, the CORPUD initiated an evaluation of multiple rehabilitation technologies and methods for large-diameter gravity sewer. The evaluation included four alternatives that involved possible rehabilitation of all or a portion of the existing interceptor, and installation of a parallel gravity main to provide additional capacity. The alternatives were:

1. A single replacement interceptor located in the same alignment as the existing interceptor and sized to carry the entire future flow.
2. A single parallel interceptor replacement sized to carry the entire future flow and abandonment of the existing 48-inch and 54-inch interceptor.
3. Rehabilitation of the existing 48-inch and 54-inch interceptor and construction of a parallel interceptor sized to carry the remainder of the future flow.
4. A combination of Alternative 2 (single, larger parallel interceptor) and Alternative 3 (rehabilitation/smaller parallel interceptor) to address areas with potential constructability issues.

METHODOLOGY

Flow Projections and Future Pipe Sizing

McKim & Creed developed projected flows for the LWC sanitary sewer interceptor based upon year 2040 and anticipated zoning buildout conditions. It was determined to utilize an average daily flow of 16.4 MGD and peak flow of 69.6 MGD (including peaking factor of 4.25) for sizing the sanitary sewer improvements at three-quarters full pipe flow at peak conditions.

Using this flow projection, McKim & Creed anticipated the size of a single replacement sewer pipe in the 66-inch to 72-inch range. If the CORPUD selected rehabilitation, an additional parallel pipe in the 54-inch to 60-inch range would be needed to convey the remaining peak flow at three-quarters full. Ultimately, pipe size selection would be based on finding the best fit for the available slope, stream crossings, and existing utility conflicts within the corridor and the reduction in flow capacity of the existing interceptor due to the rehabilitation method.

Pipeline Condition Assessment

CCTV inspections performed in 2012 indicated that pipe defect scoring ranged from 3 to 5, with the majority of the recorded defects involving some form of surface type degradation. Rehabilitation of several sections of the piping could potentially be deferred for several years, but the cost to remobilize for a later construction effort, coupled with the additional disruption to adjacent property owners, would likely outweigh any financial benefits of delaying the activity. In addition, these isolated repairs would not address potential capacity issues expected in the pipe due to wet weather flow and expected growth in the Walnut Basin.

At the request of the City of Raleigh, McKim & Creed performed limited structural analysis of the existing 48-inch and 54-inch pipes to evaluate the potential for failure from crossing of heavy equipment during the construction of a greenway trail planned by the city. During this analysis, it was determined that the pipe class and the wall thickness of existing reinforced concrete pipe were not known. In addition,
assumptions had to be made that the inner wall of concrete had deteriorated to the inner cage of steel reinforcement (approximately one inch of missing concrete), based upon the surface reinforcement visible in the CCTV inspection reports. This assessment indicated that the presence of deterioration and the minimal soil cover over certain sections could potentially cause the pipe to fail under certain vehicle loading conditions and directions of travel (perpendicular and/or parallel). The results of this analysis highlighted the need for any rehabilitation technology to provide structural integrity independent of the existing host pipe.

**Manhole Condition Assessment**

Thirty-two manholes are present in the LWC sanitary sewer. The majority of these manholes appear to be constructed of brick and have not been rehabilitated. Manholes at the upstream side of the project area are constructed of concrete. Limited inspections on four manholes revealed moderate hydrogen sulfide corrosion in the concrete manholes, and missing mortar in the brick manholes.

**Rehabilitation Technology Evaluation**

Based on the available CCTV inspection data, a rehabilitation technology for the LWC should, at a minimum, provide the following:

- Applicable to the LWC pipe sizes and materials (48" and 54" RCP).
- Corrosion resistance inherent to the rehabilitation technology materials without additives or field-applied coatings or sealants.
- Stand-alone structural characteristics without secondary reinforcement and grouting to achieve the required strength.
- Reduced requirements for manned entry, typically resulting in reduced costs and increased job safety.

