

Slipline Rehabilitation of Watermains with High-Density Polyethylene Pipe

By Jack Q. Zhao

Sliplining is a trenchless pipe rehabilitation technology that offers many advantages compared with traditional open-cut and cover methods. This Update presents information on sliplining installation, performance and cost, based on recent work at NRC's Institute for Research in Construction.

Sliplining is a method for rehabilitating buried pipelines (water, sewer and gas) by pushing and/or pulling a new liner pipe into the existing pipe.¹ It does not require excavation except at selected locations and therefore it offers many benefits compared with replacement or repair using the open-cut and cover method (less traffic disruption, less disturbance to the environment, and less disruption for the public).



Figure 1. Watermain slipline rehabilitation, Gloucester Street, Ottawa

For example, the slipline rehabilitation of a 915-mm diameter watermain under a street in Ottawa in 1999 was hardly noticeable to the public, except at installation pits and material stockpile areas (Figure 1).

This Update focuses on the slipline rehabilitation of watermains with high-density polyethylene (HDPE) pipe with grouting of the annular space between the liner and the host pipe. It is intended to help municipal engineers achieve durable and economical pipeline rehabilitations.

Slipline Design

Flow Capacity

One of the major factors to be considered in the design of slipline rehabilitations is flow capacity. The outside diameter of the liner pipe is usually at least 10% smaller than the inside diameter of the host pipe. Therefore the flow area, A_L , of the rehabilitated pipe is smaller than the original flow area, A_H . The flow capacity of the liner increases as the dimension ratio (the ratio of its outside diameter to its thickness) increases (Figure 2). Because the liner pipe is usually smoother than the host pipe, the capacity reduction due to reduced flow area may be somewhat offset by less flow resistance.

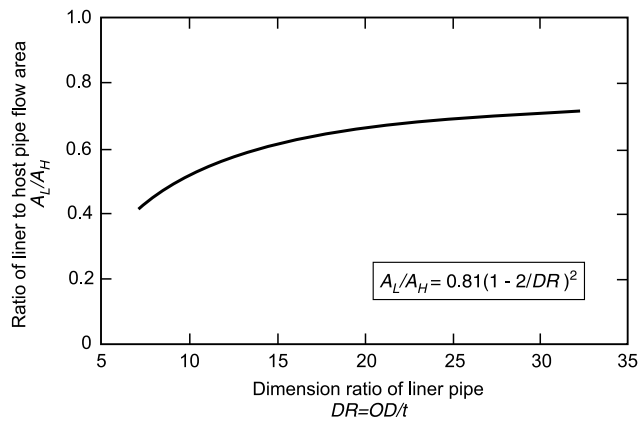


Figure 2. Effect of liner dimension ratio on flow area reduction

Loads

Another major consideration is the extent to which the liner must be capable of resisting soil and surcharge loads. Although a watermain is subjected to both internal hydrostatic and external soil loads, the external loads are resisted by the host pipe, both before the installation of a liner pipe and after the sliplining, for as long as the host pipe retains its integrity. The liner pipe in an ungrouted sliplined watermain is subjected only to the internal and external hydrostatic loads. In the grouted case, the internal and external loads are distributed to the host pipe, the grout ring and the liner pipe according to their relative stiffness. (This does not apply to the liner pipe in installation pits where sections of the host pipe have been removed to facilitate insertion and connection of the liner). Research is continuing so as to determine the duration and extent to which the host pipe can be relied upon to resist external loads.

Joints

The ease with which HDPE pipe can be butt-fused into long sections makes it ideal for sliplining. Properly made butt joints are as strong as areas of the pipe without joints. However, adverse field conditions (for example, rapid cooling, dust, moisture) can impair joint strength. Fusion-joining procedures² must be followed carefully and it must be verified that the joining machine heater plate is clean and functioning properly for each joining session.

Quality control and testing of completed joints is also required. Independent inspectors should be engaged to test butt-joint specimens using acceptance criteria similar to those established in a recent IRC study.³ There is presently a lack of consistent quality control measures for field fusion-joining and IRC is working to address this deficiency.

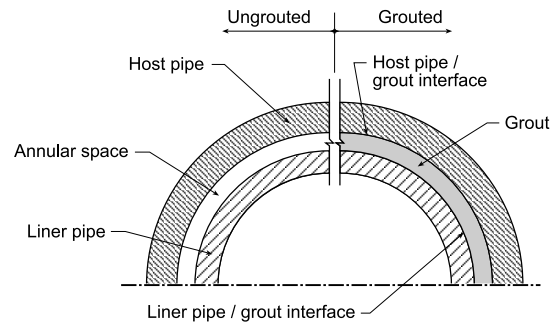


Figure 3. Grouted and ungrouted annular spaces

Other types of joints (for example, flanged joints) are necessary for certain configurations or for pipe segments that meet in installation pits. For flanged joints, T-connections, lateral connections and connections to valves or other types of pipe materials, it is essential to use fasteners and materials that will be at least as durable as the HDPE liner pipe.

