Available online at www.sciencedirect.com

ScienceDirect

Soils and Foundations 57 (2017) 882–891

www.elsevier.com/locate/sandf

Fracture controlling of vertical shaft lining using grouting into neighboring soil deposits: A case study

Xiaodong Zhao [a,*], Guoqing Zhou [a], Guangsi Zhao [a], Lianfei Kuang [a], Xincheng Hu [b]

[a] *State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China*

[b] *School of Safety Engineering, China University of Mining and Technology, Xuzhou, Jiangsu 221116, China*

Received 31 October 2015; received in revised form 2 May 2017; accepted 4 July 2017
Available online 7 October 2017

Abstract

Vertical shaft lining (VSL), which usually performs as a place for shaft sets to bolt into and a smooth surface to minimize resistance to airflow for ventilation, is one of the important approaches to gain access to underground coal seam. Extensive fracturing phenomenon of VSL were uniquely observed in Southeastern China due to the rapid increase of negative skin friction (NSF) from continuous settlement of thick soil deposits. Compaction grouting into these soil deposits was utilized to reduce the existing strain in fractured VSL, thus controlling the fracture development. And the efficacy of grouting was quantitatively interpreted via the strain variation in VSL and VSL rise comprehensively. The results showed that the strain as well as the elevation of VSL presents perfect increasing, decreasing, and then increasing characteristics correspondent to the grouting, grouting intermission, and re-grouting respectively. Further, the maximum released strain ε_{max}^{re} induced from grouting accounts for over 50% of the accumulated strain ε_{bg}^{ac}, with the maximum VSL rise making up over 25% of the VSL settlement. These significant observations identify that the method of using grouting to stabilize and strengthen fractured VSL works well under such special strata. The capability and reliability of this method make it attractive in controlling of fractured VSL constructed in thick alluvium deposit.

Keywords: Fractured VSL; Compaction grouting; Field monitoring; Strain releasing; VSL movement

1. Introduction

Over 100 vertical shaft linings (VSLs) in Southeastern China subjected to the unpredictable fracturing, which led to a financial loss of over 10 billion RMBs. And there were over 200 VSLs embedded in thick alluvium suffering from challenges of potential fracturing. (Cheng et al., 1993; Zhou et al., 1999; Li and Li, 2005).

The continuous increasing of negative skin friction (NSF) induced from the drainage of water-saturated deposits well interpreted such extensive fracturing phenomenon, and that was universally regarded as the governing indicator to determine the VSL stabilization (Cheng et al., 1993; Zhou et al., 1999). The NSF applied on the outer surface of VSL was the response of an interaction between VSL and surrounding soil deposits, and that was derived from the settlement of water-saturated deposits. The initiation as well as the growth of NSF could be determined using multiple methods, such as theoretical formulation in terms of axisymmetric conditions, FEM-based numerical tools, large-scale physical model simulation in the laboratory, and field study. Significant findings and observations concerned with the NSF distribution were drawn, and the related thickness of the soil deposits

Peer review under responsibility of The Japanese Geotechnical Society.
* Corresponding author.
E-mail address: zxdcumt@126.com (X. Zhao).

https://doi.org/10.1016/j.sandf.2017.08.018
0038-0806/

was over 300 m (Zhou et al., 2004, 2009; Xu et al., 2014). After that, the field monitoring on hydrogeological characteristics of surrounding soil deposit, ground settlement and the stress responses of the VSL were carried out in a large area of 79 km^2 (Yang et al., 2007; Zhao, 2009; Zhao et al., 2009; Liang et al., 2009).

The commonly accepted and approved factors to affect the NSF mainly concentrated on the self-weight of hoisting facilities, temperature fluctuation in VSL, and the disturbances from processing activities related to the fractured VSL (Zhou et al., 2009;Xu et al., 2014). The relationship between fracturing time, water table reduction of aquifer, and ground settlement was then established and thoroughly analyzed (Cheng et al., 1993; Zhou et al., 1999; Li and Li, 2005; Xu et al., 2014). Some scholars strongly believed that the re-distribution of soil pressures after the fracturing produced significant influences to the stress states in VSL (Xu et al., 2010). There were also some scholars argued that the NSF distribution in VSL was changed due to the varying interaction formed between soil deposits and the fractured VSL. Because these soils deposits had subjected to repeatable grouting or disturbances from asymmetrical movements (Zhao, 2009; Li and Li, 2005).