McKim & Creed first performed a preliminary evaluation of available rehabilitation technologies to eliminate those that did not meet four minimum criteria and to identify those that warranted additional detailed evaluation. Twelve technologies were reviewed and three were slated for further investigation. Those three were segmented sliplining, geopolymer centrifugal spray-in-place pipe, and cured-in-place pipe (CIPP).

Seven evaluation criteria were then established to further assess the pipe renewal methods. These included:

- Flow capacity and diameter range
- Structural integrity
- Corrosion resistance
- Expected useful life
- Construction factors
- Social costs
- Previous experience with the city

**RESULTS**

The Environmental Protection Agency (EPA) characterizes renewal of gravity sewer mainlines as repair, rehabilitation, or replacement. Repair techniques are generally referred to as spot or point repairs and not applicable to this project. Rehabilitation techniques are defined as those that utilize the existing pipe structure, such as CIPP or spray-in-place pipe. Replacement techniques make no use of the existing pipe.
structure and a new stand-alone pipe is provided, such as slippining. Following are the results of the
detailed evaluation conducted on the three technologies determined to be most appropriate for the LWC
sewer basin.

**Replacement - Segmented slippining**

Slippining is one of the earliest forms of pipeline rehabilitation recorded, with installations dating back to
the 1940s. The process involves installing a smaller diameter carrier pipe within the existing host pipe by
pushing or pulling the carrier pipe into place and filling the annular space between the two pipes with
gROUT. The final product provides a new pipe with adequate structural stability and a projected life
expectancy of between 50-100 years.

There are numerous different types of piping materials that have been successfully used for slippining
applications, with small diameter slippining typically utilizing more flexible materials, (PVC/HDPE), fused
together, and larger diameter typically utilizing more rigid materials (FRP/GRP) of discrete segmented
lengths. Flexible, fused pipe materials are typically not utilized in large diameter applications due to the
space requirements and need for additional pulling mechanisms. Segmented slip lining allows for a
“cartridge style” installation generally requiring less area needed for installation and laydown.

The three generally utilized pipe materials for segmented slippining are glass-reinforced plastic
(GRP)/fiberglass reinforced plastic (FRP), Polypropylene (PP), and PVC (closed profile).

Slippining will require a reduction in the capacity of the pipe, typically approximately 10% smaller than the
host pipe. For 48” and 54” host pipes, new slipline pipes could be in the approximately 36” to 43” and 42”
to 49.50” inner diameters, respectively, depending on the type of pipe material specified. Generally
speaking, at the minimum slopes and using the NCDENR required Manning’s n of 0.013 for design of
wastewater pipes, this reduction in diameter will result in approximately 20-25% less flow capacity.
However, slippining pipe manufacturers indicate that the smoothness of their products (n < 0.011) can
minimize the loss of flow capacity to less than approximately 10%.

Pipe pushing force and push lengths for each type of slippining pipe material are project dependent.
Typically, the GRP/FRP type pipe material allows the greatest allowable pushing forces during the
installation process, which minimizes the potential of joint damage when the carrier piping is pushed into
the host pipe, which corresponds to longer push lengths. Reduced push lengths will increase the need for
multiple insertion points on the majority of pipe sections and potentially increase construction and social
costs. As construction of the push pit and installation requirements are basically the same for each type of
pipe material the primary difference is in the cost of the material itself and the number of installation pits
required. Detailed design of the slippining pipe will dictate the required pipe stiffness class, allowable
pushing forces, and length of slippining that can be achieved. For many of the manufacturers presented,
projects have been completed with push lengths of greater than 1,000 LF. In most cases, CCTV
evaluation of the host pipe for off-set joints, obstructions, and ovality is recommended prior to installation
to identify any issues that could impact the installation of the new pipe.

