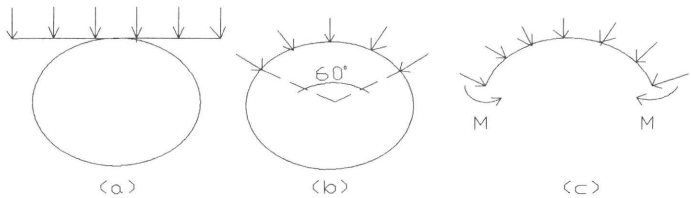

Figure 2: Distribution of Traffic Load on Manhole Structure

The critical load for a uniformly loaded circular arch, as defined in Equation 12,

$$w_t = \frac{E_L I}{R^3}\left(k^2 - 1\right) \text{ N/mm} \qquad \text{(Young)} \quad (12)$$

can be solved for t_t to determine the required thickness to prevent buckling.

$$t_t = \sqrt[3]{\frac{w_t R^3}{6.10 E_l (1mm)}} \text{ mm} \qquad (13)$$

The thickness required to withstand a wheel load that is directly applied to the vertical axis of the manhole can be determined with Equation 14.

$$t_a = \sqrt{\frac{P}{1.74 E_l \cos^2 \alpha}} \text{ mm} \qquad \text{(Young)} \qquad (14)$$

Safety and Impact Factors

None of the methodologies discussed thus far include safety or impact factors. Work with reinforced concrete pipe suggests an appropriate safety factor ranges from 1.3 to 1.5 (Moser 1990). These factors should be applied to anticipated hydrostatic pressure, soil pressures, and traffic loads.

Impact factors account for the dynamic nature of traffic loads and need to be applied only to non-symmetric loads acting on the manhole. Impact factors in Table 1 were developed for horizontal pipe beneath a road but should be suitable for this application.

Table 1: Impact Factors for Cementitious Liner Design

Depth of Cover (mm) H	Uni-Bell Handbook (Moser 1990) I_f
0 < H < 304.8	1.50
304.8 < H < 609.6	1.35
609.6 < H < 914.4	1.15
914.4 < H	1.0

Comparative Evaluation

Figure 3 is a comparison of lateral stresses estimated by the methods previously described. The example is for a 86,539 N wheel load over a 254mm x 508mm area located at the edge of a manhole. The pavement structure is 304mm of portland cement concrete over a sandy soil unit weight = 1.75×10^{-5} N/mm^3. Friction angle of soil = 35°. Impact factors varied with depth according to Table 1 and SF = 1.3 was used.

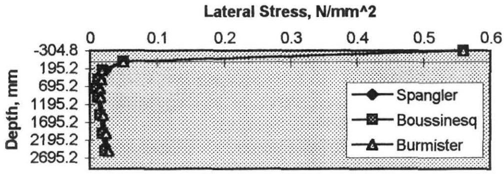

Figure 3: Lateral Stress from Soil and Traffic Loads

Conclusions

Results in Figure 3 show that for this example, the method of calculation makes little difference. Two solutions based on elastic theory produce results equivalent to that of classical and experimental soil mechanics.

List of Variables

a = Radius of circle with area equal to that of tire contact area, mm
A = Contact area of wheel used for traffic loading, mm^2
A_2 = Area of wheel load at pavement-soil interface, mm^2
c= Vertical stress influence coefficient
c_u = drained soil cohesion, N/mm^2
d_{cr} = critical depth of an unbraced cut, mm
E_l = Young's Modulus of the liner material, N/mm^2
h = Thickness of pavement layer, mm
h_a = Lateral unit pressure at a given point, N/mm^2
h_c = Lateral pressure, N/mm^2
H = Depth of cover, mm
I = Moment of inertia of structure about axis perpendicular to plane of buckling
I_f = Impact factor
k = constant = 8.62
K_o = Rankine at-rest lateral stress coefficient
p = Pressure applied to pavement by wheel, N/mm^2
p_a = Pressure at pavement-soil interface, N/mm^2
P = Wheel load, N
R = Radius of pipe or liner, mm
R_l = Radial distance from point load to point of interest, mm
R_{x1} = Radial distance from point on manhole to near side of load, mm
R_{x2} = Radial distance from point on manhole to far side of load, mm
r = Horizontal radial distance in xy-plane from wheel load to given point, mm
t = Thickness of pipe or liner, mm

