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Field performance of concrete pipes during jacking in cemented sandy silt

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ABSTRACT

Although many field investigations into pipe-jacking installation have been reported within the literature, there are few reports on the rebar stress in jacking pipes. This paper presents the field performance of concrete pipes during the jacking carried out under the Guan River in Jiangsu, China. Rebar stresses at two wings (the left and right side), the top crest, and the base in the longitudinal and circumferential directions for four different pipes were monitored. The maximum rebar stresses during the jacking were 37.1 MPa in the longitudinal direction and 36.6 MPa in the circumferential direction. However, the maximum rebar stresses after construction were only 18.5 MPa in the longitudinal direction and 20.3 MPa in the circumferential direction. A normalized jacking force "α" is proposed to evaluate the additional rebar stress in jacking pipes. The range of α is from 0.04 to 0.25. The relationship between the rebar stress and the construction procedure is presented and discussed. An excessive jacking force, an alignment deviation or an increased penetration rate would generate a large incremental rebar stress.

1. Introduction

Pipe jacking is commonly used as a trenchless method in the construction of lined tunnels for sewers, gas and water mains, oil pipelines, electricity and telecommunications cable ducts, and drainage culverts (Shou and Liu, 2004; Shou and Chang, 2006; Ma and Najafi, 2008; Liu et al., 2010; Ma and Zhou, 2013). As shown in Fig. 1, the process of pipe jacking consists of the following steps (PJA, 1995; Sofianos et al., 2004). After being lowered from the ground surface and positioned between the thrust steel ring and the jacking machine (i), the first pipe segment is jacked into the ground (ii). The jacks are contracted and the next pipe segment is placed and jacked into the ground (iii). This operation is repeated until the full length of pipeline is completed (iv). Future problems, such as excessive jacking force and alignment deviation caused by overcutting, may arise if during construction the pipe jacking process is not well controlled or is of poor quality. These problems can be minimized through continuous monitoring and the determination of the normal stress state of the pipe section. Therefore, in order to observe feedback during construction, field monitoring of the pipe sections while under construction needs to be conducted.

Recent advances in pipe jacking have mainly concentrated on minimizing soil disturbance and environmental damage around the jacking pipes based on field data, such as surface and subsurface settlement and lateral displacement (Saric-Coric et al., 2003; Sofianos et al., 2004; Shen et al., 2010; McGuigan and Valsangkar, 2011; DeGrande et al., 2013; Yang et al., 2013; Bolton et al., 2014; Zhen et al., 2014). There have also been many studies reporting on laboratory testing (Shen et al., 2014; Yang and Liu, 2012; Lee et al., 2011; Liu et al., 2011) or variation theories (Molina et al., 1993; Qiao and Wang, 2004; Liao et al., 2008) of rebar stress in reinforcing concrete. However, there are few reports on the field performance of jacking pipes in published articles (Chen and Mo, 2008). The innovative technique of using rebar stress as an indicator of jacking pipe performance is used in this paper (Hong et al., 2006; Shen et al., 2009).

This paper presents a field test conducted on pipe-jacking construction in the soft deltaic deposits along the ancient estuary of the Yellow River in the north of Jiangsu (Han and Ye, 2006; Hong et al., 2007; Xu et al., 2009) on the eastern coast of China (Xu et al., 2012a, 2012b, 2013a, 2013b; Shen et al., 2013; Ma et al., 2013). The majority of these soft deposits were laid down during the Quaternary period (Shen and Xu, 2011). These Quaternary deposits possess a high water content with high compressibility, high sensitivity, high viscosity and low strength (Yin et al., 2010, 2013). The objective of this paper is to investigate the behavior of reinforced concrete jacking pipes by measuring their rebar

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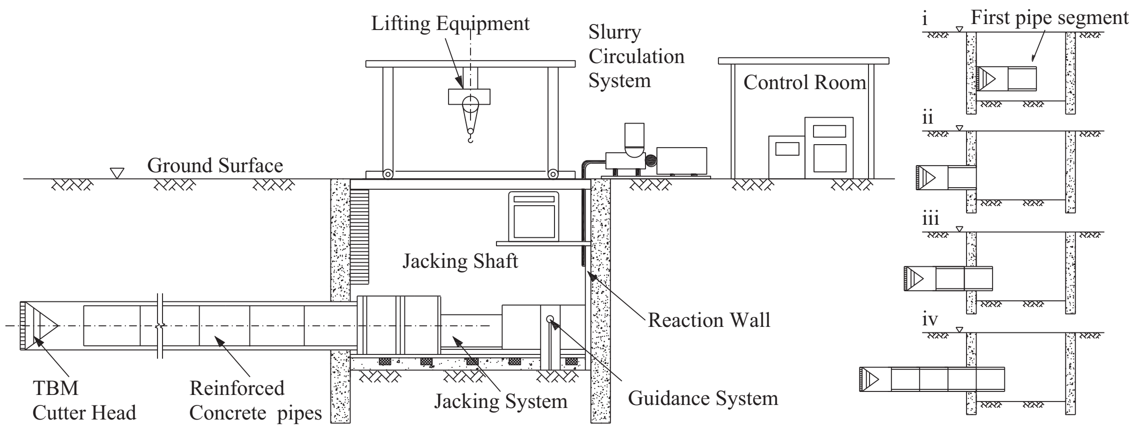

Fig. 1. Process of pipe jacking.

stress, which is a key, but difficult to control parameter which reflects the jacking pipe performance. A normalized jacking force "α" is proposed to predict the relationship between the excess rebar stress in the jacking pipes and the total jacking force. The relationship between the rebar stress and the construction procedure is also presented and discussed.