Grouting is required to seal the annular space between the new, slipline pipe and host pipe. In segmented
slippining, the new pipe is structurally independent from the host; however grouting is required to lock the
pipe in place, prevent flotation, maintain the desired grade, and transfer loads from the host pipe to the
new pipe. It is also important to properly grout the pipe in manholes to minimize groundwater infiltration
into the system through defects in the host pipe.

Another benefit of a segmented installation approach involves the potential to install the carrier pipe
without having to bypass the flow during the slippining installation. Slippining can typically be completed
without bypassing if the host pipe is flowing less than half full. In this case, the pipe is exposed in the pit
and the upper half of the pipe removed allowing the wastewater flow to remain in the lower section of the
pipe. The slipline pipe is then inserted and grouted in place.
The evaluation of this technology produced the following results:

Table 1: Segmented Sliplining

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Sliplining - Segmented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Capacity/Diameter Range</td>
<td>Reduction of pipe capacity of approximately 20-25% based on LWC slope. Diameter reduction of approximately 10% depending on pipe material selected.</td>
</tr>
<tr>
<td>Structural Integrity</td>
<td>Excellent. Structural strength of the slipline pipe is independent of the host pipe.</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>High</td>
</tr>
<tr>
<td>Expected Useful Life</td>
<td>50-100 years</td>
</tr>
<tr>
<td>Construction Factors</td>
<td>May not require bypass pumping. Requires excavation of installation pits depending on material/length of push. Offset joints or other conditions can impact the ability to push the pipe and should be taken into consideration when selecting the slipline pipe size.</td>
</tr>
<tr>
<td>Social Costs</td>
<td>Residents could be impacted by noise and limited access due to staging of equipment. Impact to residences due to excavation of installation pits (access, safety, removal of landscaping).</td>
</tr>
<tr>
<td>Previous Experience with City</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Rehabilitation - Geopolymer Centrifugally Sprayed-In-Place Pipe

The most utilized material for rehabilitating large-diameter concrete pipes and concrete structures is a Portland cement-based cementitious mortar. When working in the wastewater collection/conveyance/treatment arena, the mortar systems generally include admixture materials that are intended to lengthen the life of the repair by combating the effects of hydrogen sulfide gases and microbiologically induced corrosion.

Recent advancements in the development of geopolymer-based materials with anti-microbial systems now provide the wastewater industry with another renewal system applicable for large-diameter piping systems and structures that are subjected to corrosive environments. There are two primary types of geopolymers: phosphate-based and aluminosilicate-based. The aluminosilicate material is the latest to be introduced and contains a combination of silica, alumina and oxygen atoms that, when fully cured, produce a monolithic synthetic inorganic structure that resembles stone or ceramic. The resulting inorganic polymer composite provides strength, corrosion resistance, and flexibility to adhere to many types of substrates, and presents no chemical hazard during or after application.

McKim & Creed conducted a site visit to observe a pipe rehabilitation utilizing EcoCast™ geopolymer that involved the spray cast application of geopolymer in 210 LF of 60-inch corrugated metal pipe (CMP) storm pipe and vertical pond riser at the Keowee Key Golf Course in Salem, South Carolina. The work included bypass pumping of a golf course stream and pond, repair of the pond riser pipe, cleaning of the culvert, hand application of geopolymer to repair heavily deteriorated or missing areas of pipe, and spray cast application of the geopolymer in the culvert and vertical riser.

One available geopolymer, marketed as EcoCast™ by Inland Pipe Rehabilitation (IPR) Company and utilizing Milliken’s GeoSpray™ material, claim better inherent corrosion resistance of the product to primarily Portland cement based mortars due to the reduced porosity of the material and chemical structure. In addition, a field applied anti-microbial treatment, AMS Biokill, is available to provide additional corrosion resistance. For the purposes of the LWC evaluation, the inherent corrosion resistance of the material was evaluated only without the further addition of AMS coating. Since this is a relatively new product in which the City has no prior experience, information on the corrosion resistance of the material and AMS Coating, including research papers and third-party laboratory testing information.
was reviewed. Limited long-term corrosion resistance data exists for current installations of the geopolymer in sanitary sewer environments in North Carolina.