Factors Affecting the Strength of Sliplined Pipes

Grouting

The annular space between the host and liner pipes may or may not be grouted (Figure 3). Although the effects of grouting are not fully understood, grouting has the following benefits:

- increased resistance to buckling when the pipe is dewatered
- increased resistance to shear failures at lateral connections
- enhanced protection of the liner pipe in the event of host pipe failure
- longer service life of the liner due to load sharing⁴

It is common to design the liner pipe structurally as though the host pipe and the grout make no contribution to resisting loads.⁵ This approach assumes full deterioration of the host pipe. In reality, a watermain is rehabilitated long before full deterioration occurs. The decision to rehabilitate usually depends on whether or not the break rate has passed a set tolerance level (for example, three breaks/km/year). Even when the tolerance level is exceeded, the pipe is only partially deteriorated.

The rupture strength of a grouted sliplined pipe depends on the contribution of the host pipe, the grout, and the liner. The strength of the grout has a significant effect on the rupture strength⁴ of the composite pipe. The strength of the rehabilitated pipe increases as the strength of the grout increases (Figure 4).

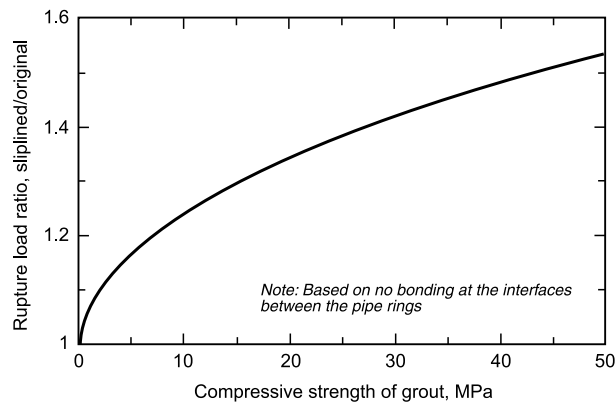


Figure 4. Effect of grout strength on pipe rupture strength

Bonding of the Grout to the Pipe Surfaces

Bonding at the interfaces between the host, grout and liner rings (Figure 3) determines how the three rings in a sliplined pipe will behave structurally. If there is full bonding, there will be no movement or separation of the rings at the interfaces, resulting in a so-called composite pipe. Fully unbonded interfaces mean the rings act individually but interact with one another (this is also called a pipe-within-a-pipe system⁶). The fully bonded and the fully unbonded cases represent the best and the worst, respectively, in terms of structural performance.

Bonding at the interface of a rusted cast iron host pipe and the grout is much higher than at the HDPE pipe-grout interface. Innovations for increasing bonding and friction at HDPE pipe interfaces, such as profiles on the liner pipe exterior, are becoming available.

Eccentricity

Unless spacers are inserted at regular intervals, the liner and the host pipes are usually eccentric (Figure 5). Although it might seem that eccentricity would negatively affect the ability of the host, grout and liner rings to act as a uniform, composite section, a recent study shows that

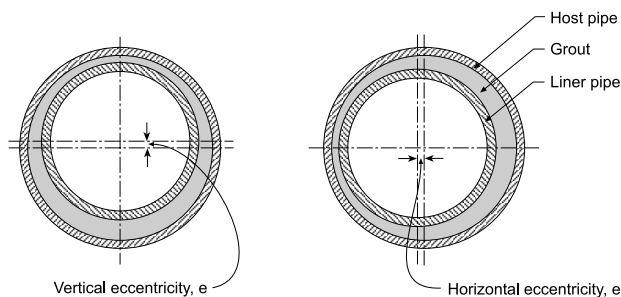


Figure 5. Slipliner eccentricity in vertical and horizontal directions

eccentricity does not necessarily reduce strength.⁷ Horizontal eccentricity enhances the pipe's performance in terms of decreased stresses and deformation under external loads for both fully bonded and fully unbonded cases.

