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Analysis of formation fracturing for the Maxi-HDD Qin River crossing project in China

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ABSTRACT

A new irrigation pipeline was installed using the Horizontal Directional Drilling (HDD) method in order to alleviate the water shortage situation in Jiaozuo City, Henan Province, China. This pipe installation project included two parallel HDD crossings, with a pipe diameter of 1016 mm and a driven length of 1750 m for both of them. Based on the preliminary detailed geological survey report of the riverbed, hydro-fracturing control under high slurry pressure would be a big challenge for this project. This paper summarizes the prediction methods for the maximum allowable mud pressure in the borehole based on different mechanisms of formation fracturing. Based on the geological data of this crossing project, the Delft equation and another prediction method based on tensile failure (termed here the Xia method) were used to calculate the maximum allowable annular pressure. The real pumping pressure of this project was recorded by the contractor. By comparing the theoretical predictions of allowable pressure with the actual pressures for the horizontal section of the borehole, it indicated that the Xia method is conservative and the limits of the Delft equation could not be verified in this project. As a solution dealing with potential hydro-fracturing, finite element modeling shown that increasing the ground surface load would rise the borehole allowable pressure at which fracturing would occur. This solution was used to deal with a blow-out in the entry section of one pilot hole on this project. Under the guidance of the theoretical and numerical simulation results, the Qin River crossing project was successfully completed.

1. Introduction

The Horizontal Directional Drilling (HDD) method has been widely employed for the installation of buried pipelines in China and worldwide over the past two decades, accompanying the rapid economic development in China (Ma and Najafi, 2008). Many new pipeline networks for various purposes have been designed and constructed in China, such as the East to West natural gas transmission projects (Lan et al., 2011). To meet the increasing pipeline installation demand, the HDD method has been developed as an alternative to traditional open-cut methods for installation of buried pipes. In particular, HDD is preferred to open cut in most of the projects where rivers, lakes, environment protection zones, streets, highways were crossed.

In 2013, a new irrigation pipeline, invested by local government, was planned to alleviate the water shortage situation in Jiaozuo City, Henan Province, China. Based on its many advantages, the owner decided to use HDD method to install the pipe segment crossing the Qin River, which was considered as the key section of the entire new pipeline project. This pipeline installation project comprised two parallel crossings, each with 1016 mm diameter steel pipe and driven lengths of 1750 m, at a horizontal separation of 15 m. As is well known, the drilling slurry used in HDD performs the primary functions of stabilizing the HDD borehole and transporting cuttings to the ground surface as well as providing lubrication for the pipe pullback process and cooling the drilling hardware and electronics (Shu et al., 2014; Shu and Ma, 2015). Both previous on-site experiences and research data show that a low, insufficient slurry pressure may lead to borehole instability and inefficient Cuttings Transport Performance (CTP) (Jiao et al., 2011). The latter condition may lead to the formation of a cuttings bed at the bottom of the borehole, which may then lead to a sharp, excessive increase in the mud pressure in the annulus space. In order to maintain a high CTP, drilling slurry with high viscosity and velocity is needed, with sufficiently high slurry pressure to maintain normal circulation. However, when a high borehole annulus pressure exceeds the maximum allowable pressure of the overburden, the elevated annular pressure could lead to formation fracturing (Murray et al., 2014) and loss of drilling fluid circulation. In addition, if the formation fractures link the original borehole to the ground surface, the slurry can be released at the ground surface,

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corresponding to a so-called "blow-out", "oozing slurry" or "frac-out" condition.

When the mud releasing occurs in a crossing project, the mud loss increases sharply, which could lead to higher overall project cost. The drilling mud penetrating into the soil surround the borehole also changes the stress status of the soil, which works against the borehole stability and increases the risk of the crossing project. In addition, for small HDD project, the main ingredients of the slurry are water and bentonite, which does not have any negative effect on the environment, while for large HDD project, environmentally harmful additives, such as CMC, PAM, NaOH, are employed to obtain a high performance drill fluid and keep high CTP. Hence, the drilling fluid released to the ground surface poses a potential threat to environment in large HDD project. So, it is necessary to work out the mechanism of the "blow-out" to prevent this from happening, and develop an emergency response plan to deal with it if occur.

The objective of the present research is to determine a proper method to evaluate the potential blow-out of drilling slurry during a riverbed HDD crossing, including its application to the Qin River HDD crossing project.