t_a = Thickness required to withstand axial loading, mm
t_t = Required liner thickness for traffic load, mm
w_t = Critical load for a uniformly loaded circular arch, N/mm
x = Distance along x-axis from wheel load to given point, mm
x_1 = Horizontal distance from manhole to near side of load, mm
x_2 = Horizontal distance from manhole to far side of load, mm
y_1 = Length of loaded area, mm
z = Distance along z-axis from wheel load to given point, mm
α = Angle at intersection of manhole vertical axis and slope of the cobel
ϕ = Drained angle of internal friction, degrees
γ_s = Soil unit weight, N/mm^3
v_s = Poisson's Ratio of soil
σ = Stress, N/mm^2
σ_1 = Horizontal stress, N/mm^2
σ_2 = Vertical stress, N/mm^2
$\sigma_{buckling}$ = Buckling strength of a structure, N/mm^2
σ_h = Lateral stress as determined by the Boussinesq solution, N/mm^2
σ_s = Lateral soil stress, N/mm^2
σ_z= Vertical stress, N/mm^2

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Innovative Methods for Rehabilitating Sanitary Sewer Service Laterals

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Abstract

This paper discusses two trenchless installation methods for rehabilitating gravity sanitary sewer service laterals. The methods discussed include pipe bursting and the cured-in-place liner installation processes. The paper identifies the procedures necessary for completing the rehabilitation and benefits associated with its implementation.

Introduction

The City of Norfolk, Virginia has one of the most aggressive sanitary sewer rehabilitation programs in the nation. The City's Department of Utilities manage the projects and annually allocates in excess of 15 million dollars to remediate wastewater collection system deficiencies and eliminate extraneous volumes of groundwater infiltration and stormwater inflow. While several ongoing projects have been mandated by the State of Virginia's Department of Environmental Quality, due to illegal discharges (overflows) of wastewater into state waters, the majority of the projects have been scheduled as part of a preventive maintenance program. The areas of the City in which the rehabilitation projects are scheduled are prioritized based on the age and condition of the gravity sewers. Of the 840 miles of sewer main within the City, the Department of Utilities has rehabilitated, or is in the process of rehabilitating, approximately 95 miles of piping. While their program has been under way for only 6 years the results achieved to date have had a great impact on the overall system operations.

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Because of the City's aggressive attitude concerning rehabilitation of its wastewater infrastructure many state-of-the-art techniques for performing sewer rehabilitation have been initiated on their projects. This paper discusses a recent project, West Ghent Sanitary Sewer Rehabilitation, in which several innovative methods for rehabilitating service lateral piping has been implemented.

Project History

The West Ghent Sanitary Sewer Rehabilitation project first began as an Inflow/Infiltration (I/I) Analysis of the wastewater collection systems within the neighborhood and then developed into a Sewer System Evaluation Survey (SSES). Based on the identification of excessive I/I and structural deficiencies with the 70 year old collection system infrastructure a rehabilitation program for the entire gravity piping systems within the neighborhood was established.

Because the City of Norfolk, Department of Utilities had recently completed the entire renovation of the neighborhood's water distribution system it was determined that any proposed rehabilitation to the sanitary sewer system would encompass all piping within the City's right-of-way. These improvements entailed rehabilitation, or replacement, of the sewer mains, property line cleanouts and all service laterals located on City property.

The West Ghent neighborhood was constructed in the 1920's and much of the original wastewater conveyance system was installed at that time. The collection system piping consisted primarily of vitrified clay and terra cotta materials, and the manholes are of brick and mortar construction. The gravity piping ranges in size from 6-inch to 15-inch diameter and conveys the wastewater discharged from approximately 785 single family houses, several duplexes and apartment buildings, an elementary school, churches, and a few small businesses. The neighborhood was developed around the original Norfolk and Western (Norfolk Southern) Railroad terminal building and coal loading piers and many of the original inhabitants worked for the railroad. The majority of the buildings in the neighborhood have basements with plumbing connections for laundry discharge making the service lateral fairly deep below existing ground elevations. This condition compiled with the use of granite curbing which is difficult to remove, and size and age of trees within the City's right-of-way make replacement of the service laterals within the right-of-way difficult.

The construction bid documents for the project were assembled in a manner which allowed the contractor to bid either open cut excavation and replacement of the laterals or rehabilitation using a pre-approved 'No-Dig' lining process. The low bid contractor for the project originally bid the public lateral portion of the project as open cut excavation, but then provided the City an option of trenchless rehabilitation. The methods presented to the City for review included a cured-in-place lateral lining system and a replacement system utilizing the pipe bursting technology. Table 1 describes the various components and magnitude of the project and highlights the extent of service lateral rehabilitation.

