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The formation and broken of cuttings bed during reaming process in horizontal directional drilling

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ABSTRACT

Horizontal Directional Drilling (HDD) is an environment-friendly and high efficient method for underground utilities and pipelines crossing. The formation of cuttings bed, due to low Cuttings Transport Performance (CTP) in large-size HDD, has resulted in the overwear of reamer and been required additional borehole cleanups which will result in high construction risk and extending the work period. In order to investigate the formation and broken mechanism of cuttings bed, two tests were designed to determine the potential effect of mud rheological properties, flow rate, borehole inclination and rotation of drill rod on the cuttings bed state. The drill rod laid down at the invert of the borehole, broke the stability state of cuttings bed and take some cuttings away from the cuttings bed, which causes an incremental trend of CTP, even for the cuttings bed consisting of 8–12 mm diameter cuttings. The observations and results of the tests indicated that drill rod rotation had a positive impact on the instability of cuttings bed, whereas, YP of mud, average velocity of mud and borehole inclined shown a limited effect on it for the large-scale HDD reaming. Further study is needed to determine the details about drill rod behavior and extend the tests results by the finite element method.

1. Introduction

Horizontal Directional Drilling (HDD) enables the installation of conduits and pipelines with minimum surface excavation. HDD has made a significant impact on both the utility and pipeline installation industries over the past decade due to limited surface disturbance, moreover, large-diameter HDD crossings have become increasingly employed, especially in China (Ma and Najafi, 2008).

A HDD construction typically consists of three phases: pilot, reaming and pullback. Pilot and reaming drilling products cuttings, and cuttings typically are mixed with mud and then removed from the borehole to mud pit on the ground. Cuttings transport performance (CTP) is used to describe the transport efficiency of soil particles in the drilling borehole, and a low Cuttings Transport Performance could increase the risk of drilling process. In HDD borehole, cuttings transportation performance can be lessened due to the increment of borehole diameter in reaming process. On the one hand, the larger borehole be drilled, the more cuttings can be produced, on the other hand, the increase of borehole diameter will result in a lower average flow velocity in the annular space if the pump volume remains unchanged. Given the cuttings gravity and HDD driven length, cuttings may settle down and then form a cuttings bed in the invert of borehole which causes increment of the pull-back force, possibly resulting in drilling rod broken or even failure of the HDD project. Hence, the mechanism of formation and broken of cuttings bed become the key problem in large-diameter HDD crossing practice.

Since the drilling technology was developed in oil and geological exploration, experts and researchers have put their focus on the drilling fluid and tools to improve CTP. And the development of HDD has also been supported by these researches. Some researchers have pointed out CTP is one of the critical problems in inclined and horizontal drilling since 1980s (Tomren et al., 1986; Ford et al., 1991). Based on the experimental investigation, they observed the different cuttings moving laws between vertical drilling and inclined drilling, and have shown that existence different layers in directional wells and inclined boreholes. To address these concerns, studies have been conducted to research and quantify different aspects of CTP in inclined or horizontal drilling. Han et al. (2009) conducted an experimental study on solid-liquid mixture upward hydraulic transport of solid particles in vertical and inclined annuli with rotating inner cylinder. This study discussed the effect of annulus inclination and drill pipe rotation on the carrying capacity of drilling fluid, particle rising velocity, and pressure drop in the slim hole annulus. However, these tests were conducted in a slim borehole with annular fluid velocities varied from 0.4 m/s to 1.2 m/s, while the velocity of HDD mud was usually below 0.4 m/s when the borehole diameter is up to 800 mm. Although these research

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conclusions are certain limitation in HDD field due to technical difference, it presented several straight forward approaches for testing the cuttings transport performance (Han et al., 2009).

Piroozian et al. (2012) aimed to concentrate on the effect of velocity on CTP and also took a serial cuttings transportation tests in horizontal and highly deviated wells. The results revealed that increasing the plastic viscosity of the mud results in a remarkable increase in the amount of recovered cuttings, while the surplus amount of viscosity inverses the result. He explained that the behavior of mud is attributable to the flow regime changes from turbulent flow to laminar flow. Thought researches of CTP in oil field provided basic theories and available test system for CTP tests, does not provide the necessary means of CTP in HDD crossing, especially for large-diameter borehole, due to the different mud rheological properties.

Ariaratnam et al. (2003, 2007) addressed the concern of the mud pressure in his works and determined flow characteristics for HDD drilling fluid returns under a variety of soil conditions and bore penetration rates. Through these researches did not point out the cuttings transport performance, he provided a model to predict mud pressures in HDD borehole which can be useful not only for hydraulic fracturing, but also for analyze the drilling fluid flow law and cuttings transport performance in HDD crossing practice.