Prior to application of the geopolymer mortar, the substrate of the receiving surface must be free of dirt, roots, grease and debris. Generally high pressure, 3,500 psi, washing is undertaken to ensure the surface is clean and all loose material removed. Access to the piping for application of the material can be gained through a manhole; therefore, it is recommended that a minimum of two sections of piping be bypassed so that one section of piping could be utilized as a staging area during the spray cast process.

Evaluation of the geopolymer technology indicated that, to accurately identify the associated cost for completing rehabilitation of the 48-inch and 54-inch gravity sewers, several key items would need to be evaluated, including:

1. bypassing of wastewater flows if necessary, based on the size of the parallel line,
2. equipment setup for centrifugal casting, and
3. application thickness.

Overall, the results of the evaluation were as follows:

**Table 2: Geopolymer Sprayed-in-Place Pipe**

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Sprayed-In-Place Pipe - Geopolymer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Capacity/Diameter Range</td>
<td>Negligible. Geopolymer application will only be ½-inch thicker than original deteriorated thickness of concrete pipe.</td>
</tr>
<tr>
<td>Structural Integrity</td>
<td>Excellent</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>High, but limited age on existing applications in sanitary sewer</td>
</tr>
<tr>
<td>Expected Useful Life</td>
<td>50-100 years</td>
</tr>
<tr>
<td>Construction Factors</td>
<td>May require bypass pumping of a minimum of two sections of interceptor at a time if parallel line is not available to convey flow. Receiving surface must be cleaned and all loose material removed.</td>
</tr>
<tr>
<td>Social Costs</td>
<td>Does not require excavation pits. Residents could be impacted by noise and limited access due to staging of equipment.</td>
</tr>
<tr>
<td>Previous Experience with City</td>
<td>None</td>
</tr>
</tbody>
</table>

**Rehabilitation - Cured-In-Place Pipe (CIPP)**

CIPP was the initial product utilized for rehabilitating deteriorating utility piping, with the first known installation dating back to 1971. Since its original introduction, it is estimated that approximately 40,000 miles of CIPP liners have been installed worldwide to date. The basic CIPP concept involves impregnation of the felt tube liner, aka “wet-out,” with polyester resin by use of a pinch roller type assembly, with needle felt tubing being saturated at a controlled volume per length of proposed installation. Following wet-out, the tubing is inserted within a host pipe using a column of water that is then recirculated and heated to cure the resin.

A fully deteriorated cured-in-place design of both the 48” and 54” would yield a liner thickness of less than one inch and although there would be a slight reduction in the host pipe's cross sectional area the flow characteristics would most likely be enhanced due to the elimination of existing pipe joints and surface roughness.

Currently there are many variations in method of installation, tube construction, resin systems and curing methods. The following describes the variations for each.

1. Tube Construction
Rehabilitation Or Replacement? That Is The Question

- Resin Felt Composite
- Fiber Reinforced Resin Felt Composite
- Resin Glass Fiber Composite

2. Installation Method
   - Water Inversion
   - Pull-In and Air Inflate

3. Cure Method
   - Hot Water
   - Ambient Air
   - Steam
   - Ultraviolet Light

4. Resin Type
   - Polyester
   - Vinyl Ester
   - Epoxy

Structural enhancements in CIPP lining are more related to resin and tube material changes than installation and cure methods. Improvements/changes in installation method generally dictate the cure method and are completely driven by cost saving advantage. In general, the least costly method of CIPP lining is needled felt with polyester resin that is pulled into place and steam cured. Applications that require styrene free composites, storm water & potable water piping, require use of epoxy resin which generally provide a higher compressive and flexural strength, as well as a higher modulus of elasticity. Although the epoxy resins can be installed with any type of tube, using any cure method, the cost is significantly higher. Although each CIPP product utilizes an interior material that is specifically designed to combat corrosion each of the resin systems inherently are corrosion resistant as well.

