Tunnelling and Underground Space Technology 76 (2018) 194–201

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

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

Numerical simulation of pipe-soil interaction during pulling back phase in horizontal directional drilling installations

Guangli Xu[a,b], Liangxue Cai[a,*], Rui Ji[c], Zhongliang Wang[d]

[a] School of Petroleum Engineering, Southwest Petroleum University, Chengdu 610500, China
[b] Oil & Gas Fire Protection Key Laboratory of Sichuan Province, Chengdu 611731, China
[c] Xi'an Changqing Technology Engineering Co. Ltd, Xi'an 710018, China
[d] PetroChina Oil & Gas Pipeline Control Center, Beijing 100007, China

ARTICLE INFO

Keywords:
Horizontal directional drilling
Pipe
Soil
Interaction
Numerical simulation

ABSTRACT

The displacement of pipe-soil contact points in the radial direction and the wedging effect of surrounding soil on the pipe perimeter during pipe pulling-back may have a substantial effect on predicting pulling forces for horizontal directional drilling installations. However, the influence of pipe-soil interaction on pulling force predictions is not considered in existing methods to predict the required pulling force. This paper provides a model representing the interaction between pipe and borehole. The mechanical characteristics of the pipe-soil interaction were numerically investigated with program ANSYS. Two parameters, the wedging coefficient and pipe displacement, were defined and associated parametric studies were performed to analyze the influences of relative factors based on a Yangtze River crossing project. The wedging coefficient is shown to increase with external load and ovality of the borehole, and decrease with increasing over-cut ratio, Poisson's ratio and elastic modulus of soil. It can improve the prediction accuracy to consider the wedging effect since the difference among predicted results caused by wedging effect can differ up to 7.7% in example analysis.

1. Introduction

Horizontal directional drilling (HDD) technology has advantages with respect to improved work efficiency, reduced overall project cost, and protecting the environment in comparison to traditional open-cut trench construction for pipe installation. Since a 220 m (m) length of 100 mm (mm) diameter steel pipe was installed across the Pajaro River near Watsonville, California using HDD for the first time by Martin Cherrington in 1971 (Mohammad and Sanjiv, 2004), HDD technology has developed rapidly in the domestic and foreign market, including for the installation of communication and power cables, oil and gas pipelines, and water pipelines (Yan, 2010).

However, there remain various issues to be addressed. The prediction of the pulling force is an important factor in the design of a crossing project since it affects the selection of the drilling rig and the required strength of the pipe, and/or the procedures to be employed during installation, such as methods for drag reduction. Among the existing methods (Driscopipe, 1993; Drillpath, 1996; Huey et al., 1996; NEN, 2007; ASTM, 2011; Cheng and Polak, 2007; CNPC, 2015) to predict pulling forces, the model given by Polak et al. considers three theoretical components of resistance and calculates the corresponding pulling force. In this model, the frictional resistance between the pipe and soil, which is determined assuming that the soil is a rigid body and the pipe deflects according to the beam bending theory, is the main component of pulling resistance (Polak and Chu, 2005). The analysis deviates from reality as the pipe-soil interaction and the associated chocking (i.e., wedging) effect of the soil on the pipe are not considered. The results, therefore, may not meet the needs of HDD design and planning procedures (Francis et al., 2004).

During pulling back phase, the pipe contacts with the surrounding soil in some parts of the borehole and the pipe-soil contact points displace in the radial direction under the effect of the normal reaction force since the surrounding soil is not a rigid body. This is called pipe-soil interaction. In the present study, the soil is represented by a Drucker-Prager model, for which the soil is assumed to behave as an elastic-plastic foundation, and the pipe-soil interaction is analyzed using the finite element method. The wedging coefficient, which is the ratio of the normal reaction force between the pipe and the surrounding soil and its component force in vertical direction, can amplify the frictional drag and the wedging effect may be reflected by a modification to the model given by Polak et al. (Cai et al., 2012). The influences of external load, over-cut ratio, ovality of the borehole, elastic

* Corresponding author.
E-mail address: cailiangxue-184@163.com (L. Cai).

https://doi.org/10.1016/j.tust.2018.03.022
Received 29 June 2017; Received in revised form 15 March 2018; Accepted 24 March 2018
0886-7798/ © 2018 Elsevier Ltd. All rights reserved.