Shu et al. (2014), Shu and Ma (2016, 2018) provided an analysis on the cuttings transport mechanism in Large-diameter HDD crossing projects. They pointed out that laminar flow is the typically flow pattern of annular mud in large-diameter HDD borehole rather than turbulent flow, and put forward a methodology for selecting the proper mud rheological properties and return velocity. They concluded that, based on theoretical analysis, larger-size cuttings settle down more quickly than smaller size cuttings, and only a small fraction of the cuttings been removed after several reaming cycles. However, this research did not take the broken of cuttings bed into account according to the technical characteristics of HDD reaming process.

To now, the literature review of the current state of cuttings transport performance reveals that researches in this area typically put focus on the critical factors which may improve the cuttings transport performance to avoid the formation of cuttings bed, such as flow velocity, viscosity, solid concentration, etc. However, the reaming process of HDD is different from the drilling of small horizontal or highly deviated well in oil and gas field, cuttings bed is always a key problem due to the large cuttings size and low flow rate, especially in large diameter HDD crossing. The cuttings bed forms much easier and faster in large HDD borehole. Since the borehole of HDD is connected to mud pit located in both entrance and exit side after pilot drilling, cuttings bed forms in both side of the reamer in a short time. The cuttings bed located in the front of reamer can be ruined by the reamer's movement, while the cuttings bed located behind the reamers may be disturbed by the rotation of drill rod which is typically design as a backup connection to the reamer in case of rod broken accidently. Therefore, cuttings bed cannot be cleaned up after single reaming process, and it always requires additional borehole cleanups to be removed. In order to improve the performance of HDD drilling, the formation mechanism of cuttings bed need to be work out and the proper way to increase the construction time can be determined.

This study relates the formation and broken of cuttings bed and the cuttings transport performance in large-size HDD crossing, and conducted sets of experimental investigations to determine factors effect on the formation and broken of cuttings bed.

2. Lab test design

In order to investigate the formation and broken of cuttings bed, two tests were designed to determine the potential impact factors such as flow rate, borehole angle, rheological properties of mud and the rotation of drilling rods. All these tests were implemented in Trenchless Lab, located in west campus of China University of Geosciences (Wuhan), which have sufficient space for designed HDD mud testing system. This study focused on the formation and broken of cuttings bed, hence, the borehole of HDD is assumed to be stable without any collapse or hydraulic fracture. Additionally, two more assumptions were made: the drilling fluid is assumed to hydrated completely and the borehole has a uniform cross profile and friction factor. Therefore, the acrylic pipe, which provides a regular circle shape and stable friction factor, was used as stable borehole in the tests.

2.1. Mud material selection

Photo contrasting technology is a directly approach to observe the formation and broken of cuttings bed during the reaming process in horizontal directional drilling. In order to obtain a series of clear photos, the medium between the camera and cuttings need to be transparency. Therefore, the traditional water based bentonite drilling fluid cannot be used in these tests. To meet the tests requirements and the properties requirements of drilling fluid in HDD practice, several high-molecular polymers materials (such as Sodium Alginate, Sodium salt of Caboxy Methyl Cellulose (CMC), Polyacrylamide (PAM), Xanthan Gum (XC)) are tested, and the procedure for measuring mud rheological properties including Apparent Viscosity (AV), Plastic Viscosity (PV), and Yield Point (YP) follows API Recommended Practice for Field Testing Water-based Drilling Fluid (API RP 13B-1, 2006).

A ZNN-D6 6-speed viscometer (Fig. 1) was used to determine filtration property in these tests. The six rotation speeds, 600, 300, 200, 100, 6, and 3 rpm, represent six different shear rates. Shear rate can be calculated by using the following equation:

$$\gamma = 1.7023N \tag{3}$$

Based on the Bingham plastic model, the basic properties of the mud are calculated from the dial readings (Eq. (1)) (Bingham, 1916):

$$\begin{cases} AV = 300\frac{\theta}{N} \\ PV = \theta_{600} - \theta_{300} \\ YP = 0.511\cdot(\theta_{300} - PV) \end{cases} \tag{1}$$

where θ is the Fann viscometer reading (θ_{600}, θ_{300}, θ_{200}, θ_{100}, θ_6, θ_3), N is the rotate speed of the rotor (rpm).

Fig. 1. ZNN-D6 6-speed viscometer.