Hitherto there were two main methods for strengthening such fractured VSL. One was characterized by dual-layer VSL. The outer VSL was to resist the NSF and the inner VSL was to resist the hydrostatic pressures (Zhou et al., 1999). The other was achieved indirectly by injecting the cement-based grout into the soil deposits to reinforce the stratum. This could enhance the compression modulus and thus reduced the correspondent settlement. The purpose of the latter method was to decrease the existing strain, thus controlling the fracture expansion in the VSL. The performance of grouting brought no interruption to the shaft working in comparison with the method of adding inner VSL, and that was accepted by most adopters. (Zhou et al., 1999, 2004; Yang et al., 2007; Liang et al., 2009; Zhou et al., 2004).

In this study, the characteristics of the fractured VSL and the properties of soil deposits were initially investigated. Meanwhile, the field monitoring data on the strain in VSL and the VSL elevation between February 2004 and November 2014 were collected and analyzed. On the foundation of that, the compaction grouting into neighboring soil deposits under dynamic adjustment was conducted to reduce the accumulated strain in the fractured VSL, thus controlling the fracturing of the VSL. Further, the efficacy of grouting was discussed and quantitatively interpreted through the strain and the elevation of the fractured VSL.

2. Characteristics of fractured VSL and soil deposits

2.1. Fractured VSL

The investigated VSL is XZ auxiliary shaft managed by XZ colliery. XZ colliery is situated within easy access of the Shandong Province and Jiangsu Province. Over half of the coal seam locates beneath the Shaoyang Lake and Dushan Lake. The railways exclusively designed for conveyance of coal resources and the supplies of mining material are connected with the Longhai railway. The fractured VSL was equipped with a double-mine cage, guiding-beam, drainage duct, ventilation duct, and power cables. The boring method was used in the excavation, and the construction of the VSL was completed in 1977. The depth and inner diameter of the fractured VSL (Auxiliary shaft) were 459 m and 6.0 m respectively. Besides, the fractured VSL with a thickness of 400 mm was poured with reinforcement concrete in alluvium and plain concrete in rock strata respectively. Likewise, the diameter of the main shaft with a thickness of 800 mm in soil deposits and 350 mm in rock strata was 6.6 m.

The XZ auxiliary shaft had subjected to first fracturing in 2005. And the fractures concentrated in a depth ranging from 156 m to 160 m. The compaction grouting into surrounding soil deposits was then carried out to reduce the compressive strain level in July 2005. However, the sudden fracture expansion was observed in April 2012 due to the continuous ground settlement induced from the consolidation of the water-saturated deposit.

There were several reprehensive characteristics of such fractures according to the summarizations and findings by numerous investigations from mine designers and engineers. First, the falling of the concrete debris usually caused serious damages to the shaft sets, and the obvious curvature arose in longitudinal rebars followed by the underground water penetration. Second, the initial fracturing was concentrated on a narrow range, while the newly observed fractures expanded towards to a greater range, and had a trend of moving upwards. Third, the fracturing was significant dependent on the in-situ stress states, and it was also related to the temperature fluctuation in the VSL (Zhou et al., 2009). The local environment and atmosphere inside the fractured VSL were the incubator and catalyst of the fracture development.

2.2. Soil properties

Table 1 is the soil profile around the fractured VSL. It can be noticed from Table 1 that the soil deposits around VSL are mainly clay, sandy clay, sand layers, and little quicksand strata. And the rock beneath the soil deposits are mainly the sandstone and shale formed in Jurassic period. It should be indicated that the sand deposit was defined as the water-saturated deposit or aquifer, and the clay deposit was recognized to be the aquiclude. So, the thickness of water-saturated deposit is 32.42 m when the depth is less than 90 m, while that is 23.96 m when the depth varies from 90 m to 170 m. The aquiclude and the aquifer distribution are significant to the determination of the grouting zone, and that would be discussed in the following sections.