Sewer Main Replacement		
Size(Inches)	**Length(Feet)**	**Cost**
6,8,10,12&15	16,575	$764,685
Sewer Main Rehabilitation		
Size(Inches)	**Length(Feet)**	**Cost**
8,10,12&15	18,859	$863,697
Sewer Lateral Replacement/Rehabilitation		
Size(Inches)	***Length(Feet)***	***Cost***
4&6	25,545	$1,190,000

Table 1.

The contractor's recommendation as to which rehabilitation system would be used on individual laterals was based primarily on the new piping material of the sewer main. If the sewer main was part of the replacement activities, and a new PVC sewer had been installed, the lateral rehabilitation was recommended to be a cured-in-place liner. If the sewer main was rehabilitated using a cured-in-place liner then the lateral was recommended to be rehabilitated in the same manner. Pipe bursting of the existing laterals was only recommended when the sewer main was rehabilitated using a deformed/reformed polyethylene liner.

Prior to the actual insertion of the cured-in-place liner the contractor was required to clean and TV all laterals to ensure that the process could achieve the specified rehabilitation results. If the lateral had joint offsets, root intrusions, or other miscellaneous defects, which would result in a significantly reduced cross sectional area after lining, the lateral rehabilitation would be defaulted to pipe bursting. The only recorded limitation of the pipe bursting activity was the inability to burst through cast iron 90 degree fittings. The following paragraphs describe in detail the preparation required for each rehabilitation technology and the actual installation process.

Pipebursting Laterals

Preparatory work included marking the underground utility locations adjacent to the sewer main and the property line cleanout. Once all utilities were identified excavation at the main and at the property line were made. The pipe bursting equipment, pipe and pipe fittings were then mobilized to the excavations. The contractor then disconnected the lateral at both the property line and at the main and the bursting cable was pulled through the lateral to be bursted. Any necessary dewatering equipment was then placed in service and the contractor began the pull. Figure 1 shows the polyethylene lateral being pulled to the main through the access pit at the property line.

Figure 1. Polyethylene Lateral

When the lateral is pulled to the main the bursting head is removed from the lateral and the contractor would then breakout the host pipe to expose the polyethylene liner. The new polyethylene lateral was then joined to the main utilizing an electrofusion polyethylene saddle and necessary electrofusion fittings. Figure 2 shows the final connection to the main with the saddle already connected and the lateral piping being joined to the saddle utilizing an electrofusion fitting.

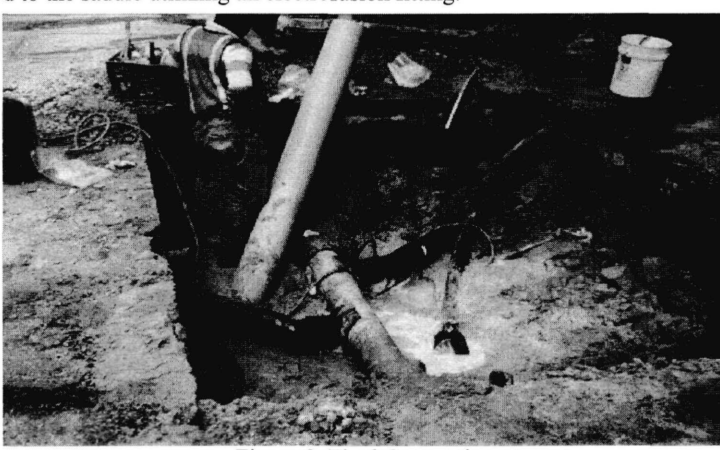

Figure 2. Final Connection

Final connection at the property line entailed the use of a PVC wye and dresser couplings and installation of a new property line cleanout.

The piping/fitting material specifications are listed in Tables 2 and 3:
Pipe: Plexco PE 3408 HDPE (SDR 17)

Property	Unit	Test	Typical Value
Material Designation	---	PPI/ASTM	PE 3408
Material Classification	---	ASTM D-1248	III C 5 P34
Cell Classification	---	ASTM D-3350	345434C
Density [3]	g/cm^3	ASTM D-1505	0.955
Melt Index [4]	g/10 minutes	ASTM D-1238	0.1
Flexural Modulus [5]	MPa	ASTM D-790	917
Tensile Strength [4]	MPa	ASTM D-638	22
ESCR [3]	hours	ASTM D-1693	> 5000*
HDB [4]	MPa	ASTM D-2837	11
UV Stabilizer [C]	% Carbon Black	ASTM D-1603	2 to 3
Elastic Modulus	MPa	ASTM D-638	758

* Test discontinued after 5000 hours non-failure.

