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Effect of close-fit sliplining on the hydraulic capacity of a pressurized pipeline

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Abstract

A full-scale laboratory testing setup was used to examine the flow conditions through a new steel pipe with relatively smooth interior (no tubercles, encrustations, holes, scales, etc.) before and after sliplining with a high density polyethylene (HDPE) liner. Results of the tests indicate that the relative roughness of the lined pipe section was generally lower than that of the new steel pipe at Reynolds Numbers of 200,000 to 500,000. The average friction factor (Swamee–Jain) for the lined pipe was 0.0180 compared to 0.0185 for the original steel pipe. The minimum and maximum friction coefficients were 0.0146 and 0.0208 for the lined pipe and 0.0148 and 0.0241 for the new steel pipe, respectively. This indicates that a deteriorated pipe with significant roughness could be restored back to its original condition using close-fit sliplining. Meanwhile, installation of the 6.35 mm (1/4 in.) thick liner in the 152.4 mm (6 in.) pipe reduced its cross-sectional flow area by about 16% and, accordingly, would decrease the flow by about 20% under the same head loss. To further explore this condition, two design parameters, the liner thickness and its buckling resistance, were examined analytically using a practical application of 152.4 mm (6 in.) pipeline with an internal negative pressure due to a water hammer. Results of the analysis indicate that a 3.4 mm (1/8 in.) thick HDPE liner with average quality installation would provide about 100 kPa (≅ 10 m or 33 ft water column) of buckling resistance, but would also reduce the flow capacity by about 12.7%. While the laboratory tests were only performed on one type of liner material (i.e., HDPE), the general concepts and findings of this study would apply to other types of polymeric liners.

Keywords: Trenchless technology; Friction; Head loss; Liners; Close-fit sliplining; Buckling

1. Introduction

Aging infrastructure has become the most intriguing challenge facing modern societies. Most metropolitan infrastructure facilities were constructed decades ago and continue to serve larger communities with little or no maintenance. Years of use and neglect have left their marks on virtually every aspect of these urban lifelines. The out-of-site/out-of-mind attitude adopted for maintenance and repair of many of these systems have left entire networks in serious need for repair. Unfortunately, the need for such repair comes when cash-strapped towns and cities across America are scrambling to allocate adequate funding to maintain their daily operations along with major reconstruction programs (ASCE, 2003).

A recent survey (USEPA, 2003) indicates that water authorities need to invest $83.2 billion by 2018 to improve the nation's drinking water distribution infrastructure, which accounts for over 55% of the total water infrastructure investment needs nationwide. At least $65.6 billion is needed immediately to rehabilitate or replace pipes for adequate protection of public health. As municipalities modernize their treatment

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capability, they are becoming increasingly aware of the need to upgrade their distribution systems so that they can reliably deliver safe drinking water. EPA estimates that water transmission and distribution infrastructure needs will be even greater after 2019 as more pipes and valves reach the end of their useful life.

Rehabilitating and replacing transmission and distribution infrastructure can be costly because of the difficulty in accessing underground pipes and valves. The majority of water mains and service pipe replacement is typically performed using open-cut or trench methods (Boyd et al., 2001; Kirmeyer et al., 2000; Deb et al., 1999; Heavens, 1999). These methods impose public burden both in terms of cost and nuisance. Trenchless, or no-dig technologies are relatively new techniques used to replace or rehabilitate water distribution systems. More water authorities across the country are considering recent advances in trenchless technologies because they minimize the need for excavation and can save up to 20–60% of the overall cost (USEPA, 2003). Several trenchless technologies are currently available and new technologies are being developed to meet the needs of the industry.

For drinking water pipeline utilities and applications, trenchless technologies can be classified as either pipe replacement or rehabilitation techniques (NASTT, 2003; Kirmeyer et al., 2000; Boyd et al., 2000a,b; Deb et al., 1999). Pipe replacement techniques include replacement along new routes (e.g., horizontal directional drilling, impact moling, etc.) and replacement along existing routes (e.g., pipe pulling, pipe bursting, etc.). Pipe rehabilitation techniques include cement mortar lining (reinforced or un-reinforced), cured-in-place-pipe (CIPP), epoxy resin lining, woven hose lining and close-fit sliplining (spiral wound, fold-and-form, deformed-reformed, etc.). Each technology has its own merits depending on existing site conditions.

Trenchless technology is not a panacea for any water rehabilitation project. Many processes rely, at least partially, on the structural integrity of the existing pipeline to resist loads. Resistance to internal pressure (transported fluid) and external pressure (groundwater, soil, traffic, etc.) are the main factors to be considered in the design of liners for water distribution systems. A liner installed in a pressurized system should withstand hoop stresses due to internal pressure and pressure exerted by external loads (International Standard Organization R161-1960, Chunduru et al., 1996). Consequently, an optimum ratio of liner diameter to its thickness (DR) is required to provide adequate structural resistance with an acceptable reduction in flow capacity.

This paper addresses capacity concerns in water distribution pipelines. It involves the specific application of close-fit sliplining, which entails a number of processes where a liner pipe is inserted into an existing line by pulling or pushing continuous or short length pipes of slightly smaller diameter into a deteriorated pipeline (ASCE/WPCF, 1983). Through laboratory experiments, this work examines the head losses, friction factors and relative roughness parameters associated with a section of a steel pipe before and after lining with a HDPE liner. At issue is the claim that the smoother inside surface of the lined pipe would result in lower friction losses and, thereby, offset the reduction in flow associated with the reduced cross-sectional area due to liner thickness. While testing on a relatively new steel pipe with a smooth interior wall, this research does not address the effects of tubercles, encrustations, scales, etc. that may be typically seen in a deteriorated pipe. Accordingly, there was no need to clean the interior of the test pipe before installation. It should be noted that, flow capacity difference between the lined and unlined pipe may substantially vary depending on the initial condition of the host pipe, and the quality of installation.

Selection of a liner for use in a given rehabilitation project depends on several parameters including its buckling resistance, which is a function of liner thickness, and applied external pressure. Wall buckling resistance of a liner is also critical with regard to installation conditions and possible negative internal pressures due to a water hammer, whereas excessive wall deformation may produce partial or complete loss of flow capacity (Bakeer et al., 1999). However, the capacity of the liner is also affected by the roughness of the liner and its thickness. Hence, an analysis of the efficacy of liner thickness relative to external buckling pressure is briefly examined in this paper for the purpose of illustration.

2. Analytical background

Design of closed-conduit pressurized pipelines, such as water supply networks, requires determination of parameters such as head loss, pressure, discharge and internal and external loads acting on the pipe. The classical continuity, energy and momentum equations are used for solving these types of problems (Robertson et al., 1988). For a typical steady flow problem, only the continuity and energy equations need to be implemented. These well known equations are:

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2, \tag{1}$$

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g} + h_\mathrm{L}, \tag{2}$$

where, ρ is the fluid density [M/L^3], V is the velocity [L/T], A is the cross-sectional area [L^2], γ is the specific unit weight [M/L^3], g is the acceleration due to gravity [L/T^2], P is the pressure [M/L^2], Z is the elevation [L] and h_L is the head losses [L].