Sections in Trenched Zones

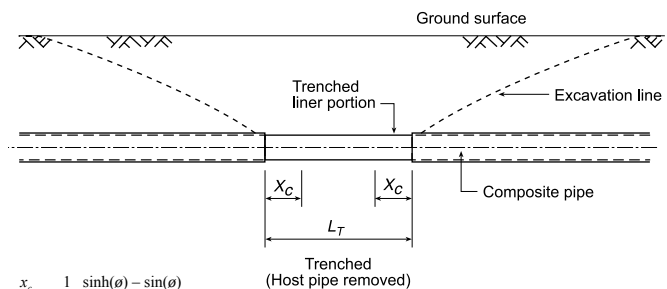
Due to installation needs, there are always sections of the liner that are direct-buried. For instance, excavation is the only installation option at locations such as:

- connections of two segments inserted from opposite directions
- T-connections, elbows or abrupt changes in direction or elevation
- connections between two different sizes or different pipe materials

At such locations, the loading on the liner pipe changes so that it includes not only the internal hydrostatic load, but also the full exterior soil and surcharge loads. It may be more cost effective to strengthen those trenched sections at isolated locations than to strengthen the entire liner pipe length. Moreover, a recent study⁸ defines a critical zone, X_c , at each end of the trench section where joints should be avoided because of the high moments and shear forces (Figure 6). The length of the critical zone is determined by the quality of bedding, the pipe's stiffness, and the length of the excavation.

Cost

The total cost for watermain rehabilitation includes both direct costs and social costs (which are difficult to quantify) resulting from traffic delays, public inconvenience and



$$\frac{x_c}{L_T} = \frac{1}{2\sigma} \frac{\sinh(\sigma) - \sin(\sigma)}{\cosh(\sigma) - \cos(\sigma)}$$

$$\sigma = L_T \sqrt{\frac{k}{4EI_x}}$$

Where:

- L_T is the trenched length of the liner pipe (host pipe removed) (m)
- k is the stiffness modulus of the elastic soil foundation (kPa)
- E is the modulus of elasticity of pipe (kPa)
- I_x is the moment of inertia of the liner pipe cross-section (m⁴)

Figure 6. Critical zones in the trenched portion

effects on the environment.⁹ Based on published cost data of sliplining projects¹⁰ in North America, the direct cost of watermain slipline rehabilitation can be estimated using the following equation:

$$C = 1.18D^{1.053} L^{0.944}$$

Where:

C is the direct cost (Canadian \$)

D is the diameter of the liner pipe (mm)

L is the total rehabilitation length (m).

Summary

Sliplining with HDPE pipe is an effective watermain rehabilitation method. This Update presents new information about sliplining summarized as follows:

- Liner flow capacity increases as the dimension ratio (DR) of the liner increases.
- The host pipe and the grout help to resist the soil and surcharge loads, and the structural performance of the sliplined pipe depends on the bonding at the interfaces of the pipe rings.
- Butt-fusion is an important feature of HDPE pipe but acceptable joining procedures must be followed and quality assurance procedures should be instituted to ensure joint integrity.
- Flange and other types of joints need to employ materials and methods at least as durable as the HDPE liner.
- Trenched sections expose the liner pipe to sudden load changes. There is a critical zone at both ends of trenched sections where joints should not be situated.
- Historical North America sliplining data have been used to develop a means for estimating the cost of slipline rehabilitation.

Further research on slipline rehabilitation is underway to quantify the benefits of grouting and the effects of eccentricity. A better understanding of these subjects will further increase performance prediction and economy.

References

1. ISTT/WRC. Trenchless technology database. The International No-Dig Multimedia CD-ROM, Version 1.0. International Society for Trenchless Technology, London, UK, 1996. <http://www.istt.com/>
2. The Plastics Pipe Institute, a Division of The Society of the Plastics Industry, Polyethylene Joining Procedures, Washington, DC, 1998.
3. Zhao, J.Q., Daigle, L., and Beaulieu, D., Effect of joint contamination on the quality of butt-fused HDPE pipe joints, Canadian Journal of Civil Engineering, Vol. 29, No. 5, pp. 787-798, 2002.
4. Zhao, J.Q., and Daigle, L., Structural performance of sliplined watermain, Canadian Journal of Civil Engineering, Vol. 28, No. 6, pp. 969-978, 2001.
5. Hickie, J.E., and Glasgow, K.L., Design and installation of large diameter slipliner pipe in Lakeland, FL. Proceedings of Trenchless Pipeline Projects: Practical Applications, Boston, MA, June 8-11, pp. 382-389, 1997.
6. Water Research Centre, Sewerage rehabilitation manual, Third Edition, Wiltshire, UK, 1994.
7. Zhao, J.Q., Daigle, L., and Rajani, B.B., Effect of eccentricity and bonding on behaviour and performance of sliplined pipe, submitted to Tunnelling and Underground Space, 2003.
8. Zhao, J.Q. and Doherty, I.J., Behavior and performance of liner pipe in trenchless and trenched portions of sliplining rehabilitation, submitted to No-Dig 2003 Conference, Las Vegas, NV, April, 2003.
9. McKim, R.A., Bidding Strategies for Trenchless Technologies, Cost Engineering, Vol. 40, pp. 37-41, 1998.
10. Zhao, J.Q. and Rajani, B.B., Construction and rehabilitation costs for buried pipe with a focus on trenchless technologies, Research Report No. 101, Institute for Research in Construction, National Research Council of Canada, 37p., 2002.

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