2. Project descriptions

2.1. Geological characteristics

The project site is located at an alluvial plain where the Yellow River and the Qin River intersect. The Qin River is a wide, shallow meandering river, flowing from west to east (Fig. 1). The width of the river at the HDD crossing segment is approximately 130 m, with the riverbed at an elevation of 98.78 m, and a maximum water depth of 5.5 m. The groundwater consists of Quaternary loose bed pore water, containing the chemical HCO_3–Mg–Ca, and having a slight corrosion potential for steel. Table 1 presents the detailed soil properties at the job site by field sampling and laboratory tests.

The K_0 is defined as the ratio of the lateral effective pressure to the vertical effective pressure, and it can be estimated in sandy and normal consolidated soil using the following empirical formula (Jaky, 1944):

$$K_0 = 1 - \sin\varphi \quad (1)$$

2.2. Project design and construction

2.2.1. Drill path design

This pipe installation project includes two parallel HDD crossings with 1016 mm diameter pipes and 1750 m driven length. Based on the detailed preliminary geological investigation information, the Qin River riverbed includes weak soil formations, prone to fracturing. Hence, the drill path was designed very carefully. Fig. 1 illustrates the design path for the Qin River crossing, including a 7° entry angle, 8° exit angle, 2290 m entry and exit radius of curvature, 1015 m horizontal path segment, 33.50 m maximum depth and 29.78 m minimum depth below the riverbed.

2.2.2. Pilot hole drilling

During the initial pilot hole drilling, Share-well guidance equipment was used to ensure the drill bit was following the design path. The main drilling rig utilized a 325 mm diameter tri-cone bit with a mud motor to drill the pilot hole, a non-magnetic drill collar and a 600 mm diameter reamer. The 600 mm reamer that followed the tri-cone drill bit was used for forward reaming operation. A total of 2500 m of 168 mm diameter high strength drill rods were available for this project.

2.2.3. Back reaming

The back reaming operation was constructed using a sequence of 900 mm, 1300 mm, and 1500 mm diameter reamers. As shown in Fig. 2, the significant characteristic of this project is that no auxiliary drill rods were connected behind the reamer while back-reaming, indicating that the reamed borehole would just be relying on the slurry properties and pressure to prevent collapse and maintain stability. Thus, following each reaming operation, the drill rig pushed the drill tools back to the exit point. When pushing back, the drill rods kept connecting with the reamer and the drill tool assembly remained rotational for a better guidance and cleaner borehole.

2.3. Drill rig and back reamers

The FDP-1000 drill rig, produced by LianYunGang HuangHai Machinery Co., Ltd., was used for this project. The FDP-1000 has 1000 tons pulling force capability and is presently the largest

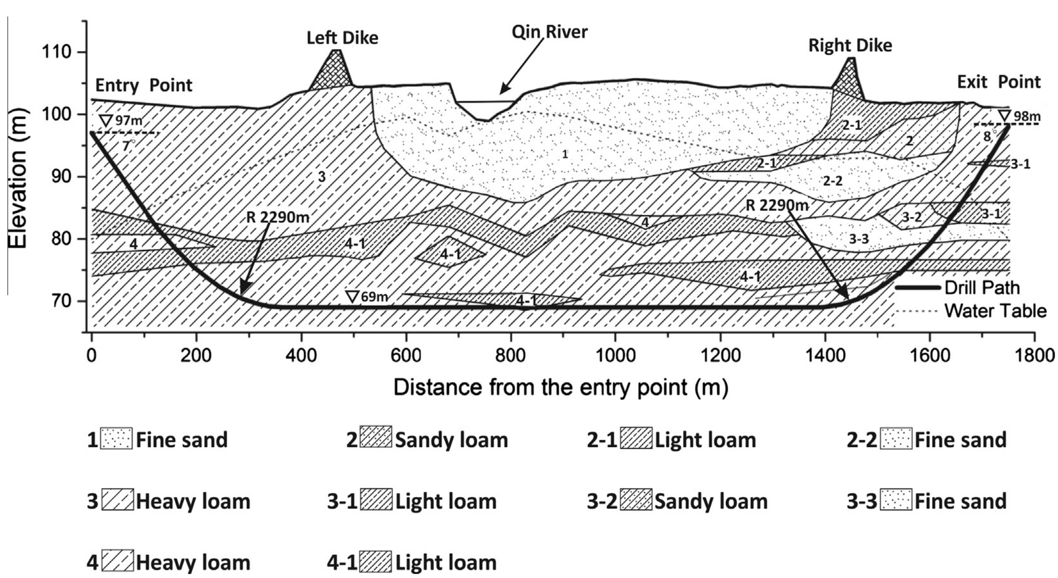

Fig. 1. Drill path profile.