Tunnelling and Underground Space Technology 76 (2018) 172–176

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Simple methods for fluidic drag estimation during pipe installation via HDD

Montazar Rabiei[a], Yaolin Yi[b], Alireza Bayat[c,*], Roger Cheng[c]

[a] Hatch Infrastructure, 1066 W Hastings St, Vancouver, BC V6E 3X2, Canada
[b] School of Civil and Environmental Engineering, Nanyang Technological University, Singapore 639798, Singapore
[c] Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB T6G 1H9, Canada

ARTICLE INFO

Keywords:
Horizontal directional drilling
Fluidic drag
Simple method
Annular Couette flow
Planar Couette flow

ABSTRACT

This paper proposes a series of simple methods for fluidic drag evaluation of non-Newtonian slurries flowing within a bore during Horizontal Directional Drilling (HDD) pipe installation operations. The methods are based on adapting the solutions of annular and planar Couette flow problems to the HDD pullback problem and are favorable for practical uses by the HDD industry. In comparison to the existing methods, the proposed method accounts for a wide range of parameters, including slurry rheology, bore geometry, and pullback rate. For verification purposes, verified fluidic drag forces for two actual HDD crossings have been used. Comparison of the forces obtained via different methods confirms the ability of the new simple methods to capture the fluidic drag changes accurately.

1. Introduction

With the number of large congested urban areas sharply increasing over the last several decades and the rising costs of normal vehicular traffic and business disruption, the demand for new construction methods with minimal impact on the surrounding environment has been growing within the underground utility installation industry. This need has been the main driving force behind the development of different trenchless (no-dig) techniques, where the underground utility lines are laid without creating a continuous trench on the ground surface. Originating from the oil well drilling industry, Horizontal Directional Drilling (HDD) has been utilized for about four decades and is one of the most promising trenchless methods (Najafi and Gokhale, 2005; Allouche and Ariaratnam, 2000). HDD is an ideal technique for pipe placement through urban areas, environmentally sensitive areas, traffic-heavy streets, and other high-risk regions (Sarireh et al., 2012; Willoughby, 2005). To place a pipe using HDD, first a small diameter hole (pilot bore) is drilled along the predetermined path using a downhole assembly with steering and tracking capabilities. Over the second stage of installation, the hole is then widened, typically up to a dimeter 50% larger than the final product pipe size, by passing a reamer (hole opener) over one or multiple passes depending on the final bore size. Finally, the product pipe is pulled back into the enlarged hole. These three construction phases are often referred to as the pilot hole drilling, reaming, and pullback stages, respectively.

Pipes installed via HDD need to sustain loads imposed on them during installation and service periods. From a pipe design perspective, the installation loads often govern, so the majority of researchers have focused on identifying and quantifying the installation loads (Huey et al., 1996; Rabiei et al., 2015, 2016a). In spite of a notable surge in the number of HDD projects, pipes are still designed cautiously because professionals are unsure how the pipe will interact with the surrounding environment (soil and in-bore drilling fluid) during the pipe installation operation (Baumert et al., 2005). Current design references, such as ASTM F1962 (ASTM, 2011) and Pipeline Research Council International (PRCI) (Huey et al., 1996), ignore some unique characteristics of HDD because of a lack of relevant investigations to use as a resource. As a result, the current design procedures depend on investigations undertaken by other industries, such as oil well drilling and utility cable installation (Slavin and Petroff, 2006). Evaluating the fluidic drag during the pipe installation stage is an area that greatly needs investigation, and thus it is the focus of this paper. Fluidic drag is the incremental force created on the pipe's leading head during installation due to slurry interaction with the in-bore portion of the pipe.

To estimate the fluidic drag component of the pullback force, ASTM F1962 suggests using Eq. (1), which was originally used to calculate the drag force applied on a utility cable's outer surface during installation via "cable blowing" method (Slavin, 2009; Slavin and Petroff, 2006):

$$F = \Delta P\frac{\pi(R^2 - R_P^2)}{2} \tag{1}$$

where R (m) and R_P (m) are the bore and pipe radii, respectively, and ΔP (Pa) is the hydrokinetic pressure, which the standard suggests to be 70 kPa. Eq. (1) provides no data on drag change as the installation

---

* Corresponding author.
E-mail addresses: montazar.rabiei@hatch.com (M. Rabiei), yiyaolin@ntu.edu.sg (Y. Yi), abayat@ualberta.ca (A. Bayat), roger.cheng@ualberta.ca (R. Cheng).

https://doi.org/10.1016/j.tust.2018.03.007
Received 30 June 2017; Received in revised form 14 November 2017; Accepted 5 March 2018

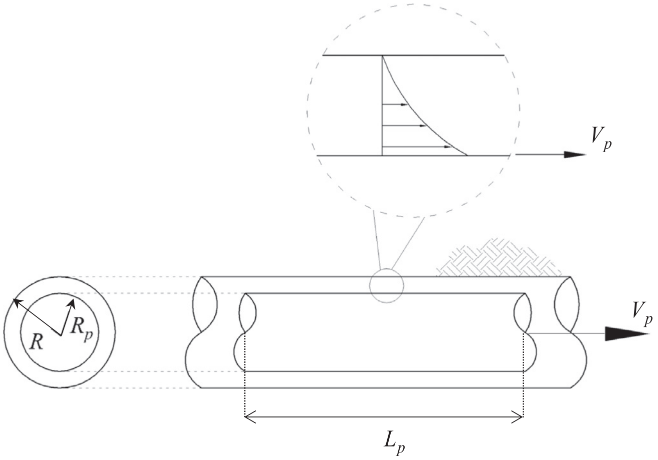

Fig. 1. Schematic representation of ACF.

develops, and the slurry (drilling mud) rheology is considered in the pressure implicitly.