Table 2.

ElectroFusion Fittings:Central Plastics PE 3408

Property	ASTM Test Method	NominalValue
Density, gm/cc	D-1505	0.955
Melt Index, gm/10 min	D-128-E	0.12
High Load Melt Index, gm/10 min	D-1238-F	15.0
Tensile Strength @ Break, MPa @ Yield, MPa	D-638	 31 12
Elongation, %	D-638	>800
Flexural Modulus, MPa	D-790	827
Environmental Stress Cracking	D-1693	
Shore D Hardness	D-2240	68
Hydrostatic Design Basis @60°C, MPa @23°C, MPa	D-2837	 4 11
Notched Iod Impact (ft.-Lb/in)	D-256	6.0

Table 3.

As the contractor established a system for bursting the laterals, production generally varied from 4 to 8 per day, and each lateral service was usually reinstated within 2 hours of the initial disconnection from the main. The property line cleanout was installed during this time, and the site restoration was completed shortly thereafter. The excavation at the main was then backfilled and compacted and a temporary pavement patch placed to match the existing pavement elevation. If the contractor was able to expose more than one lateral at the street excavation production increased dramatically as the majority of time and effort was associated with exposing the connections at the main. In many cases connecting laterals for houses on either side of the street were in the same vicinity, and contractor was almost able to double his lateral installation production.

At the beginning of the project the contractor developed an elaborate winch system for pulling the bursting tool, but by the end of the project the bursting was being accomplished primarily by backhoes and the winch system was used only for the bursting of the laterals which were constructed of cast iron.

Cured-In-Place Laterals

Preparatory conditions were very similar as the pipe bursting method except access was only required at the property line. The existing utilities in the area were marked, and the excavation pit was dug. The existing lateral is then accessed and cleaned of all debris, roots, and other materials which would block the inspection of the piping. Portable CCTV equipment was then used to ensure in fact that the lateral could be lined. The resin impregnated ambient cure liner bag is kept at the site in a refrigerated truck where it remains until it is ready to be inserted. A CCTV inspection truck is located over an adjacent manhole, and the camera unit is inserted into the sewer main and is focused where the liner will enter the main. A compressor, pressurized blower and rubber inflatable bladder is mobilized next to the excavation pit.

At the excavation pit, a two foot section of the existing lateral is cut out and removed where the cured-in-place liner will be inserted. If the existing cleanout is to be replaced, the cuts are made on both sides of the cleanout where it connects to the lateral.

Depending on the depth of the lateral and the elevation of the water table, a dewatering pump maybe used. The liner is then impregnated with resin at the site within the refrigerated truck in what is described as a wet-out procedure. At this time the resin is injected into the center of the liner and then rolled throughout the liner to ensure complete saturation. The wet-out procedure is generally completed just prior to the installation.

A flexible fiberglass rod is then inserted into the lateral at the excavation pit and pushed towards the main line connection. The camera operator in the TV truck signals when the rod tip reaches the main. This method is used to measure the exact length of the lateral so the liner bag can be cut to the proper length. The next few steps must be completed very quickly as the impregnated liner begins to cure once it is exposed to sunlight. The resin impregnated liner is unloaded from the refrigerated truck and cut to the proper length. The impregnated liner is either pushed with rods, or pulled by cable, into place and is positioned so that the "cuffed" resin rich end is flush with the inside of the main. The camera operator signals when it has reached the main line.

A calibration hose (bladder) is inverted by air into the liner by the blower expanding the bladder and molding the liner to the host lateral piping. Ambient air is provided by the blower at approximately 10 psi, and the liner is cured for approximately 30-45 minutes. After the lateral is cured, the bladder is deflated and removed from the lateral. Figure 3 shows the blower inverting the bladder into the liner.

Figure 3. Inverting Bladder

After the curing process is completed, the next step is to reinstate the lateral connections. At the excavation pit PVC pipe and fittings along with Dresser Couplings are installed to replace the previously removed section of existing lateral. If the cleanout was removed, a PVC wye is installed to accommodate the new cleanout. Inside the sewer main the protruding liner is cut off flush using a remote control robotic cutting device. After these two connections have been made, the lateral is in service. Excluding any unforeseen delays, the total amount of time a resident will be without sewer service is approximately 2 hours.

When the lateral is placed back into service, back of the excavation pit is backfilled. The backfill material is carefully tamped in around the lateral and cleanout in 12 inch layers, to reduce settlement and stabilize the cleanout, until it is brought up to existing