2. Site conditions

Fig. 2 illustrates the plan view and the geological sectional view of the pipe-jacking project. The field construction site is located at Xiangshui, in the northern part of Jiangsu province, China. The pipe-jacking project was constructed under the River Guan, and was part of a project conveying water from southern to northern Jiangsu. The project is at the confluence of the River Huangxiang and the River Guan (Fig. 2a). Four jacking shafts were excavated and four receiving shafts were constructed at the far ends of the four pipe-jacking lines. Four parallel pipe-jacking lines (labeled Line 1 to Line 4), spaced at an average horizontal spacing of 4.8 m, were jacked over a distance of 450 m under the River Guan, 18.9 m below the ground surface. Fig. 2b shows the plan layout of the pipe sections. The jacking pipes were jacked by two slurry balance pipe-jacking machines, comprising a slurry circulation system, a guidance system and an air supply network. The external diameter of the shields was 4.17 m. Eight hydraulic jacks with a combined capacity of 40,000 kN were applied against the thrust ring to provide the jacking force. A thixotropic slurry, consisting of bentonite, CMC (a powdered chemical paste) and soda, was employed to reduce the friction at the pipe and soil interface.

Fig. 2c depicts the geological section along the alignment of the pipes. The ground up to a depth of 35 m consists of various types of soil including fill, sandy clay, clay, silty clay, cemented silty sand and silty sand. The soft deposit, a deltaic deposit of the ancient Yellow River, was part of a multi-aquifer-aquitard system. Typical subsoil profiles and soil properties of the test site are depicted in Fig. 3. The pipes were jacked mainly through silty clay, cemented silty sand, and silty sand. These soils contained irregular cementitious sand particles, which can lead to difficulty in cutting during the installation of pipe jacking. The natural water content of these soils ranged from 25% to 28%, with a compression index varying between 0.04 and 0.16.

3. Pipe manufacturing and monitoring program

Fig. 4 shows the sectional and longitudinal views of a precast pipe. As indicated in Fig. 4, 2.64 m long pipe sections with an internal diameter of 3500 mm, an external diameter of 4160 mm and a wall thickness of 330 mm were adopted in this project. The reinforced pipes were manufactured by a core vibrated casting process using ordinary Portland cement with hot-rolled-ribbed and 335 MPa-yield-stress rebar. The layout of the rebars in the jacking pipes is shown in Fig. 4. To protect them from chemical deterioration, the pipe sections were coated with a zinc-rich epoxy primer and an epoxy asphalt topcoat. There were four grouting holes and a hoisting hole set in the pipe section. The connection of the pipe sections involved a rebar-collar socket. The locations of the stress meters were at the two wings (left and right side), the top crest and the base of the pipe section in the longitudinal (UG, RG, DG and LG) and circumferential (UC, RC, DC and LC) directions. The stress meter used was a GJJ-11 vibrating wire rebar stress dynamometer, and the results were shown on a ZXY vibrating wire frequency readout (Fig. 4).

During the pipe-jacking process, the rebar stresses in 4 pipe sections were monitored. Four stress meters, installed in pipe sections #44 and #119 of Line 1, and #59 and #118 of Line 4 respectively, were used to monitor the rebar stress during the pipe-jacking process as shown in Fig. 2b. The stress meters of pipe sections #44 and #119 of Line 1 recorded measurements during the jacking of the pipe section until the completion of Line 1, and similar with pipe sections #59 and #118 of Line 4. The stress meters of pipe sections #44 and #119 of Line 1 also recorded measurements during the installation of Line 2. In addition, measurements of jacking force and alignment deviation during jacking were continuously recorded during the construction process.

The jacking progress of the four parallel lines is shown in Fig. 5. The jacking of Line 1 and Line 3 was completed prior to that of Line 2 and Line 4. As can be seen, the advance rates of Line 2 and Line 4 (13.6 m/day and 14.1 m/day) were slightly higher than those of Line 1 and Line 3 (11.3 m/day and 12.2 m/day). Overall, there was no delay caused by pipe jacking through the Guan River.

4. Results

Figs. 6–11 show the monitored incremental rebar stresses of pipe sections #44 and #119 (Line 1) and pipe sections #59 and #118 (Line 4). Recording of the rebar stress commenced immediately after the pipe section was jacked into the tunnel. The horizontal axis represents jacking distance and the vertical axis shows the incremental rebar stress (IRS). The rebar stress varied along the installation of the pipe jacking and all of the rebar stress was in a compression state.

4.1. Rebar stress in pipe sections of Line 1 during installation of Line 1

Figs. 6 and 7 show the rebar stresses of pipe sections #44 and #119 of Line 1 in the longitudinal and circumferential directions,