PRCI provides no value for the hydrokinetic pressure, but it suggests an equation that accounts for the length of the pipe in contact with slurry as:

$$F = 2\pi R_P L_p \mu_{mud} \tag{2}$$

where L_p (m) is the in-bore length of the product pipe, and μ_{mud} (Pa) is the fluidic drag coefficient with a value of 350 Pa taken from the Dutch standard *NEN 3650, Requirements for Pipeline Systems* (NEN, 1992). While each of these two procedures account for some aspects of pipe-slurry interaction, both ASTM and PRCI ignore slurry rheological characteristics and pullback rate (Rabiei et al., 2016b). A study by Baumert et al. (2005) found that the calculation of fluidic drag by either ASTM or PRCI can result in overly conservative forces by as much as 1–2 orders of magnitudes.

In an attempt to model the fluidic drag component of pullback force more realistically, Duyvestyn (2009) implemented the slot flow approximation and considered slurry flow direction change during the pullback stage. Duyvestyn assumed that in an installation with the pipe leading head between the pipe entry and crossover points, the total slurry volume flows to the surface through annular space between the product pipe and bore. Once the crossover point has been reached, the slurry flow direction switches, and the slurry moves in front of the product pipe toward the rig. To determine the crossover point location, the hydrokinetic pressure required for exhausting the slurry via product pipe and drill rod annuli were calculated in terms of in-bore pipe length. After equating these pressures and solving for the in-bore pipe length, the crossover point was calculated. The major shortcoming of this study was ignoring the fact that in a typical HDD installation, the slurry returns to the surface through both the product pipe and drill rod annular spaces over a considerable length of installation. Furthermore, this study did not consider the pullback rate effects.

Table 1
Main parameters of the two actual studied installations.

Parameter	Case 1	Case 2
Crossing length (m)	998	604
Pipe outer diameter (m)	0.508	0.914
Pipe wall thickness (m)	0.112	0.204
Borehole diameter (m)	0.762	1.219
Drill rod outer diameter (m)	0.140	0.140
Mud pump flow rate (m^3/min)	1.50	1.80
Pullback rate (m/min)	7.32	7.32
Recorded end pullback force (kN)	268	525

Recently, Rabiei et al. (2016c, 2017) developed two methods for the fluidic drag estimation problem: one implements Finite Volume Method (FVM) to solve the fluid equation of motion (Rabiei et al., 2016c), and the other, Three-stage Method, is based on fluid flow pattern change identification during installation (Rabiei et al., 2017). Compared to the existing methods, these new methods are more sophisticated in the sense that they both account for slurry rheology, annulus geometry, pullback rate, and drilling fluid flow direction change during installation. Aside from these advantages, however, they require high computational effort, making them unsuitable for practical applications. Hence, this paper suggests a set of simple methods for fluidic drag evaluation, tailored to be implemented by HDD practitioners for quick fluidic drag evaluation while the accuracy of more refined methods is maintained.

2. Proposed methods

The results of fluidic drag analysis by FVM and Three-stage Method revealed that this component of pullbakc force almost varies linearly with in-bore pipe length (Rabiei et al., 2016c, 2017). This behaviour is observed during HDD pullback operations because of two reasons: (i) the amount of drilling fluid pumped down the hole is small since the bore is already clean, and (ii) compared to the slurry average annular velocity, the pipe is being pulled at high rates. Therefore, for the purpose of fluidic drag evaluation, the forthcoming study suggests that drilling fluid circulation might be ignored and, as a result of that, the solution to the annular Couette flow (ACF) problem can be utilized. Also, a more simplified solution may be obtained by approximating the annulus with a slot and using the solution to the planar Couette flow (PCF) problem. In the next subsection, both solutions are presented and discussed.

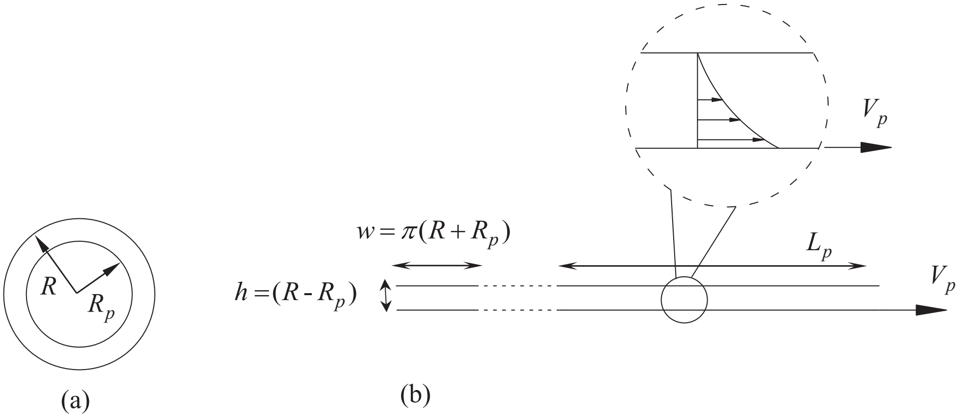

Fig. 2. Representation of PCF: (a) annulus geometry, and (b) equivalent slot geometry.