Prior to a CIPP liner installation the pipe must be clean and free of all dirt, roots, grease and debris and all flow must be bypassed from the host pipe receiving the liner. In most cases the liner is delivered to the site, via refrigerated truck, ready to install, but in larger diameter installations the “wet-out” occurs on site. This is referred to as “wet-out over the hole”, and understandably includes a great deal of additional installation variables. Larger diameter installations also dictate the use of an inversion based process to mitigate the potential of damage caused by dragging the liner through the host pipe. Many also believe that water inversion provides a better system for keeping the pressure and curing temperature consistent throughout the installation.

A summary of evaluation criteria is provided in Table 3 below.

### Table 3: CIPP

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>CIPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Capacity/Diameter Range</td>
<td>Negligible. CIPP liner will generally replace original deteriorated thickness of concrete pipe and flow characteristics of the pipe will be enhanced with reduced roughness and elimination of joints.</td>
</tr>
<tr>
<td>Structural Integrity</td>
<td>Excellent</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>High</td>
</tr>
<tr>
<td>Expected Useful Life</td>
<td>50-100 years</td>
</tr>
<tr>
<td>Construction Factors</td>
<td>Onsite wet-out will significantly affect the cost of installation. May require bypass pumping if parallel line is not available to convey flow.. Receiving surface must be cleaned and all loose material removed.</td>
</tr>
<tr>
<td>Social Costs</td>
<td>Does not require excavation pits, however due to the size of the CIPP liner tops of manholes will need to be removed. Residents could be impacted by noise and limited access due to staging of equipment.</td>
</tr>
<tr>
<td>Previous Experience with City</td>
<td>Yes (smaller diameter applications)</td>
</tr>
</tbody>
</table>
DISCUSSION

The analysis revealed that each of the three types of products/installation processes evaluated could be successfully employed on the LWC project. All of the products provide corrosion resistance, and have design life estimates of 100 years. When evaluating the soft costs associated with each option, the commonality that exists is the need for accessing the piping to install any of the products. While the sliplining approach requires the most excavation, both the geopolymer and CIPP liner installation processes also require limited excavation. These techniques also require flow bypass, unless the parallel conveyance piping is installed prior to rehabilitation, which would dramatically reduce the overall installation cost.

The geopolymer and CIPP liner approaches offer the best solution from a hydraulic standpoint, as they would require a slight reduction in the overall pipe cross-sectional area and would maintain roughness coefficients equal to any of the other processes. Geopolymer products have limited long-term data available on corrosion resistance in sanitary sewer environments, though available lab data indicates that the material has a high corrosion resistance. In addition, the City has limited experience with geopolymer products and there are limited applications of the relatively new product in North Carolina.

CONCLUSIONS

Evaluation of three rehabilitation technologies indicated that each of the three methods is applicable to the LWC project and has unique qualities that may be beneficial. Based on presentation of the results and discussions with CORPUD, the client selected CIPP and segmental sliplining with fiber reinforced plastic/glass reinforced plastic (FRP/GRP) pipe to be further evaluated for applicability and cost in this particular situation.

Analysis of the four alternatives involving rehabilitation of all or a portion of the existing interceptor indicated that Alternative 2—a single parallel interceptor replacement sized to carry the entire future flow and abandonment of the existing 48-inch and 54-inch interceptor—offers the most viable and economical solution for the CORPUD. This is due to the fact that the parallel line sizes required for rehabilitation of the existing interceptors were only one to two typical pipe diameters smaller than the single replacement line, and the capital and social cost incurred to install the parallel lines in addition to rehabbing the existing lines outweighed the cost of a single replacement line.

The Lower Walnut Creek Interceptor replacement is currently under design.