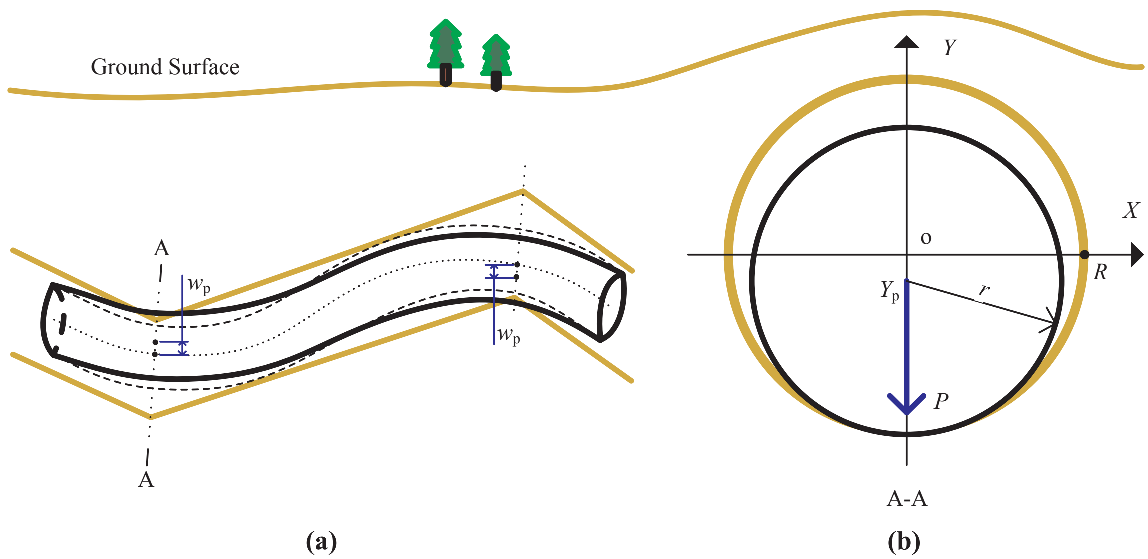

Fig. 1. Schematic diagram of pipe-soil interaction in profile section and cross section.

modulus and Poisson's ratio of the soil on the wedging effect and the application of wedging coefficient in predicting pulling forces are discussed.

2. Model of pipe-soil interaction

2.1. General concepts

The issue of pipe-soil interaction during pulling back phase in HDD installations, which is different from conventional interaction between buried pipe and soil, is a kind of non-fixed boundary problem when the diameter of borehole is bigger than that of pipe (Fig. 1). It is simplified as an issue of the pipe deforming in a vertical plane while pipe-soil interacting characteristics in the cross section of the pipe are not considered in existing pulling force predicting methods, which is not in accordance with the actual physical phenomenon.

In calculations of the friction between pipe and borehole wall, the assumption that soil is treated as a rigid body does not match the fact that contacting points displace in the process of pipe-soil interaction, which results in overestimation of the normal reaction force caused by pipe bending (Fig. 1a). Moreover, pipe-soil interaction is analyzed only in a 2-D plane in which the borehole profile is located and then the normal reaction force derived from such analysis is only the component of pipe-soil normal reaction force in vertical direction. In horizontal direction, however, there are two other components of normal reaction force when the wall of borehole supports the pipe (Fig. 2). Although the total force of the two component forces is equal to zero, for they are equal to each other and opposite in direction, they contribute the pipe-soil friction.

The mechanical state of a pipe inside of a borehole in the process of pipe-soil interaction during the pulling back phase is similar to a chock and the phenomenon is defined as the wedging effect. The ratio of the normal reaction force between the pipe and the surrounding soil and its component force in vertical direction is defined as the wedging coefficient, denoted by K_c. The displacement of the pipe center from the position tangential with the initial wall of the borehole to the position where the pipe is in mechanical equilibrium is defined as pipe displacement, denoted by w_p. It should be noted that the initial wall of borehole should be assumed as that of a circular borehole with short radius as its radius while the cross section of the borehole is oval, i.e. pipe displacement is not equal to w_0 as shown in Fig. 2b, which is determined by the theoretical model of predicting pulling forces.

2.2. Physical model

The ideal shape of the borehole in HDD installations is a circular cross section. While the borehole in small-scale HDD (e.g., mini-HDD) projects can be treated as approximately circular (Duyvestyn et al., 2001), boreholes in large-scale HDD (maxi-HDD) projects tend to be pear-shaped because of the heavy weight of the reamer and drill string and the tendency for the drill string to cut inside corners at route bends (Hu, 2005).

Therefore, two models are considered, including a borehole with a circular cross section and a borehole with an oval (or elliptical) cross section, as shown in Fig. 2. The pipe-soil interaction is treated as a nonlinear strain-stress problem, of unit length pipe in the axial direction. The center of a circle or an ellipse is selected as the origin of the rectangular Cartesian coordinate system. The pipe located on the bottom of borehole is subjected with the load P in the vertical downward direction.

2.3. Numerical analyzing model

Pipe-soil interaction is one issue of fluid-solid coupling because the pipe placed inside the borehole is surrounded by the slurry during pulling back phase in HDD installations. However, the slurry is not considered in analysis herein because it has no influence on calculations of the wedging effect coefficient and pipe displacement. Pipe-soil interaction is assumed to be in mechanical equilibrium for the speed of pipe pulled back is low and studied through structural static analysis. The commercial analysis program ANSYS is used to simulate the pipe-soil interaction.

According to the Saint Venant's principle, the width and height of the soil body is set about 11 times the diameter of the borehole. The length of the soil body is set per unit. The center of the borehole coincides with the centroid of the soil body in the cross section of the pipe. The model is symmetric with respect to the YZ-plane and half of it is used in numerical simulation, as shown in Fig. 3.

Pipe-soil interaction is an issue of flexible-flexible contacts between surfaces and it is highly nonlinear. The 3-D structural solid element SOLID45 is used to model soil and pipe and meshes are generated using the method of mapped meshing. As the contacting area cannot be determined accurately before getting the results of the simulation, contact elements including 3-D target segment TARGE170 and 3-D contact element CONTA174 are set on the potential contacting area. The elastoplastic model D-P based on the Drucker-Prager yield criterion and the

Download English Version:

https://daneshyari.com/en/article/6782575

Download Persian Version:

https://daneshyari.com/article/6782575

Daneshyari.com